EXCELLENCE IN AN OVERLAPPING CULTURE

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The Big History of India's National Chemical Laboratory

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Dedication

Indian science and technology as the country rapidly moves forward to global eminence.

Council of Scientific and Industrial Research (CSIR), that ubiquitous stairway to technological dominance, for taking science in India from concept to commerce.

And most particularly, my erstwhile colleagues at the National Chemical Laboratory, rewarded and unrewarded, sung and unsung, for their conduct and contributions, each "adding height to his/her own length," and for providing that bimodal quality of ambience and accomplishment that has made the laboratory what it is: forever moving towards a constantly advancing horizon of excellence.

A Babylonian tablet of the 3rd century BCE laments:

The world is coming to an end. Children no longer obey their parents and every man wants to write a book!

Notwithstanding this assessment of book writing 4-and-odd millennia ago, the present book is an attempt, however feeble, to draw attention to Paul Valeryse's great challenge:

I want this work to be written
in a style of my own invention
which will permit me
to marvelously go and come
from the bizarre to the every
day,from fantasy to extreme rigor,
from prose to verse,
from the flattest truth to ideals,
the most — the most fragile ones.

Paul Valeryse
(see Quankin, 2004)

CONTENTS

FOREWORD

Some of life's most fulfilling experiences are a result of chance encounters and casual conversations. This book certainly conforms to this kind. It was several years ago that I asked Dr L. K. Doraiswamy (LKD) whether he would be willing to undertake the writing of the "Story of National Chemical Laboratory (NCL)." I strongly believed that this was a story worth telling and that none other than LKD was the most appropriate storyteller. LKD spent all his life in the NCL, from its early days, and rose to occupy the position of the fifth Director. He was personally acquainted with all the directors of the NCL. He was a keen observer, critic as well as an ardent and passionate supporter of NCL. He had an eye for excellence and a remarkable felicity with the English language. As a Director, he used to pen a letter at the beginning of every year to the staff of NCL. I often used to wonder whether the letter was a factual account of the laboratory in the year past or a piece of literature to be preserved for posterity. With his deep understanding of NCL, Indian science, technology and industry for over six decades, I felt that his perspectives of what NCL was, has been and could be, will be a compelling story and could become an important point of reference to the emergence of scientific institutions in post-independence India and their continuing quest for excellence.

LKD agreed instantly to undertake this onerous task in spite of his advancing age and failing health. I am beholden to him for the passion and commitment with which he undertook this task. It took us some time to gather the many facts that his memory recalled; in several instances his memory reigned supreme and all our collective efforts could not trace the documents to support his recall. Yet this was an interesting journey. This project gave the NCL the excuse and opportunity to put its historical records in order and archive them into a digital format.

We have often failed LKD in terms of speed and attention due to several other pre-occupations. I am particularly aware of my own failings in not promptly answering his innumerable e-mails seeking information and follow up on actions needed to complete this project. But for this, this book may have seen the light of the day sooner.

The NCL has just completed 60 years of its glorious history and sustained excellence. It has nurtured some of the best minds of India and has continually transformed and reinvented itself to meet the new challenges at the turn of every decade. The organization has left a lasting imprint on the fabric of science and technology in India.

LKD captures the magic of the NCL in beautifully crafted words. His understanding of the institution is perfect and his prescriptions for the future remarkably prescient. Every page of the book is a testimony to his love for the institution. He is objective, laudatory and critical at the same time. His words resonate with a rare clarity and help all of us to understand better our heritage, traditions and culture, strengths as well as weaknesses.

The NCL is at a crossroads and in the cusp of change. The baton of leadership is progressively passing into the hands of a breed of young men and women who have little acquaintance with the glorious past of the NCL. I hope that this book will become a prized possession of every new scientist who joins the NCL and will enable him or her to appreciate the rich heritage that they are part of. I hope it will instill in them the need to nurture this heritage with care, embellish it with their own contributions and pass it on to the next generation. A Chinese proverb most appropriately captures the link between the past and the future and I quote:

Know the past to know the present; reflect on the future to change the present.

I also earnestly hope that this book will become a part of the vast literature documenting the history, etiology and sociology of scientific institutions and will provide valuable lessons on how institutions such as the NCL can make the leap from good to great.

Happy reading.

Dr S. Sivaram
Director, National Chemical Laboratory,
Pune, India
1 April 2010

PREFACE

If a little knowledge is dangerous,
Where is the man who knows so much
As to be out of danger?

T. H. Huxley, 1886

Here is a book of which I can rightly say: *I wish I had thought about it and entrusted the task to a distinguished writer.* The credit for the initiative must go entirely to the present Director of the National Chemical Laboratory, S. Sivaram. As to his choice of writer (who accepted the invitation with alacrity), judgment must be reserved. To me it has been a re-visitation, with the wisdom of hindsight, uncolored (one hopes!) by the biases and weaknesses of association. It has also been an exercise in separating the personal from the general, for the NCL has always been, and continues to be, a part of my life. I am grateful to Sivaram for inviting me to write the history of the NCL. At this stage of my life, no task could have been pleasanter, no physical infirmity a disabling obstacle. This is no idle assertion as it was put to the most stringent test following an accidental fall resulting in a serious head injury and a few heart attacks. Even as I was recovering, I resumed my writing, thanks to my daughter Sandhya's maternal care with her own brand of strictness that made no concessions and brooked no deviations from rules for which no doctor was responsible. Equally responsible for my recovery were my son Deepak's persistent telephone vigils, frequent visits, and constant discussions with the doctors attending me. Thus, I recovered sooner than the doctors had anticipated. My son-in-law Sankar and daughter-in-law Kelly's robust and affectionate support was no less responsible.

And so I begin this voyage into the past of an institution with threads of accomplishment, adjustment to changing times, failures, dreams realized, dreams dormant, all woven in a web of the founders' vision and the successive directors' unwavering purpose. There is also an element of the NCL's self-discovery in the attempt, a sense of increasing scientific empowerment.

On re-reading the book after writing the preface, I believe I may have occasionally strayed from absolute detachment in tone. But there has been no selective presentation of facts, jogging of memory or search for records, no intent to obscure or emphasize an event more than it deserves. Long association does tend to induce some imbalance, reflected in variations in tone and enthusiasm but never in fact (and this is as it should be lest the narration become barren and bereft of life, a mere chronicle of events). But, on the whole, detachment has been an article of faith in the present narration and any deviation, though rare and unintended, is no more than a passing intrusion of human frailty.

Sivaram perhaps subscribed to Robert Frost's view that *You can be a rank insider as well as a rank outsider*, and felt that I would bring in perspectives both as an insider and an outsider to the NCL, probably more as the former. In the words of Sandage (2005), a historian of the Carnegie Institution of Washington:

> *Scientific histories of major developments are never complete except in the memories of those who lived through them, and memories die with each generation...*

I hope the final product of his initiative is not just a chronological, itemized foray into the past, but much more: a readable document, anecdotal and story-like, with concise descriptions of major evolutionary steps, technical and non-technical, supplemented with appropriate detail, tables and figures: all these garnished with the personal fare of the major makers of its history and the silent contributions of the many who provided an ambience all its own and fostered the reputation it now enjoys.

The NCL has its strengths and weaknesses, but overall how does it come through? Records show that it has never attempted to hide its weaknesses, although there has been an eagerness to emphasize its strengths. Alarmed by the number of scientists who were seen as "whiling away their time," B. D. Tilak, a no-nonsense Director (1967–78), engaged the services of the Arthur D. Little Inc. of Boston, Massachusetts (USA) to evaluate the NCL's performance and atmosphere, and present a candid report to him. The report did say some extremely positive things about the NCL but it also noted some unhealthy vibes within the lab that needed to be addressed. While this report (and many others, critical and laudatory) will be briefly discussed in this book, I am highlighting them here to stress the laboratory's basic tenet: to learn the truth about itself and address its weaknesses openly. The readers may now judge for themselves how an institution born at the intersection of a nation's captivity and sovereignty and nourished in an overlapping cultural regime, has evolved over the years to become a major force in the country's science and technology.

I would like to say a few words about the general inadequacy of any writer to capture a "whole" over time, with expertise in no more than a few "parts" over a small fraction of the time. Even some of the greatest minds of the world have expressed this sentiment in their own inimitable ways. A classical apology for making such an attempt is that of the 1933 Nobel Prize winning physicist Erwin Schrödinger (of the wave equation fame) in his *What is of Life* (1944). Daring to draw a parallel with his, I reproduce this great scientist's apology as my own. The sheer beauty and truth of his words transcend time and context:

> *A scientist is supposed to have a complete and thorough knowledge, at first hand, of some subjects, and therefore is usually expected not to write on any topic of which he is not a master. This is regarded as a matter of "noblesse oblige." I beg to renounce the noblesse if any, and to be freed of the ensuing obligation.*
>
> Schrödinger, 1944

Then, after emphasizing the role of many sciences in formulating theories regarding the origin of life, he goes on to write:

> *It has become impossible for a single mind fully to command more than a small specialized portion of* [the total picture]. *I can see no other escape from the dilemma (lest our true aim be lost for ever) than that some of us should venture to embark on a synthesis of facts and theories, albeit with second-hand and incomplete knowledge of some of them, and at the risk of making fools of ourselves.*

While fully accepting this view, I would like to draw some solace from the lines of Huxley with which the Preface began.

The history of the NCL forms the major part of this "big" history. I realize that when Sivaram entrusted the task of writing this to me, that is exactly what he had in mind: the history of the NCL. The "big" part is entirely my addition. In view of the justification I have provided in my description of "big" history as a contextual way of writing the history of any institution, I hope he will accept this book as a broader version of what he had in mind. Let me hasten to add that nothing has been taken away from the NCL's history itself. Given the broader context in which it has been placed in the two-coordinate system of time and concurrent events, it provides for the first time, the history of an institution in India as part of the new, bigger way of looking at history championed by Christian (2004).

The material of the book is presented in six parts covering a total of 18 chapters:

- The roots of excellence (how it all began)
- Grasping the future (a modern chemical laboratory arrives)
- The sinews of excellence (evolution of research and development)
- The bridge to industry (technology transfer practices)
- The *compleat* laboratory (general scientific matters, infrastructure, and campus facilities)
- This and that (comments, anecdotes, and the road ahead)

Of these, Part I is concerned with the "big" part of the story. It summarizes the achievements of ancient Indian scientists, from pre-*Vedic* times all the way to the medieval period and then to the British era. It is shown how different cultures contributed in their own ways and times to the evolution of a single scientific culture, dominated in recent times by western science. It is argued that while the ancient Greeks contributed enormously to the evolution of science, the perception that they hold the sole hegemony is presumptuous. Other cultures, including Indian, were major players in their own times, but unfortunately many Western historians have been dismissive of their contributions — with some refreshing exceptions like Dick Terreci. It is hoped that this intellectually profound ancestry will serve as a latent stimulus for modern India's quest for scientific supremacy after centuries of torpor.

Parts II to IV are concerned with the evolution of all aspects of the NCL. Part II begins by describing the educational, research and industrial environment in which the NCL evolved. The narration then takes the first step towards describing the institute's history, by describing the birth and evolution of its parent organization, the Council of Scientific and Industrial Research (CSIR). This logically leads to the history of the NCL (the "small" history) starting with its launching by Prime Minister Jawaharlal Nehru in the presence of a galaxy of scientists, including several Nobel Laureates and other dignitaries. This is followed by anecdotal accounts of the regimes of all its directors since its founding and a description of the NCL's evolution over more than half a century. The emphasis is on the making of a modern state-of-the-art laboratory with its persistent call to excellence, including the formation of several resource centers and computerization of the laboratory. Part III is concerned with the laboratory's R & D programs, with accounts of its important areas of research and links with the academia and industry. Part IV covers the NCL's technology transfer practices over the years with several examples of different types of transfer, and its smooth transition into the free-market era with its demands on the laboratory's ability to attract industrial collaborations and funding.

Part V deals with various review committees, seminars, and other general scientific issues, followed by a description of the laboratory's infrastructure like its administration, workshop, library, etc., and finally its medical center, garden, and campus facilities.

Part VI tries to capture the NCL as viewed by a distinguished Indian, M. M. Sharma, who was associated with the laboratory for about four decades, and also records the reminiscences of the children of its directors, thus providing a personal touch to the history. Several anecdotes, technical and non-technical, bringing out the human side of the makers of the NCL, add a particularly fascinating chapter to the history of the laboratory, and as many of them as I could collect or recollect are recounted in this part.

I would like to emphasize that the craft is far more important than the craftsman, a veritable truism no doubt, but one that bears retelling. I might have missed or misinterpreted some facts, but the true facts can never be fully lost, even as the celebrated Jacob (Jacques) Bernoulli's desire, ruined by an erring engraver, could never by kept out of history. It seems that Bernoulli wanted a logarithmic spiral (a logarithmic function in polar coordinates) engraved on his tombstone in Basel, Switzerland. Instead, the engraver had the Archimedean spiral (a straight line function in polar coordinates), a gross error that was soon discovered but no correction was made. In my mundane effort, any errors are my own, which, I hope, will be forgiven by an indulgent readership and corrected in a future attempt (if any), unlike the uncorrected spiral that still adorns Bernoulli's tombstone. In any case, as the well known theologian, Reinhold Niebuhr (1892–1971), has remarked, *Sometimes truth comes riding into history on the back of error.*

I end this preface by referring to two features of the book, one that does not heed Ralph Waldo Emerson's (1803–1882) admonition: *I hate quotations; tell me what you know*. and the other that seeks a balance between van Leunen's three types of footnotes:

> *There are scholars who footnote compulsively, six to a page, writing what amounts to two books at once. There are scholars whose frigid texts need some of the warmth and jollity they reserve for their footnotes, and other scholars who write stale, dull footnotes...* (Barrow, 2000)

Most books follow Emerson's advice, some notable exceptions being the books/articles of Barry Gould, Richard Dawkins, Marc-Alain Quankin, and my own late friend Rutherford

Aris, a rare combination of scientist, engineer, and man of letters. Quotations from famous writers have an important role to play. They add perspective to a narrative by projecting a specific fact against a larger truth. As for endnotes, in the right amounts they add color and provide pertinent (sometimes amusing) departures from the text. I have tried to spread some historically relevant ones throughout the book (with Chapter 18 claiming, rightly as its title indicates, a larger share of both). All figures, tables and boxes have been sourced from the National Chemical Laboratory, Pune or from my personal archives unless otherwise mentioned.

Acknowledgments

This work is the result of many peoples' efforts. Although I have no official connection with the laboratory, it is a pleasure to record that all members of the NCL staff, with no exception, treated me as if a link, a strong one at that, still existed. Their kindness was overwhelming and their readiness to help most pleasing. If I name a few persons here for special thanks, it does not mean that the others were any less special, only that I bothered the named people more routinely for help and information.

Sivaram named P. K. Ingle and S. B. Katte as my special links with NCL. They were much more. They helped me re-live my days at the laboratory, and I sincerely thank them for their help. Ingle has been particularly responsive to my calls for information. Wafia Masih and P. Venugopal came a little later into the picture. Their efficiency was exceeded only by their readiness to help. H. B. Singh compiled most of the information I needed from him. He was matter-of-fact and always pleasant and helpful. My son Deepak introduced me to the fascination of history, the history of science in particular, and was an instant source of information in diverse areas, not to mention the many suggestions he made from time to time.

I met Wafia for the first time, but she made me feel like I had known her all along. Her commitment, even as I wrote from Ames, was refreshingly genuine, and I cannot adequately thank her for her help. She bore the brunt of my intrusions on their collective time — with dignity, and a smile that I could only see in my mind's eye across continents.

And now I come to the scientists (including those who have retired) for their technical help, those who wrote notes for me, held discussions with me, and were patient to a fault as I burnt the e-mail highway, and amended or completely re-wrote their notes. Their work forms the bulk of Chapters 8 to 11. In them I sought my answers, and found them. I name them, in no particular order: Paul Ratnasamy, R. A. Mashelkar, V. Jagannathan, Sukh Dev, B. D. Kulkarni, M. G. Kulkarni, M. C. Srinivasan, Ranjani Nadgauda, K. N. Ganesh, Sourav Pal, R. N. Sharma, S. Devotta, P. Vijayamohanan, B. L. V. Prasad, V. V. Ranade, R. B. Mitra, S. Sivasankar, R. V. Chaudhari, V. R. Choudhary, G. R. Venkitakrishnan, S. B. Halligudi, Nileema Iyer, S. Ganapathi, M. K. Gurjar, G. S. Grover, S. Krishnan, M. P. Chirmule, Mala Rao, J. V. Rajan, V. Ravi Kumar, C. V. Avadhani, A. J. Varma, Veda Ramaswamy, A. V. Agashe, M. M. Jana, V. G. Neurgaonkar, B. A. Nagsampagi, B. D. Kochar, and K. V. Krishnamurthy. I also received a great deal of help from the technical and non-technical staff, which I acknowledge with much thanks. In particular I would like to mention the help of N. B. Dahibhate and T. A. B. Mulla.

I wish to express my profound thanks to B. D. Kulkarni, V. Ravi Kumar, V. K. Jayaraman, and M. G. Kulkarni for giving so freely of their help and time. I am also thankful to F. A. A. L. Shaikh, A. S. Banerjee and K. Radhakrishnan for helping in various ways, and to Vijay Vaichal and his colleagues of the guest house for their courtesy.

I would like to record in what is perhaps one of my last major writings, my deep sense of appreciation to my life-long friend and scientist-technologist *par excellence*, M. M. Sharma. We held as many views in common as those we did not, some of which come through in this book, and I have had the benefit of his specific views on the NCL through a formal interview as well as comments on a few chapters. The attachment was both intellectual and personal, and I join the many scientists of the country in thanking him for his immense services and advice. I am equally grateful and thankful to my friend Edwin Lightfoot, a scholar of the highest class, who has greatly influenced my own thinking over the years.

I wish to thank the publisher, Routledge, and its editorial team for accommodating the many additions and corrections made by me till the very end.

Much of this book was written at the Department of Chemical and Biological Engineering of the Iowa State University (ISU) in Ames, Iowa, USA. I am grateful to Charles Glatz and James Hill, the two Chairmen of the department during the time the book was written, for their generous help and support, without which I could not have written this book. The present chair, Surya Mallapragada, has been even more vigorously supportive. Linda Edson provided constant help in all my writings from ISU. I am thankful to her for helping in many ways.

The story of this book is thus a story of two institutions, one about which it is, and the other from where it was written: tracing the meandering path to excellence of one institution from the scholarly ambience of the other. Robert Frost's belief that one can be a "rank insider" as well as a "rank outsider" (mentioned in the earlier part of the preface) was put to a severe test here. To what extent I have succeeded is not for me to judge. One thing I can truthfully say: it would not be for want of trying.

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L. K. Doraiswamy
Anson Marston Distinguished
Professor in Engineering (Emeritus)

INTRODUCTION
STATING THE CONTEXT

> *The difference between what we do and what we are capable of doing would suffice to solve most of the world's problems.*
>
> Mahatma Gandhi

Born at the intersection of Britain's rule (the Raj) and India's independence (*Swaraj*), the National Chemical Laboratory has evolved in the bicultural regime of the West and the East. Steeped in the pluralistic heritage of ancient and medieval India, it quickly embraced the Aristotelian empire of reason emanating from Greece, during the Raj to become a force in the modern world of science. The present book is an attempt to trace the evolution of the NCL against this unobtrusive cultural background.

Before proceeding with the book, I would like to place the National Chemical Laboratory (NCL) in a cascading series of frameworks: first, by stating the position of Indian scientific research in the broader world context, then examining whether the voice of ancient Indian science has been stilled forever in the country's justifiable commitment to modern science, and finally, placing the NCL in the context of Indian science. The opinions expressed are personal and are meant to be statements with no elaborate discussions (which could be a subject for another day and another book). It is my hope that this will give a flavor for the book's overall intent, progressively narrowed down as it proceeds to its specific purpose. In that way, I hope it transcends the restrictions of a prosaic factual history of a specific institution.

Indian Research in Relation to the Most Outstanding Research in the World

One of the world's most unique centers of research, the Institute for Advanced Study at Princeton, was the brainchild of the educational reformer, Abraham Flexner,

> *who persuaded two New Jersey department store heirs Louis Bamberger and his sister Mrs. Felix Fuld to charter a new type of academy dedicated to the usefulness of useless knowledge…His idea was to create a haven for the purest of thinkers, to realize the proverbial ivory tower in solid red brick.*
>
> Goldstein 2005

The most famous member of the Institute was, of course, Albert Einstein. Many other luminaries from Europe followed him including the dazzling Hungarian polymath who scandalized the Institute by beginning the construction of the world's first computer, thus compromising its commitment to keeping the Institute free of any "useful" work! The Institute's outraged conscience was assuaged only when the computer was transferred to the neighboring Princeton University! Einstein himself seems to have had a different view when he said back in 1931:

> *…concern for humankind itself and its fate must always form the chief interest of all technical endeavors…Never forget this in the midst of your diagrams and equations.*'[1]
>
> Einstein

Indirectly equating useless research to valuable research, C. V. Raman remarked that *Research does not have to be useful in order to be valuable.*

One can see this conflict, although it was not perhaps recognized as such, in ancient Indian science. The unstated commitment to useless research can be clearly seen in the conditions for stressless scholarship encouraged by certain patrons of learning in ancient India. Notwithstanding this theoretical lineage, experimental science seems to have gained in emphasis over time. The NCL was no exception, although theory was by no means abandoned.

In dealing with matters of more immediate concern, most importantly this book, the following profound if somewhat boastful statement, made by the positivist group of mathematicians known famously as the Vienna Circle (also as *Schlick-Kreis*, named after its founder, Moritz Schlick of inexhaustible friendliness) (Mengel, 1994), should serve as a signpost of encouragement (Goldstein, 2005).

> *Since the limits of knowability are congruent with the limits of meaning, no meaningful matter can escape our grasp. We are cognitively complete.*

My own interpretation is that man's cognitive potential as represented by his achievements in the most advanced countries of the world is complete within the principle of incompleteness,[2] but he is still far, far from that limit. The relevance of this statement stems from its application even under the incompleteness theory of Kurt Godel (the incomparable but tragic genius), generally regarded as the world's greatest logician since Aristotle.

As far as India is concerned, we are even farther away. Till date Indian scientists as a class have shown no great propensity for top class research that could lay claim to the highest world recognitions. But there do exist a few bright spots, the NCL being one, that could carry the day — although in a land of over a billion people that boasts of one of the finest educational systems in the world, this is hardly a consolation. It is a sobering thought that, overall, science in India continues to lag behind the West; and this in a country that once was home to some of greatest mathematicians, scientists, poets, philosophers, religious leaders, sculptors, painters, musicians, kings and warriors second to none in the progression of human accomplishment.

Do Muted Calls from Ancient Indian Science Resonate in Present Day Indian Science?

> *The study of ancient writings has disclosed in recent years the extent and variety of these scientific contributions. Much progress was made in the*

study of Arithmetic and Geometry, while the researches of Sir Prafulla Ray have brought to light the important advances made in Metallurgy and Chemistry. May we not hope that this natural aptitude for Experimental and Abstract Science, shown so long ago, is still characteristic of the Indian peoples, and that in the days to come India will again become a stronghold of Science, not only as a form of intellectual activity but as a means of furthering the progress of her peoples.

Ernest Lord Rutherford of Nelson, Nobel Laureate
(Presidential address by Sir James Jeans
at the Indian Science Congress Association, Kolkata, January 1938)

Where this book is concerned, no greater justification is needed, besides the invitation from the director of the NCL, than these words of one of the greatest luminaries of science — the discoverer of the nuclear theory of matter. The scope of the book, starting from ancient Indian science, through the days of scientific stupor in India, to the days of British rule, and coming all the way to the present, with the history of the NCL as the primal theme of independent India's scientific resurgence, is a small illustration of the loftiness of Lord Rutherford's thoughts. It is also a big history of the NCL, of what a modern laboratory can do with its rich cultural ancestry and the tools of modern science.

What is the NCL'S Place in Modern Indian Science?

NCL is a jewel among Indian laboratories

S. K. Palit

Professor Palit was a doyen among polymer chemists of the 1960s and 70s and was a member of the NCL's Executive Committee for a number of years. This view was not shared by many scientists and technologists of that period.

NCL should concentrate on process development full time and leave basic research to universities, which are more suited for this kind of research

was the refrain of many academics. Some, like H. E. Eduljee, a highly respected chemical engineer of the mid-20th century and a member of many NCL committees for a number of years, worried about the NCL's *formlessness,* while others were convinced that *with all its talent and facilities, the NCL should engage in full time basic research, the kind neither industry nor academia are equipped to do.*

Clearly the NCL meant different things to different people. Each group had its own views on how tax payers' money should be most profitably used. After passing through these vicissitudes of expectation, there is now perhaps a settled view that the NCL has a combination of talents that should be left to the dispensation of the management to be used in the best interests of Indian science and technology.

If the Indian Institute of Science and Tata Institute of Fundamental Research are the leading institutes in India in a variety of fields, the NCL is generally regarded as being in the same class in chemistry and among the best in chemical engineering in the country.

What Is Big History?

I attempt in this book to place the National Chemical Laboratory (NCL) within a wider reality, wider both in material scope and time. Any story must, at the least, find a niche in a horizontal-vertical coordinate system: the horizontal defining its reality among a whole set of parallel happenings and the vertical defining it in respect of its own evolution over time. I formulated this perspective first from my reading of H. G. Wells' *History of the World* (1922) which is perhaps one of the first attempts to write a rather restricted "big history" of the world — an opinion-enriched narration of concurrent events over time in humanity's recorded history. But the formal beginnings of big history can be more directly traced to Fred Spier's *The Structure of Big History: From the Big Bang Until Today* and David Christian's *The Case for "Big History"* (1991) and the *Maps of Time*: *An Introduction to Big History* (2004). Some other books also deal with this rather awesome subject in varying degrees of relevance (see Christian, 2004).

In a nutshell, big history is a kind of totality of things on all timescales, from zero time and zero space (nothingness) to their staggering present values of 16 billion years and 16 billion light years from end to end of detectable space — and still counting. Across this incredible timescale involving natural, inorganic, organic, astronomic, terrestrial and all life-related phenomena, there is a thread of commonness. Diversity rules but an evolutionary commonality is still discernible. The Darwin lectures of the Darwin College provide deep insights into many topics of intellectual endeavor. The 10th lecture series of 1995 compiled by Andrew Fabian (1998) under the title *Evolution* throws much light on the subject in all its ramifications.

If lecturer Freeman Dyson is right, as he almost certainly is, the central basis of all evolution — scientific, astronomical, biological, social — is a combination of speciation and symbiosis: a process of successive subdivision of form, i.e. speciation, interspersed by a process of coalescence of distant and dissimilar species into larger single entities, i.e. symbiosis. The pre-eminent big historian David Christian (2004) conveys this central edifice of evolution differently. In the nascent universe, *gravity took hold of atoms and sculpted them into stars and galaxies* (Christian 2004). Similarly, a kind of *social gravity* was responsible for cities and states. The sciences, such as biology and astronomy, also evolved by a process of *particlization* of energy followed by coalescence. Thus, stars, cities, societies, the sciences, all continually reorganize and energize to produce changed and often more complex entities.

True to this grand concept, science has evolved over the last 5,000 years in all regions of the world. It has been a two-theory approach all along, the quantum theory of the small involving strong nuclear forces and the relativity theory of the large involving electromagnetic, gravitational, and weak nuclear forces, and we are still struggling to find a common law for all forces (although the superstring theory is said to have laid the foundation for it). The ancients of different cultures contributed too, within the compass of their own knowledge. They included Indians, who played their own role in the evolutionary trail. The formation of the earlier galaxies is no less important than that of the newer one. So is the old science no less important than the new. One can continue to debate whether the concept of zero is any less important than, say, the concept of relativity. There can be no answer, because they both are important beyond measure, the old and the new — each in its own surpassingly unique way.

Between the space and time scales, the more important from our viewpoint is the time scale. I show in the accompanying Figures i to iii the evolution of events since the ice ages. Successive figures are exploded representations of the more pertinent timelines of the previous figures, starting from the last ice age all the way to the present. Three timelines are provided in the accompanying figures, the last summarizing the evolution of the NCL.

These timelines are important because the history of any event or functional entity is influenced by what happened before it. In the more formal language of Wolf (1988), to describe any such event or entity, one should think:

> *relationally — in terms of relations engendered, constructed, expanded, abrogated; in terms of intersects and overlaps, rather than in terms of solid, bounded, homogeneous entities that perjure without question and without change.*

I cannot think of a better definition of big history on a shorter, more relevant, timescale than Wolf's. But history itself, near or remote, is difficult to fully grasp in its truest sense. *Pierre Menard, the author of Don Quixote* by Jorge Luis Borges, does not define history as an *investigation of reality*, but as *its origin*. My own understanding of history is too simplistic to argue this profound point. I go along with the general run of historians and vote against Menard. My history (of the NCL) is thus an investigation of a well-defined reality, culturally influenced, however faintly, by events somewhat obscured in historical antiquity, nurtured in the reality of the immediate past, and embedded in the reality of unfolding events during its own physical existence. This is my definition of big history.

Traditional or "small history" is like a fast food restaurant, meant for readers in a hurry. A good measure of the ambience and completeness comes from the big part. Hence I make no apology for the structure of the book, particularly since the big part of the big history can be eschewed without diminishing the coherence or authenticity of the more directly relevant remainder, i.e. timelines (i) and (ii), (iii) in particular).

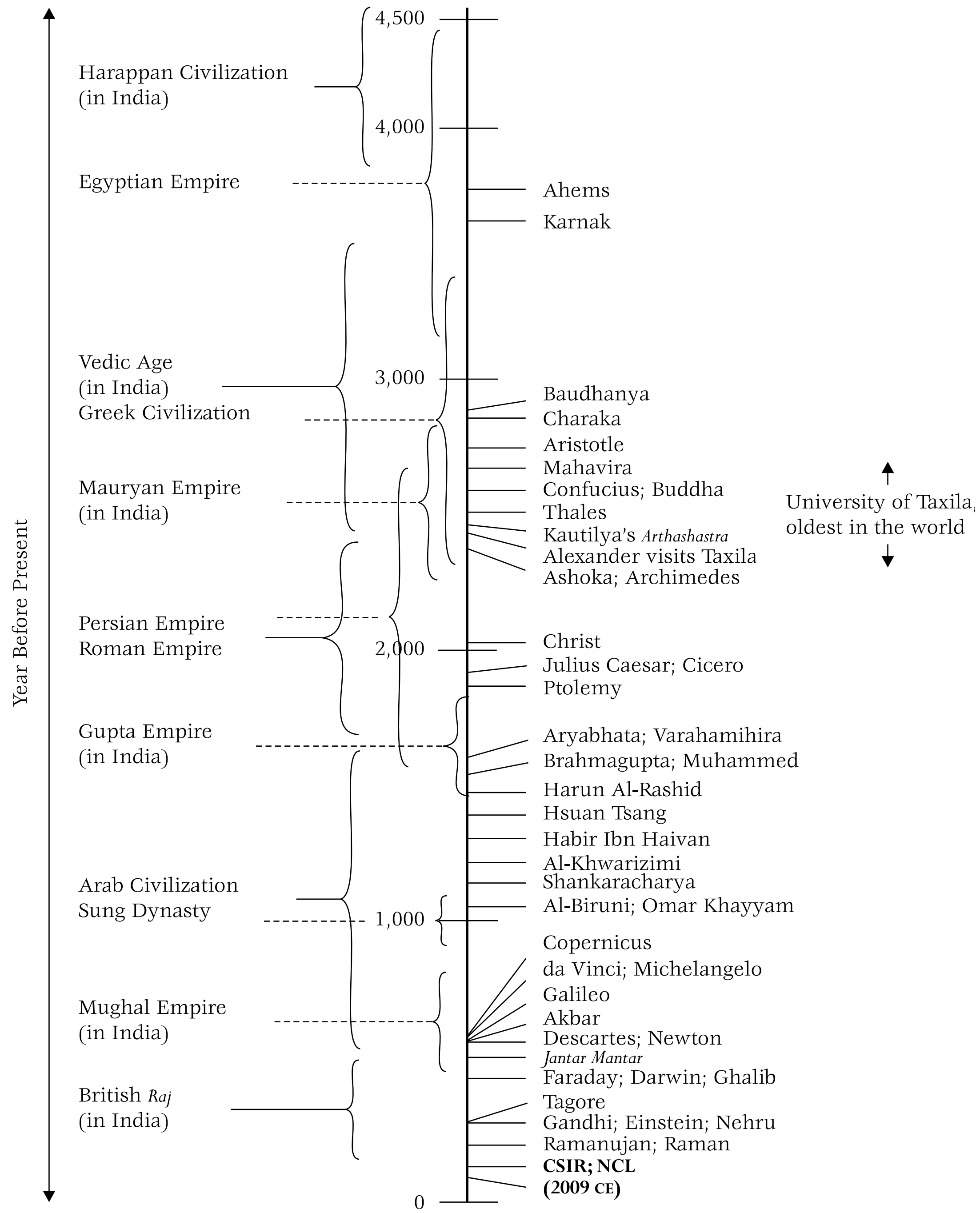
I would like to conclude this section by referring to the structural evolution of the NCL. While the details will emerge as one wades through the chapters, it is pertinent to note at this stage the complex structure in 2006 under Sivaram that has evolved from the simple structure in 1950 under McBain (Figure iv). The significant change is due as much to the progressive sophistication of the laboratory as to the increased role of management.

Perils of a Former Director of an Institute Turning Historian

A historian of science and California Institute of Technology's official chronicler Judith Goodstein (see Goodstein, 1998) has this to say about the history (written mostly as a biography of the man who started it) of an institute written by a person who was part of it:

> *Three insidious temptations assail a biographer: to suppress, to invent, and to sit in judgement, the English writer and historian Iris Origo tells us in one of her essays. An additional peril, in her opinion, confronts a biographer who is a historian. As biographers, our job is to describe a*

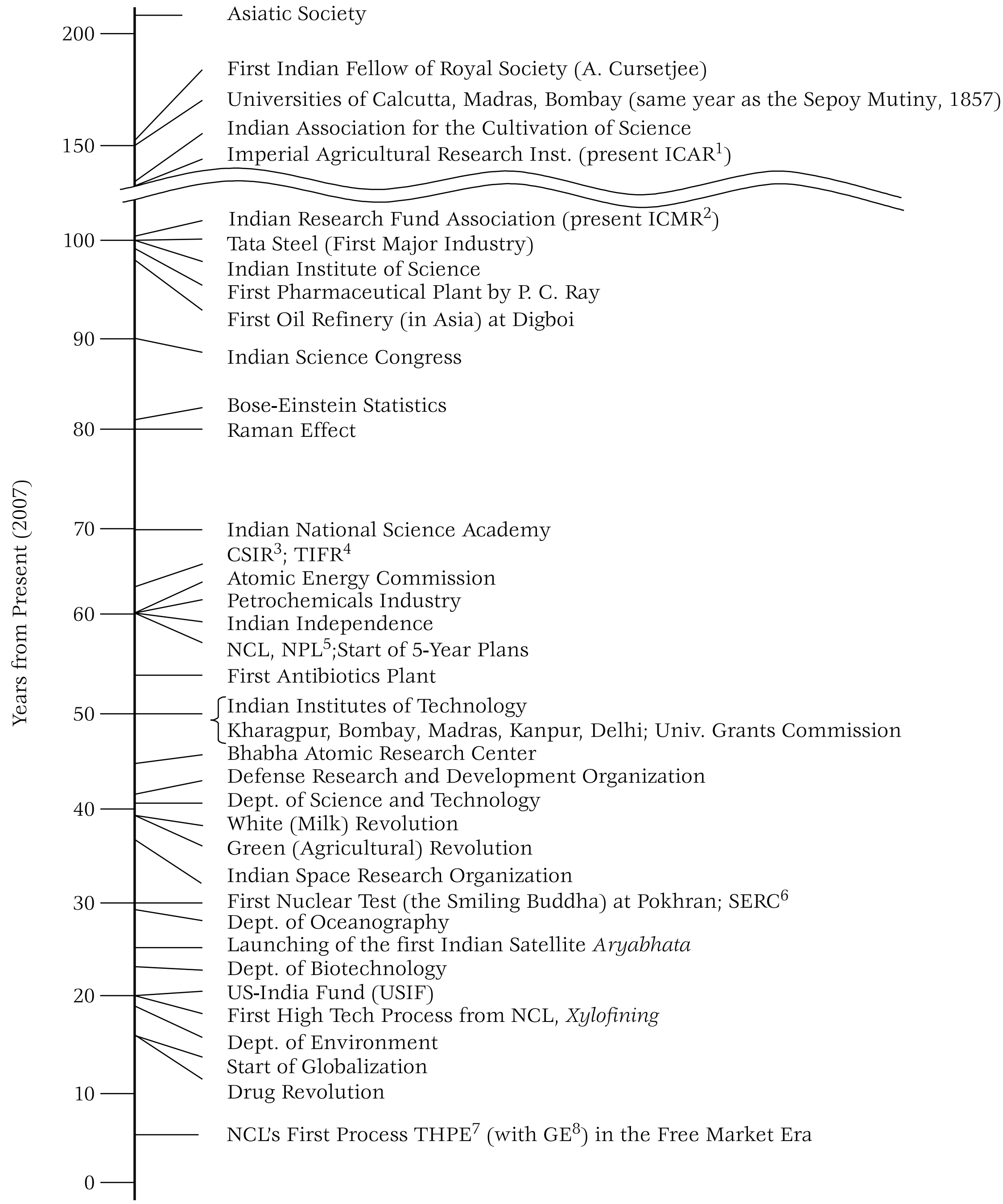
Figure i: Timeline of selected major names and periods (approximate) in the evolution of science (and its patronage) in the last 5000 years, with particular reference to ancient (mostly Indian) cultures. See next page



Brief descriptions pertaining to the names included:

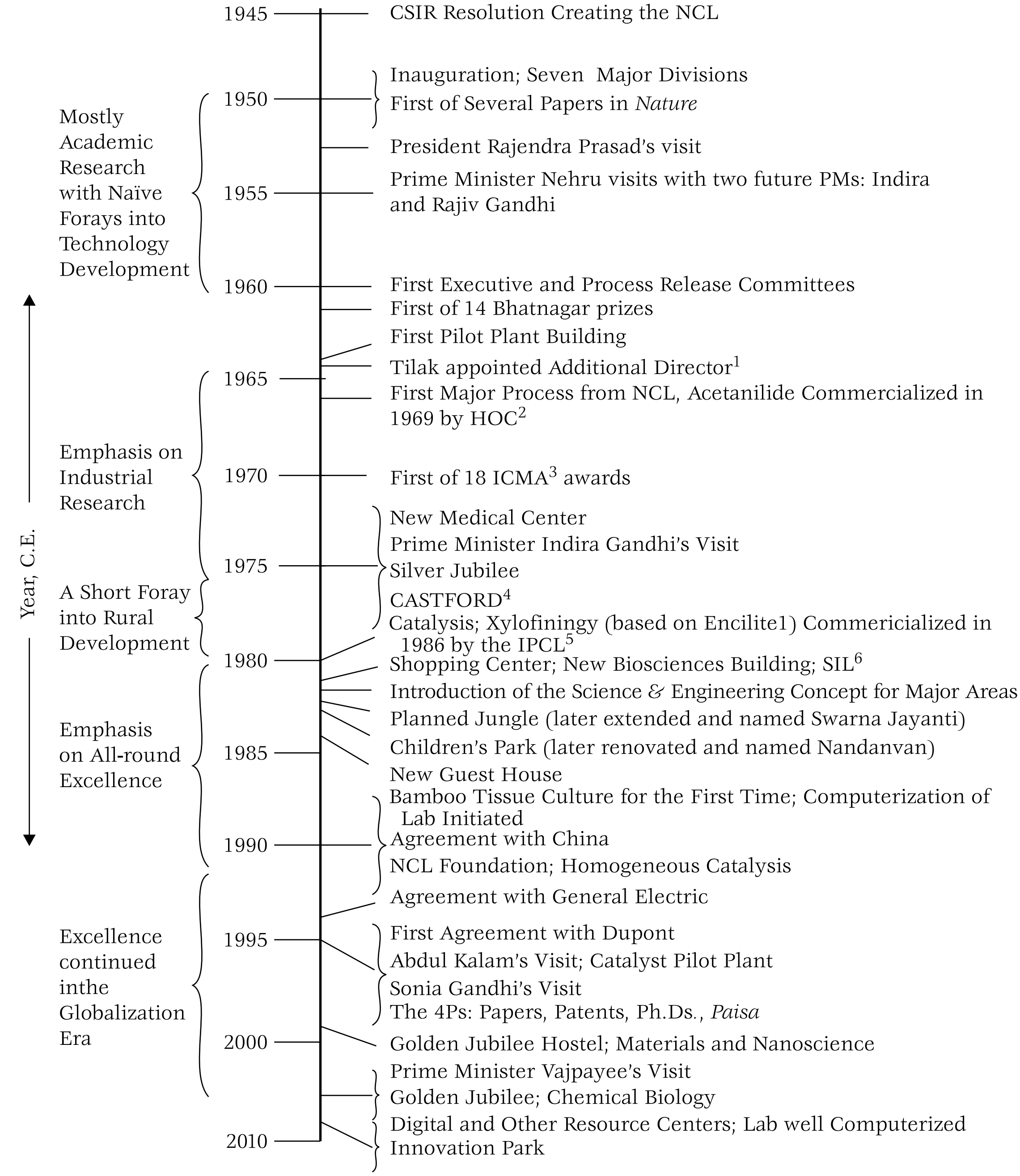
Ahems and Karnak, early Egyptian mathematicians; Baudhanya, early Vedic scholar, mathematician, author of the first *sulbha sutras*; Charaka, perhaps the greatest Vedic physician; Aristotle, father of modern Western thought and the first logician of the world; Mahavira, founder of Jainism and a great mathematician; Confucius, the pre-eminent Chinese philosopher; Buddha, a scholarly saint, the "enlightened one;" Thales, generally regarded as the "first" scientist in the modern Western sense; Kautilya's *Arthashastra*, the first "omnibook" of state matters, rules of conduct, and the sciences written during the Mauryan period in India; Alexander's visit to the first university in the world, the University of Taxila in India (now part of Pakistan); Ashoka, referred to by H. G. Wells as the "king of kings;" Archimedes, the first great "physicist" of the world; Jesus Christ, the founder of Christianity; Julius Caesar, one of the best known world conquerors; Cicero, famous Roman senator, scholar, and orator; Ptolemy, known for his concept of the sun revolving around the earth; Aryabhata, the best known early Indian mathematician and astronomer, and inventor of zero; Varahamihira, a famous Indian polymath; Brahmagupta, arguably the greatest ancient Indian mathematician; Muhammed, the founder of Islam; Harun Al-Rashid, the famous Caliph of Baghdad, known for his patronage of art and science, who ordered the mathematical works of Brahmagupta translated into Arabic; Hsuan Tsang, the first famous Chinese traveler to India; Habir Ibn Haivan, the first great Arabic chemist; Al-Kwarizimi, the great Arabic mathematician known for his algebra and popularization of Hindu calculation methods in Europe; Shankaracharya (popularly known as Shankara), the first great reformer of Hinduism; Al-Biruni, the first famous Arab traveler to India who was also a great mathematician and astronomer; Copernicus, the father of modern astronomy; Leonardo da Vinci, one of the greatest polymaths of all time; Michelangelo, perhaps the world's greatest exponent of visual art, mostly sculpting (and painting); Galileo, who was the first to use the telescope to make some of the most important early astronomical discoveries, and perhaps the most famous victim of the Inquisition; Akbar (known as the Great Mughal or *Akbar-e-Azam*), who entertained men of literary and scientific accomplishments in his court and was the greatest Muslim champion of Hindu-Muslim unity; Descartes, the great French mathematician-philosopher (after whom the Cartesian coordinates in mathematics are named); Newton, regarded by many as the greatest scientist the world has known ("God said Let Newton Be and All Was Light"); *Jantar Mantar*, the first astronomical laboratory of India; Faraday, perhaps the world's greatest experimental scientist; Darwin, father of the revolutionary theory of life, evolution; Ghalib, perhaps the most talented Urdu poet of India; Tagore, the first Indian to receive the Nobel Prize in Literature; Gandhi, rated by the *Time* magazine as one of three greatest human beings of the 20th century (a century of great men); Einstein, rated by the same *Time* magazine as the greatest human being of the 20th century; Nehru, India's first Prime Minister and a scholar, who set India on a stable course; Ramanujan of India, one of the greatest unconventional mathematicians the world has known; Raman, the first Indian Nobel Laureate in science.

Figure ii: Timeline of the last 200 years in India



Note: [1]Indian Council of Agricultural Research; [2]Indian Council of Medical Research; [3]Council of Scientific and Industrial Research; [4]Tata Inst. of Fundamental Research; [5]National Physical Laboratory; [6]Science and Engineering Research Council; [7]Tris-hydroxy-phenylethane; [8]General Electric

Figure iii: Timeline NCL, 1945-2007



Note: [1]For the only time in CSIR's history, to succeed Venkataraman on his retirement; [2]Hindustan Organic Chemicals Ltd; [3]Indian Chemical Manufacturers' Association, recently renamed Indian Chemical Council; [4]Center for Application of Science and Technology for Rural Development, under Dept. of Science and Technology; [5]Indian Petrochemicals Corp. Ltd; [6]Special Instruments Lab) *person's life in such a way as to allow the reader "to see history in the course of being lived." In the process, the biographer runs the risk of drowning "his subject's voice with his own." Is a biographer required to have a point of view? Without one, answers Origo, "no history can be written." The danger arises, when that point of view is used, in her words, "not only [to] shape but distort the facts." Her advice to the young biographer is direct: start with a dash of humility. What Origo says in her essay on writing about other people applies to historians writing about contemporary scientific subjects, to us.*

The Italian writer and chemist Primo Levi moved with ease in both worlds. "There are people who wring their hands and call it [the separation between the scientific and literary cultures] an abyss," he wrote in 1985, "but do nothing to fill it; there are also those who work to widen it, as if the scientist and literary man belong to two different human subspecies, reciprocally incomprehensible, fated to ignore each other and not apt to engage in cross-fertilization."

The present book is not a biography of an individual, but can probably be regarded as a sort of restricted collective biography of the makers of the NCL, viewed in the context of ancient and recent history and the present. I am no more than an engineering scientist

Figure iv(a): Evolution of the organizational structure of NCL under McBain in 1950

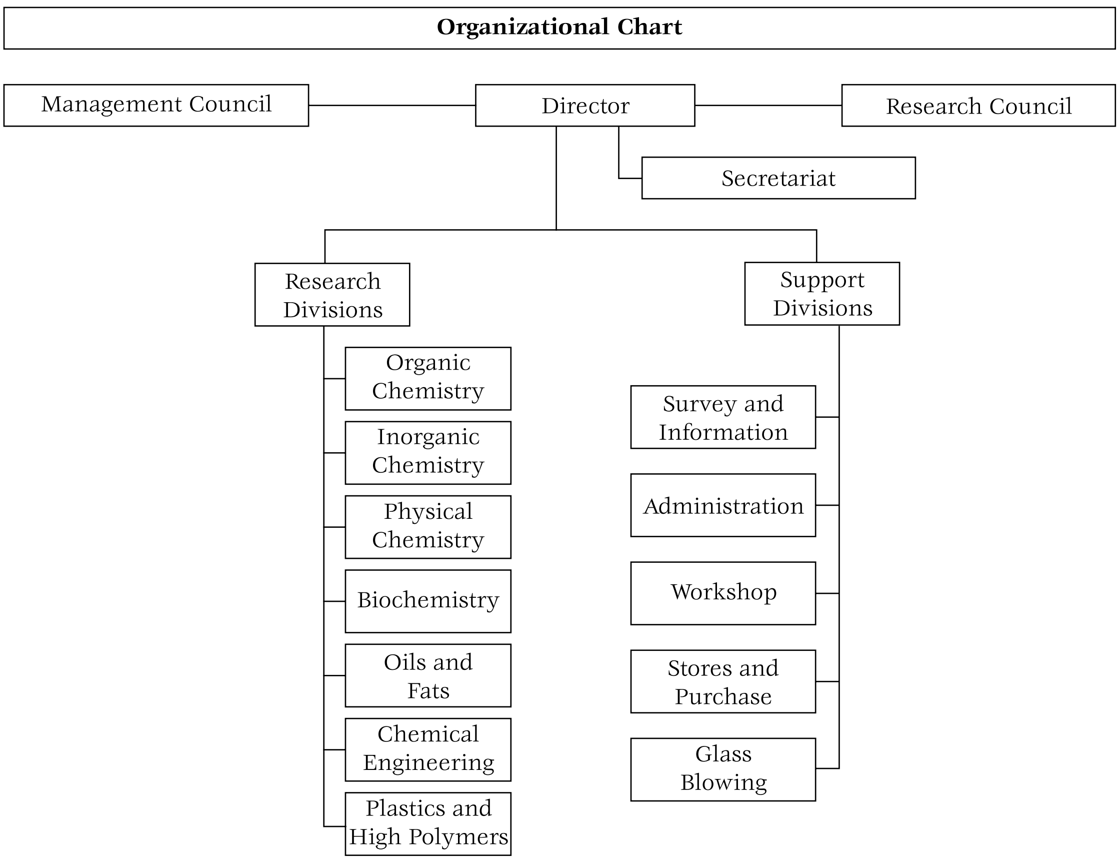
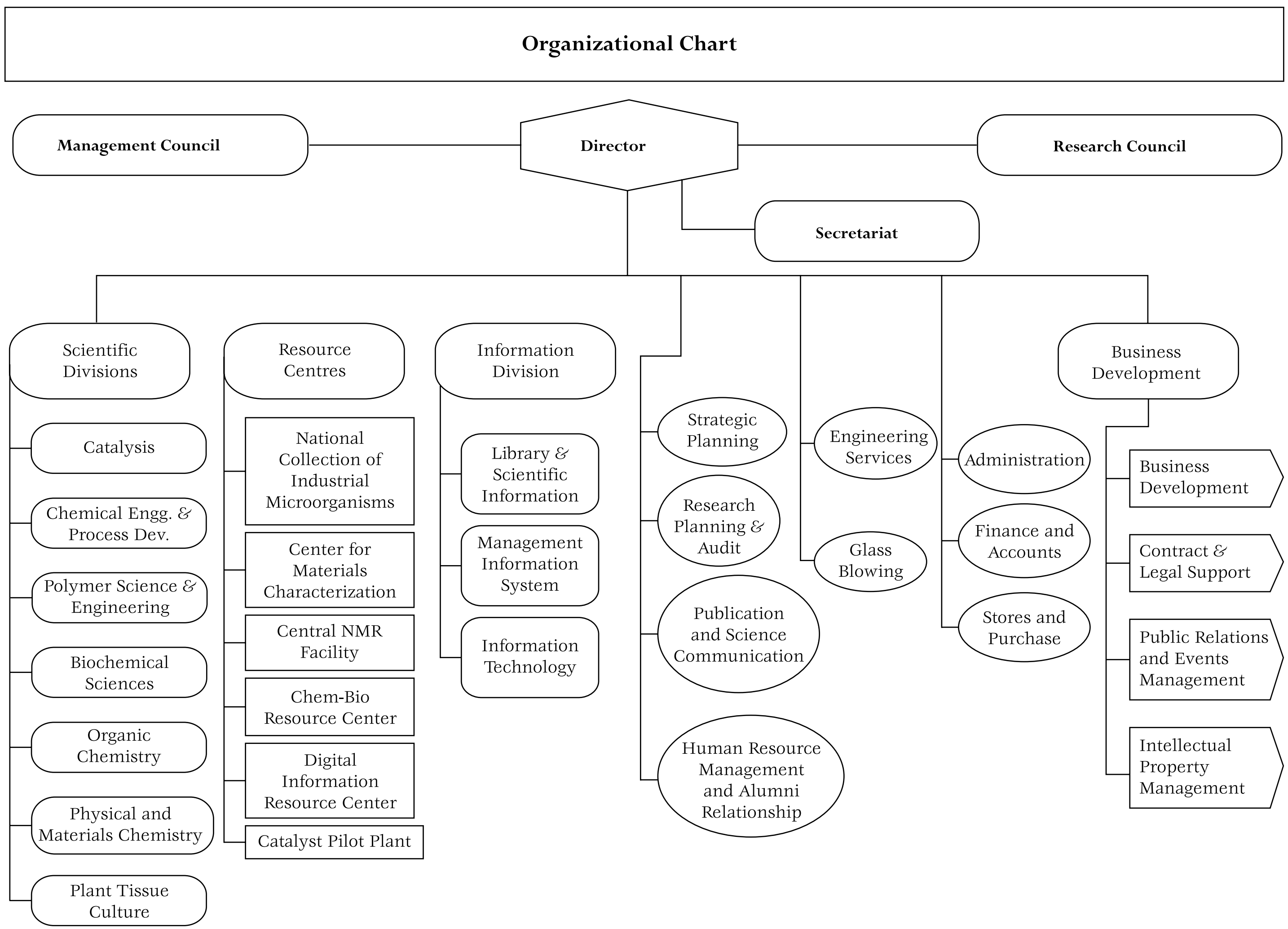


Figure iv(b): Evolution of the organizational structure of NCL under Sivaram in 2006



and have no pretensions to being a man of arts and literature. I have tried to bridge the gulf between science and literature by extending to the subject my dabbling with writing, such as it is. I hope to make it clear as I proceed with the book that, as far as CSIR is concerned, Bhatnagar played the game to win, in his own way — unorthodox, combative, and fully committed. So did the first few directors of the NCL, each in his own way, and the others have tried to extend the streak.

The biggest problem for a person like me, both an insider and an outsider, is objectivity and selectivity in the choice of facts. Distortion of facts is not an issue at all, too insidious to be even a consideration. I have tried most diligently to let the facts take me where they would, and to present them uninhibited but not entirely bereft of opinion. Selectivity has been avoided by presenting facts that reflect all sides of the laboratory. The first three chapters place the NCL in perspective (mostly in the context of past and current events in India), the middle chapters describe its evolution, and the final chapter offers suggestions for the future. This, I felt, was the best way for a former director of the NCL to tell the laboratory's story.

❄

Part I
The Roots of Excellence

I read some hopeless verses once
that don't deserve to last.
They told how the mill can never grind
with water that is past.

William Tomkins, 1730–92

And then to the beginning and after: From the country's rebirth, through changing times and policies, to a self-correcting stability and dominance laced with those indelible moments of doubt that characterize an institution in search of itself, but most of all by attempts to minimize the undulations in its intellectual continuity.

INTRODUCTION

To misquote Winston Churchill on his famous remark at the end of one of his books, indeed, to expand on what he wrote, Part I of the present book comprises

The distant beginning of the beginning;
The nearer prelude to the beginning;
The immediate run up to the beginning;
All linked in a chain from ground zero.

The beginning was when the NCL started as a functioning laboratory with its main building, primary utilities, and infrastructure in place. But much had to happen before such a beginning could be made. And for even that to happen, there had to be a cultural reservoir building up from ground zero. All this will be briefly recounted in Part I distributed over three chapters:

- Science and technology in ancient India, touching upon the scientific ethos of that time (beginning of the beginning)
- The scientific and industrial climate of the country during the Raj and the transition to free India (prelude to the beginning)
- The run up to the beginning, a story in itself, covering the formation of the Council of Scientific and Industrial Research (CSIR), planning and creation of the NCL, and the efforts that preceded the functioning of the NCL as a full-fledged semi-autonomous unit under the overall control of the Delhi-based CSIR (the run up to the beginning).

Chapter 1 of this part covers ancient science in India from Vedic times through the Mughal period to the British rule, and Chapter 2 covers science during the British rule. Chapter 3 is concerned essentially with the beginnings of the CSIR and NCL.

1

RISING FROM GROUND ZERO
THE BEGINNING OF THE BEGINNING

In the middle of Duua's forehead there was one great eye. With this eye Duua could see a place so far away it could take three days to reach it.

Francis Woodman Cleaves
(English translation of *The Secret History of The Mongols*, 1956)

Imagination was the ancients' forte. The Mongols of the 13th century seem to have preempted even Einstein with regard to the space–time concept! The lines quoted above, describing the farsightedness of Genghis Khan's descendent Duua, border on the clairvoyant.

Introducing a Familiar Stranger

This section is particularly relevant to the "big" history of a major scientific institution like the NCL in a country like India that has experienced all the stages of cultural evolution: origin and dominance, decline, and resurgence. This will not only put things in perspective but also help understand the unevenness in the country's scientific continuity. There has been a process of acceptance and assimilation, a continuing strength in a world not so blessed in its many regions. Thus, we will attempt very briefly in this section to capture and convey the historical backdrop to the country's present stable scientific structure. It is this climate that has fostered the rise of science and technology through the formation and growth of a variety of scientific agencies, as well as educational and research institutions, including government agencies and departments, universities, institutes of technology, national laboratories, test houses, think-tanks, and many more. This process has recently been accelerated by the participation of the private sector in industrial research and development.

The past is somehow built into the Indian thinking, but there has not been an explicit recognition of it. Most of us are familiar with the fact that some great feats were accomplished by ancient Indians and can even name some people like Aryabhata, more so since the space program came of age and the earliest satellite was named after him. But only a few actually know what the accomplishments were; the vast majority are strangers to it. Thus, in addition to being a part of NCL's big history, this chapter will introduce many of us to this *familiar stranger*.

Before we proceed any further with this introduction, it is advisable to begin with some conclusions from a great historian, Murray (2003), about ancient Indians' contributions to the groundbreaking thoughts of humankind, the kind of thoughts that have made *homo sapiens* what they are.

Meta-inventions: A Mixed Bag

Human accomplishments have occurred in four broad areas of cognitive development:

- Art
- Philosophy
- Mathematics
- The Sciences

To which parts of the world, to which cultures, do we trace the beginnings of the present incredible state of accomplishment in these areas? I find Charles Murray's analysis of this very difficult question most acceptable. In these four areas certain cognitive skills were developed which have since shaped human thought. The outcomes of these cognitive skills spilled over as "meta-inventions" of *homo sapiens*, 14 of them in all:

- Artistic realism (Greece)
- Linear perspective (Italy)
- Artistic abstraction (France)
- Polyphony (France)
- Drama (Greece, India)
- The novel (Europe)
- Meditation (India)
- Logic (Greece)
- Ethics (China, India, Greece)
- Arabic numerals (India)
- The mathematical proof (Greece)
- The calibration of uncertainty (Europe)
- The secular abstraction of nature (Greece, China)
- The scientific method (Europe)

It will be noted that India is the sole or shared inventor of four of them, next only to the totality of the West's, which has a share in 12. The four are, as from above:

- Drama
- Meditation
- Ethics
- Arabic numerals

China is involved in three meta-inventions. This classification, at the very fundamental level of human development, fuzzy as it is, and coming as it does from a Western scholar, who is not averse to emphasizing that 12 meta-inventions have come from Western civilization, is at once gratifying and edifying. We will see why.

When it is remembered that the proportion of Indian population to the entire Western population in the ancient world was certainly less than even, the factor of one in three of meta-inventions by the ancient Indians must be regarded in this light. In the absence of actual figures to prove the point, this is perhaps no more than an intelligent guess, but it does make a powerful argument for the importance of the Indian contribution to fundamental thought. This is the gratifying part. On the other hand, notwithstanding some major contributions of ancient Indians to the scientific method, there were no groundbreaking thoughts that found a place among the 14. This is surely an edifying thought.

Within the hazy borders of these monumental contributions, many great discoveries were made by different cultures. Those from India were among the most significant. They give us a measure of India's contributions, starting from epocal beginnings, from the time when loftiness ceased to beget loftiness in the sense that no new fundamental thought processes were added and excellence found scattered expression within mankind's meta-inventions. This chapter is devoted to a brief recollection of some of these expressions of excellence, which gave present-day Indian science a latent lineage of great vitality.

The Early Periods

It is clear that when Western science came to India, following England's occupation of the country, it was not as if the West had suddenly downloaded science and technology into a scientifically vacuous land. India had an illustrious history of science and technology for well over 3000 years (some would say 5000 — the dispute continues), even dating back to the Harappan civilization before the Aryan invasion. There were discoveries and advances in practically all branches of science and technology as known at various times. These can be classified under three broad periods:

- Harappan, Vedic, Buddhist and Jaina, c. 3500 BCE to 300 CE
- Pre-medieval and medieval, c. 300 CE to c. 1750
- British (the Raj), c. CE 1750 to 1947[1]

The first two periods are covered in this chapter while the third is deferred to the next. The first period is largely remembered as the Vedic period in spite of the significant influence of Buddhist, Jaina, and Dravidian sciences. The pre-medieval period was dominated by an assortment of Hindu empires and the medieval period by Mughal (Muslim) rule.

A feature (many might call it the bane) of ancient Hindu mathematics and science, particularly of the Vedic period, was that it was embedded in myth, mysticism and the practice of sacrifice. In fairness it must be said that all other cultures of that period had the same failing (as we would view it today). The Vedic mathematician-priest must have been a singularly awesome figure, for more than anyone else, he specialized in weaving threads of mathematics in a web of dogma and ritual. The ritual was the sacrifice and the altar was his mathematical laboratory, where he assembled bricks of varying dimensions into geometrical shapes corresponding to the rigid requirements of scriptural laws. In the process, he and his tribe addressed difficult and sometimes bizarre geometrical problems and found solutions fit for the purist. A case in point is the discovery of the method of doubling the area of a square sacrificial altar. Intuitively doubling each side was wrong because it would quadruple the area. It was posited that if the side had a unit of one, the area would be doubled by using the square-root of two as the side. Thus the concept of the square-root was born.

Some truly great concepts were proposed during the first period and the early second. Many medieval period concepts were probably the result of cross-fertilization between the Indian, Arabic, Chinese, Persian, Egyptian and other ancient cultures. Under these circumstances, it would be unfair, without irrefutable validation, to ascribe a concept's authorship exclusively to a single culture. Some over-zealous authors seem to do so. On the other hand, many tend to be hastily dismissive of any Indian authorship. The most famous example is the place-value system of numbering including zero, which is the very life-spring of mathematics and the sciences. It meandered through other cultures, principally the Arab, all the way to Greece, till its Indian roots were lost. Then, after centuries of dispute over its authorship during which period it also won universal acceptance, it wandered back to its homeland to stay permanently Indian. This journey and other details of the zero are discussed in greater detail elsewhere in this chapter. There are a huge number of Indian texts and compendia (over a million), which contain a vast body of ancient mathematical and scientific knowledge. The concepts which came to India by way of travelers' accounts or texts from Arabic, Chinese, Mesopotamian and other ancient cultures, were either independently discovered by Indians of an earlier or contemporary period, or modified and refined by them.

Before proceeding to these and a few other selected concepts of the two periods, we shall highlight below a few of the general contributions of these.

THE PERIOD C. 2000 BCE TO 300 CE

The Harappan civilization which dates back to c. 3000 BCE had considerable influence on the origin of new concepts of the Vedic, Buddhist and Jaina genre. But in view of our inability to trace that influence, we restrict the treatment to BCE 2000 and after.

It is difficult to visualize a science and engineering culture similar to our own in prehistoric and early historic times. There was, on the other hand, a feature that was common to all ancient cultures. The ancients rationalized the irrational by the simple expedient of invoking divine interference. Science was an independent relegio-intellectual pursuit unconnected with society's well being. This attitude was almost universal. Against this background, it is remarkable that the Mauryan empire around 300 BCE adopted a sort of state policy for the encouragement of science and technology in all walks of life. The versatile scholar Kautilya's *magnum opus*, the *Arthasastra* (400 BCE), became the most important document of the time. This omnibook is not only a political treatise; it contains chapters on such diverse scientific subjects as gemology, mining and metallurgical operations, minting coins, ocean mining, botany, measurement of space and time based on astronomical parameters, meteorology, sanitation and public health, and so on. Individual scholars flourished too in such areas as mathematics, astronomy, chemistry, botany, medicine, surgery, and architecture. There is no indication of the stifling of science at any time during that or subsequent periods, although royal patronage by individual emperors (an almost necessary requirement of olden times) might have varied.

Our knowledge of the scientific concepts of the earlier parts of this period comes from various scriptural writings, which date back to c. 1500 BCE These include the *Rigveda* (see tr. by Wilson, 1977), the earliest writings of the Hindus, as well as the non-Vedic literary classics of the Jains, Buddists, and Dravidians. Important treatises of Brahmanic origin are the *Vedic Samhithas, Brahmanas,* and *Arayanakas*. Other treatises of mixed authorship, i.e. composed by many scholars from different social orders/castes, which contain ideas on the principles and practices of science and technology, are the *Upanishads* (secular treatises that do not invoke God or religion), *Sutras* (manuals of instructions), and the so-called *Six Doctrines* dealing with logic, epistemology, physics, atomic theory, evolution of life, and metaphysics.

Among the *Sutras* are the *Sulbha Sutras* (aphorisms), which mean a collection of rules concerning measurements. There are a number of *Sulbha Sutras*, the oldest being that of Baudhayana (600–500 BCE). The other equally important volumes are those of Katayana and Apasthamba (400–300 BCE). The actual dates of these *Sutras* are in dispute. Some place the *Sutra* period around 800 BCE or even earlier. The *Sulbha* authors state that they were merely stating facts already known to the composers of the *Brahmanas* and *Samhitas* of the early Vedic age (Seidenberg, 1978). The range of information contained in these *Sutras* is quite remarkable even by today's standards, and includes enumeration, arithmetical reckoning, fractions, properties of rectilinear figures, surds, irrational numbers, quadratic and indeterminate equations: the list goes on. The *Sulbha* construction of a square equal in area to a given rectangle is exactly the same as formulated by Euclid several centuries later. From certain diagrams described in the *Sulbha Sutras*, several historians and mathematicians like Burke, Hankel, Schopenhauer, and Seidenberg have concluded that the *Sulbha* authors possessed proofs of geometrical results including the Pythagoras theorem (Dutta, 2002). In addition, there is the canonical work of the Jainas, the *Ganitanuyoga* (6000–300 BCE), which deals with mathematical principles, while other Jaina works such as *Kalpasurra* and *Bhagavatisurra* discuss number reckoning, fundamental operations, geometry, mensuration, permutations and combinations, etc. The philosophy of Jainism is marked by dialectical precision and a passion for numbers. Their theory of the universe's evolution shows considerable scientific insight: the universe existed from eternity and is not a divine creation; they suggest not to try to understand what can never be understood; matter is eternal; the changes in the world are due to forces inherent in nature and not due to divine fiats. The social life of the Buddhist period (700–400 BCE), as described in *Melindapanha* (c. 130 BCE), reveals a far more advanced technology-based industrial economy than the contemporary European economy which had to wait till the 7th century CE for the kind of money and credit-based economy that was prevalent in Buddhist times. Emperor Ashoka (Wells, 1921) belonged to the Mauryan dynasty, which ruled India from c. 320 to 180 BCE, and embraced Buddhism. I would regard this period as the golden age of Hindu rule (many argue that it was the Gupta period; perhaps both were in their own ways) and, as previously stated, had perhaps for the first time in the world a state policy on science and technology. Free India's science policy statements, to which we shall briefly refer in subsequent chapters, had perhaps their roots in this ancient practice.

THE PERIOD 300–1750 CE

This period saw the best and the worst of Indian science and technology, its rise and fall, the fascinating accomplishments in the Gupta, Chola, Peshwa, Mughal and other periods, followed at the end by the effects of colonial rule and the apathy that had set in. It took a resurgence powered by a new creed of resistance, non-violence (*satyagraha*), by Mahatma Gandhi and his many illustrious contemporaries to put the country back on even stronger wheels, towards independence and all-round progress. Some important achievements of this mixed period are mentioned below. This is followed by a few other, even more important, ones in a later section which deals primarily with concepts that forestalled those of today's science. The latter, together with similar achievements of the first period, constitute a part of the fascinating story of science in India, a story that was vigorously pursued in the modern context as a central policy by Jawaharlal Nehru and others, leading to present-day science and scientific institutions in the country. Thus we have a little more to tell before we zero in on the National Chemical Laboratory, a few chapters later.

As we had done for the first period, we will now look at a few notable names and achievements of the second period.

A particularly famous and respected name in ancient Indian mathematics and astronomy was Aryabhata (476–520 CE), a Brahmin from a region now part of northern Maharashtra who flourished in the 6th century CE. His work on pure mathematics consisted of 33 verses of highly condensed rules compiled in his *Aryabhatya (*499 CE), a timeless tribute to scholarly brevity that was translated into Latin.[2] Besides calculating the value of π to a very high order of accuracy, he explained the causes of solar and lunar eclipses and gave a formula for solving indeterminate equations, and proposed a variety of mathematical and astronomical rules and theories. The incredible astuteness with which he predicted the elliptical orbits of the planets, and his great acumen in estimating the period of the year to within 12 minutes and 30 seconds of the true value will always be remembered.

Another was Brahmagupta (598–660 CE), arguably the greatest ancient Indian mathematician-astronomer after Aryabhata (some would even call him the greatest), who wrote the *Brahmasphuta Siddhanta* (c. 628 CE) that was translated into Arabic and Latin and became the first Indo-Arabic contribution to the early stages of Western astronomy. He formulated his monumental theories about a century after his illustrious predecessor, Aryabhata, and was apparently envious of this great astronomer/mathematician's reputation that transcended time. This was perhaps obvious to many great thinkers of his time. For instance, Al-Biruni (see tr. by Sachau, 1910) accuses him of rudeness to his predecessor, Aryabhata. His accomplishments include: manipulations with zero, solution of indeterminate equations, and an exquisite treatment of various aspects of mathematics in his book referred to earlier. According to Dutta (2002), the height reached by the Greeks in geometry was unmatched by any subsequent ancient or medieval civilization. But progress in pure geometry reached a stage of stagnation. Between the times of Pappas (300 CE) — the last big name in Greek geometry — and early European mathematics, Brahmagupta's brilliant theorems (628 CE) on cyclic quadrilaterals constitute the solitary gems in the history of geometry.

It was soon realized that an entirely new discipline, algebra, first developed by the Arabs, was needed for any further progress in geometry. But soon algebra found its own independent place in mathematics, and Brahmagupta and Bhaskara II mastered this new-found discipline and put it to great use. The Indians were the first to recognize that a quadratic equation had two roots, and Sridharacharya (750 CE) gave the well-known method of solving a quadratic equation by completing the squares, an idea with far-reaching consequences in mathematics.

Varahamihira (505–587 CE), who wrote the five-volume treatise *Pancha Siddhantika* (540 CE) (see Thompson, 1988; Sarma, 1997), considered to be the first compendium of ancient Greek, Egyptian, Roman and Indian astronomy, was perhaps the most versatile writer of his time, although he was not credited with a great deal of originality in mathematics. He also proposed several theories pertaining to the earth and geology. For instance, he suggested that the earth was round, that precious stones were formed from rocks through metamorphosis over time, and that moon was a factor in earthquakes. Lalla (c. 748 CE), Mahavira (c. 850 CE), Manjula (c. CE), Sridhara (c. 1028 CE), Bhaskara II (1114–1160 CE), Narayana Pandita (c. 1350 CE), and Neelakantha (1445–1545 CE) were among the other great mathematicians of this period. All of them belonged to the famous Kerala school of mathematics with the exception of Brahmagupta and Bhaskara II who belonged to the Ujjain school. There were other schools too, such as those of Pataliputra and Maharashtra. The *Buddhivilasini* of Ganesa Daivajna of the Maharashtra school is an incomparable work based on Bhaskara II's *Lilavati*, which received widespread acclaim, and was translated into Persian. This remarkable work contains arithmetical problems explained by Bhaskara II to his daughter Lilavati in atonement for an accident that altered his predicted date of her wedding, resulting in its permanent cancellation. This book was masterfully popularized through copious illustrations by Daivajna.[3] Another great mathematician was Mahavira, a Jaina. He was one of the few pure mathematicians with no ties to astronomy and his book gives a lucid classification of arithmetical operations. Much of the works of these mathematicians formed the link between Vedic and other cultures that excelled in *Ganita Sara Samgraha* mathematics at that time. Aryabhata, Brahmagupta, and Bhaskara II are all credited with finding solutions for indeterminate equations of the first and second degrees. These equations had their immediate applications in astronomy.

In the field of medicine, the innumerable books on *Ayurveda*, particularly the *Caraka Samhita* of Caraka, *Susruta Samhita* of Susruta, and *Astangahrdaya* of Vagbhata, led to the encouragement of their translation into Arabic by the great Caliph Haurn-al-Rashid (e. g. the translation of the *Caraka Samhita* by the famous Arabic scholar Ali Ibn Zain as *Sarag*). The theory of matter (including the atomic theory) is another area where ancient Indian science made imaginative speculations that were surprisingly close to the reality, as we shall see later. The coming of Islam to India triggered the popularization of the *Unani* system of medicine. At the same time, *Ayurveda* went far beyond India, into

Persia, Central Asia, Turkey, Egypt, Tibet, Mongolia, Indo-China, Ceylon (the modern Sri Lanka), and Al-Razi (9th–10th century) included *Ayurveda* in his comprehensive book *Kitab-al-Hawi* (known in medieval Europe as *Liber continens*). While the Islamic and Hindu systems of medicine flourished independently, in the later centuries they also closed ranks, up to a point, and established centers where the *Unani Hakims* and the *Ayurvedic Vaidyas* are said to have worked together. These must have been isolated instances.

Discovery vs. Discoverer

SOME THOUGHTS

Unlike Western literature where each book or a concept has an author or a set of authors, many Indian books and concepts of antiquity do not have any authors. Thus, even for such a fundamental concept as the zero, all we can say is that it is Indian. There is no way of ascribing the concept to any individual. The practice changed, however, in the years following the end of the Vedic period. It is interesting to recall that there is some controversy regarding the ancient Indians' love of knowledge for the sake of knowledge. Some researchers suggest that Indian science was largely utilitarian. I strongly disagree with this view since Vedic science is full of speculations and discoveries with no attached names. To know was more important than to be known, a concept increasingly ignored, even ridiculed, but brought back to light as recently as in 2006, by the refusal of Grigori Perelman to accept the Fields award, the highest in Mathematics. In an engagingly innocent interview, he held that discovery was more important than the discoverer, a concept I mentioned in the Preface. Legitimate effort within bounds is normal, but a hunger for awards stymies the science for which it is sought. Others in the same general category are George Bernard Shaw who accepted the honor but refused the money, and Jean Paul Sartre who turned down the prize altogether.[4]

SOME BOOKS WITH SPECIFIC AUTHORS

Realizing that books with names of the authors specifically stated are more easily accepted as authentic in today's context than those with no authorship, I give below the names of some important mathematical/astronomical books of the two periods described above, along with names of the authors. Where available, the year of publication is also given. There was nothing like a commercial publishing house in those times, of course!

- *Sulbha Sutras* by Baudhanya (600–500 BCE)
- *Arthasastra* by Kautilya (400 BCE)
- *Sulbha Sutras by* Katayana (400–300 BCE)
- *Aryabhatya by* Aryabhata (499 CE)
- *Brahmasphuta Sidhanta* by Brahmagupta (628 CE)
- *Khanda Khadyaka* by Brahmagupta (c. 670 CE)
- *Pancha Sidhantika* by Varahamihira (c. 540 CE)
- *Ganita Sara Samgraha* by Mahavira (date unknown, probably c. 890 CE)
- *Lilavati* by Bhaskara II, also known as Bhaskaracharya (date unknown)

- *Bijaganita* by Bhaskara II (date unknown)
- *Sidhanta Siromani* by Bhaskara II (1150 CE)

The ancient Indians were prolific writers. As mentioned previously, a huge number of documents have so far been unearthed, many of them with no specific authors (Pingree, 1996). The books I have cited appear to be particularly important, and those of Aryabhata, Brahmagupta, Varahamihira, and Bhaskara II were translated into Latin and/or Arabic. Likewise, many books from other cultures were translated into Sanskrit. The abundance of these translations has given rise to the erroneous speculation that Indian science and astronomy were largely borrowed from other cultures and that India served as a conduit between these cultures. Books by Muslim scholars of India have also influenced Indian thought and life. A brief reference to some of these books is made later in this chapter.

I would like to end this section by quoting the concluding lines of Cajori's chapter on India:

> *It is remarkable to what extent Indian mathematics enters into the science of our time. Both the form and the spirit of the arithmetic and algebra of modern times are essentially Indian. Think of our notation of numbers, brought to perfection by the Hindus, think of the Indian arithmetical operations nearly as perfect as our own, think of their elegant algebraic methods, and then judge whether the Brahmins on the banks of the Ganges are not entitled to some credit.*
>
> Cajori, 1931

Those Surprising Ancients

It is instructive to examine how some of the ancient theories and discoveries have stood the test of time and how some wild speculations from antiquity have been validated by later, more rigorous theories and experiment, but strangely with little acknowledgment of any ancient connection. It is well to remember that ancient theories of the "universe and of what could not be seen" had necessarily to await modern experimental skills to be tested. To dismiss such theories as unproven speculation appears irrational. A description of some of these theories is briefly attempted here by first classifying them under the areas:

- Mathematics and the physical sciences
- Chemistry and chemical technology
- Medicine and other sciences

MATHEMATICS AND THE PHYSICAL SCIENCES

In theory and speculation, the areas of mathematics, astronomy, and physics were the ancient Indians' forte. Since all these areas flourished and grew together, we will not attempt to separate them here. One of the oldest original concepts of Hindu science was what is now generally known as the Pythagoras theorem (c. 550 BCE). This theorem was postulated in the *Sulbha Sutras* almost 200 years before that man said so (*ipse dixit*), an almost obsequious allusion to Pythagoras by his disciples to authenticate any statement (see Bose, Sen, and Subbarayappa, 1971). It was stated as follows:

> *The diagonal of a rectangle produces by itself the area produced separately by the two sides…*

for which proof was also adduced in the next verse:

> *The rectangles for which the above is true have their sides 3 and 4, 12 and 5, 15 and 8, 7 and 24, 12 and 35, and 15 and 36, and the sum of squares of these numbers is also a square for each pair.*

According to Subbarayappa (1982), the modern trigonometrical words sine and cosine were derived from the ancient Indian words *jya* and *co-jya*. Brahmagupta was the first to deal with indeterminate equations of the second degree with an interpolator, which was later devised by the English mathematician Pell in the 17th century and, true to form, goes by the latter's name. Bhaskara II took it from there and devised what is known as *Chakravala* (cyclic method) which is considered the finest thing achieved in the theory of numbers before Lagrange. There was even a significant mathematical spin-off from a linguistic endeavor, namely determining the number of combinations of *n* syllables in a metrical composition. To quote Subbarayappa (1982):

> *Pingala's Chandha Sutra (second century* BC*) dealt with a method which later, the tenth century* AD*, was developed by Halayudha into a triangular array of permutations and combinations — a system which also appeared in Europe as Pascal's triangle in the sixteenth century* AD.

There are many more such instances of Indian discoveries predating similar endeavors by Western mathematicians and not getting due credit for them.

The best evidence of the ancients' mastery of mathematics and astronomy comes from David Pingree, a Brown University historian of mathematics, who, in his *Astronomy in India* (1996), talks of over a million manuscripts on various aspects of *Jyotisashtra*. This ancient text is a loose compendium of writings on such fundamentally contrary subjects as astronomy and mathematics on one side and astrology and divination on the other. This speaks volumes for the vigor and vastness of the ancient Indians' propensity for scientific pursuits. In astronomy, for instance, the *Surya-Sidhanta* (c 400 CE) of Vedic times talks of *Sarva Dishanaam, Suryaham, Suryaha* meaning there are suns in all directions and the night sky is full of them. This was perhaps one of the first speculations on the existence of multiple suns.

Even the concept of heliocentricity (planets revolving around the sun) had its origins in the old Vedic belief that the sun was the center of all creation, of life, and of all the goings on in the universe, long before the Greeks thought of it. Although, unfortunately, practical Indian astronomy was predicated on the concept of egocentricity (the sun and other planets revolving round the earth, the basic tenet of the Ptolomey school), the idea of heliocentricity (named after Greece) had its early stirrings in Vedic times. This was followed by Varahamihira's conjecture for the first time that there could be an attractive force on the earth that kept bodies from flying off its surface, similar to a parallel concept from the *Surya-Sidhanta* of the string of air that pushes the planets in their irregular motion. This speculation seems to have conceptually forestalled the later theory of gravitation — clearly, vaguely, or not at all, depending on the interpreter's predisposition. In any case, the relevance of this speculation to gravitation, posited a thousand years later by Copernicus, Galileo, and Newton, was dismissed by Newton as a stretch because it had no inverse square law in it. Doubtless, this law is one of the most surpassingly important ones in the history of science; but the inference that any ancient speculation can be dismissed as a fanciful stretch even if it is later proved to be qualitatively true, unless backed by a mathematical law right at the outset, is difficult to accept. In any case, this standard has not been uniformly applied.

Again, take the question of the earth's shape. One of the early concepts of the Aryans who settled down in north India was that the earth was spherical, against the extant Greek belief that it was flat. The concept of the Big Bang (a term derisively coined by Fred Hoyle, who did not believe that the universe was created in one blazing moment of incredibly short time) had its ancient Indian counterpart in the great cosmic union between Siva and Parvati, a concept not dissimilar to those of many other ancient cultures like Mesopotamian, Chinese, Egyptian, and Central American. The concept of many universes, more recently embraced by Leslie (1996, 1998) and others, had its counterpart in Brahma's dreaming up of a universe during his day of 4.52 billion years, which then vanished during his sleep of another 4.52 billion years, with another universe of the same duration appearing the next day, the processes continuing indefinitely (Eliade, 1987). The concept of multiple Big Bangs as envisaged by the M-theory (the superstring or string theory) was also fancied or wildly speculated by the ancient Indians. Yet another theory of today that finds its counterpart in an ancient philosophy, that of the Jainas, is the steady state theory that the world always existed and that there was nothing like a Big Bang; and it will continue to exist (Sproul, 1979). And yet, when one thinks of this theory, one always associates it with Fred Hoyle of a few decades ago! Buddhism adds that it would be foolish to posit theories about something we shall never know. Many more original concepts and mathematical procedures were proposed during this intellectually vigorous second period. It would appear that two of the three current theories of cosmology, Big Bang, steady state, and plasma, were already dreamed up by ancient Indians. If nothing else, one should at least credit them with preemptive speculation! If Indian cosmology is accused of being entirely religion based, Western cosmologists appear no better in the almost religious fervor for their own theories. Referring to today's cosmologists, the Russian physicist Lev Landou has this to say (Kragh, 1996): *Cosmologists are often in error, but never in doubt!*

The scholarship was sporadic, a condition used by Western scholars to include this period in their dark age of science that lasted till the Greek school, propelled by the renaissance in Europe (called the second Greek explosion), solidified its foothold on world science. Unfortunately, this ignored its links with ancient and medieval science, and dressed it up as a rebirth of the first Greek explosion dating back to the times of Democritus (430 BCE).

Following the Arab invasion of India by Mohammad of Ghazni in the 11th century CE and Mohammad of Ghori in the 12th century CE, by all accounts among the most gory invasions in Indian history, interaction between Hindu and Arabic scholars was slow. Al-Biruni, one of the greatest Arab traveler-scholars of those times, explored Hindu science and literature after mastering Sanskrit, while Jagannatha studied Muslim works after mastering Arabic and Persian. With the establishment of Mughal power in India in the 16th and 17th centuries, the famous Samarkhand school of mathematics and astronomy became quite influential in the country. Notable contributions in Arabic and Persian came from Thabit Qurra (c. 900 CE), Al-Biruni (973–1048 CE), Al-Karki (c. 1020 CE), Al-Khayyami (c. 1110 CE) and many others in subsequent years. It is believed that ancient Indians, along with the Japanese, were the only ones to develop calculus outside the Western culture. The 16th century Mughal Emperor Akbar, a great patron of learning, ordered Faizi to translate the *Lilavati* into Persian. Over a century later, Maharaja Sawai Jai Singh II of Jaipur ordered the famous astronomer Jagannatha to translate Euclid's *Elements* into Sanskrit under the title *Rekhaganita*, taken from its Arabic version. Along with the earlier translation by the same author of Ptlomey's *Almagest* under the title *Samrat-Siddhanta*, this ancient set of Greek classics was for the first time fully available in Sanskrit.

A more recent book: *Islamic Science: An Illustrated Study* by Seyyed Hossein Nasr (1976) provides an excellent summary of the various branches of science developed by Arabic scholars, including the development of science in India during the Mughal period. Al-Biruni, the great Arabic traveler-scholar, wrote about 20 books, in which various aspects of Hindu science, as gleaned by him, are described.

A striking feature of Vedic and later Indian mathematics was the heavy dependence on intuition rather than on logical proof. In fact, even the world-renowned genius Srinivasa Ramanujan of the early 20th century wrote down his long list of identities by intuition. While many of those identities have since been proved, mathematicians to this day are struggling to find proofs for the many that still remain. The Greeks were even more contemptuous of applied science, a philosophy spreading down from Descartes, Socrates, Plato and Aristotle. If Dantzig (1967) is right, they did not even care much for mathematics and never attempted to develop even rudimentary algebra. In contrast, a unique feature of ancient Indian science was the development of sophisticated mathematical tools — even if they were based on an erroneous model of the solar system. In time, the model crumbled but they had left a mathematical legacy of exquisite vintage.

In closing this discussion on early-period bias, I would like to get back to the Big Bang theory. It must be astonishing to many to find that this theory of creation was a brainchild of the *Rigveda*, constituted about 3,500 years ago, in what is regarded as the original and most powerful hymn of doubt — a profound thought left deliberately vague. They fully justify David Christian's interpretation (2003):

> *Here we have a hint there was, first, a sort of potent nothingness — waiting, like clay in a potter's yard, to be formed into something. This is very much how modern nuclear physics views vacuum: it is empty but can nevertheless have shape and structure, and [as has been proved in experiments with particle accelerators] things and energies can pop out of the emptiness.*
>
> Christian, 2004

Had this been a Western conjecture, it might well have been hailed as a precursory speculation, or even centralized as an imaginative ancient thought, in the manner of many other speculations of Greek origin. It is fortunate that true scholarship transcends regional or cultural affiliations. Thus there are Western scholars, writers and poets who have attempted to penetrate the mist of myth surrounding some of the most vigorous intellectual achievements of the ancient Brahmins. I would like to end this section by reproducing the following lines from Ralph Waldo Emerson's poem "Brahma":

They reckon ill that leave me out,
With me they fly, I am the wings,
I am the doubter and the doubt,
And I the hymn the Brahmin sings.[5]

Quoted in David Berlinski, *Newton's Gift*, 2000

CHEMISTRY AND CHEMICAL TECHNOLOGY

In the context of big history that converges from the general to the particular, let us now devote some attention specifically to chemistry and chemical technology in ancient India. We shall begin at the beginning, even if it only demonstrates a tenuous continuity from the old to the new. Antoine Laurent Lavoisier (1743–94 CE), who was the first to propose the oxygen theory of combustion, is generally regarded as the father of modern chemistry (see Kerr's translation of Lavoisier's *Traité elémentaire de chimie*, 1965).[6] (But I agree with Bryson, 2003, that the credit should probably go to Robert Boyle who, in 1661, was the first to separate chemistry from ancient alchemy in his book *The Sceptical Chymist*.) Lavoisier was the first to show that water was not an element by percolating it through a gun barrel filled with hot iron rings and splitting it into hydrogen and oxygen. Lavoisier saw chemistry as the science of mass, a concept that Mendeleyev in 1869 exploited to construct his famous periodic table, with some gaps in it.[7]

This brings us to the subject of alchemy, the science of transmuting elements, that flourished in most ancient cultures. India had its alchemists too, though not in the mold of the best. Alchemy in India made its first appearance in *Atharva Veda* around 1500 BCE but more persistently around the 5th century CE and was in full bloom for the next six or seven centuries covering mostly the tantric period known for its secular outlook. Mercury was central to the whole Indian alchemical practice (along with sulfur to a large extent) and hence the art of alchemy was called *rasavidya* (*rasa* = mercury). Voluminous literature is available on Indian alchemy in several languages, e.g. Sanskrit, Tamil, Telugu, Marathi, Kannada, Malayalam, and Gujarati. Many of these texts are yet to be fully studied. Alchemy as practiced in the Egyptian (Alexandrian in particular), Chinese and Hellenistic cultures is considered to be superior to Indian alchemy. In keeping with practices in these cultures, Indian alchemy was much less a science than an occult gift to raise the life essence of things, metals in particular, to a nobler form.

An alchemical sulfur-mercury theory was also proposed, based on some abstract thought and mysticism. Since mercury was central to alchemy, elaborate methods for its manufacture were developed. It was believed that plants were essential for metal interconversions and were probably ancient equivalents of what are known today as reactants or catalysts. One example, from scores of them, is the use of the juicy *vitpanai*

(*Wrigutia tinctoria*) for transmuting iron into higher metals, as reported in the Tamil work *Agattyarcarakku*. As a result of the extensive use of plants in transmutation, the ancient Indian chemists recommended that any alchemical laboratory be erected in a place rich in medicinal herbs (from the alchemic classic *Rasaratnasamuccoya*).

It is an exciting though ironic fact that this discredited practice found unwitting champions in von Kempelin of Germany in the 19th century (see Edgar Allan Poe, 1850), and in our own time, in Rutherford, Fermi, and Seaborg, all Nobel Prize winners. Although there are no Indian names here, I quote this instance to draw a parallel with the question raised by another Rutherford with the last name Aris (Farr and Aris, 1986) whose concern was with the over-used reaction pot from ancient times, a full understanding of which had to wait for centuries before he unraveled its theory. In this context, the following conversation between Rutherford (one of the first to receive the Nobel Prize) and Frederick Soddy, a later winner of the Prize, should come as no surprise:

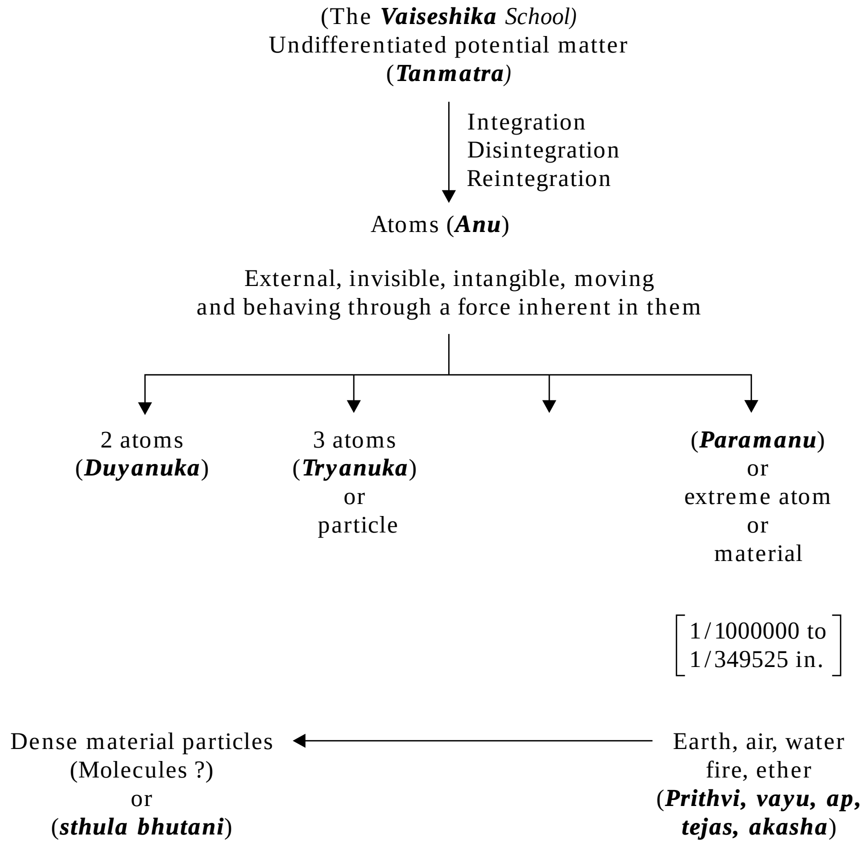
> Soddy: *Rutherford, this is transmutation.*
> Rutherford: *For Mike's sake, Soddy, don't call it transmutation. They'll have our heads off as alchemists.*
>
> Quoted by Dick Teresi, 2002

The world of chemistry had come a long way indeed! From the Chinese Wei Po-Yang's first alchemic text (c.140 CE), *Ts'an T'ung Ch'I* (*The Unification of the Three Principles*), many less known Indian texts of the time, Ben Jonson's description of the slow conversion of metals to gold in *In the Throes of Creation*, and the conjuring of noble metals from chemical cauldrons of base metals in closed pots (without the Aris understanding) — to the modern laboratories with particles zooming in circles at incredible speeds![8]

Was there real Indian chemistry and technology in pre-Vedic, Vedic and post-Vedic periods? It is generally claimed that ancient Indians did not make any substantial contributions in chemistry, but that would not be true where imaginative thinking was concerned. Some of the most fundamental concepts of today were foreshadowed by ancient Hindu speculations — as will be seen from the following few examples. An Indian chemist, Udayana, discovered that some gases are lighter than air and that hot air rises. In view of his mastery of gases, some call him the Indian Robert Boyle (Majumdar, 1963). The *Nyaya-Vaisesika* school of Kannada was perhaps the first to postulate the atomic theory of matter around 600 BCE. It was posited that the whole has an existence of its own and does not exist as separate parts, but when the whole disintegrates the parts (atoms) continue with their own discrete existence (Bose, Sen and Subbarayappa, 1952). Carrying the theory a little further, it was posited that at the beginning there was the undifferentiated potential matter (*tanmatra*) formed from the universal energy of the cosmos. The formation of matter from this energy, to the extent I can glean from the available literature, is summarized in Figure 1.1.

The amazing similarity of this speculation with the modern theory cannot escape notice. The Jainis, who were among the earliest Indian chemists, predicted the importance of opposite electrical charges and even thought of spin, a quality of particles not discovered until the 20th century. They even foreshadowed the modern ionic theory

Figure 1.1: Ancient Indians'atomic theory



by proposing entities of two kinds, *snighada* and *ruksha*, positive or soft and negative or rough, respectively, which combined to create new entities. There were other theories and concepts of matter also, but one thing clearly emerges from a study of these — Indian atomic theory was not only independent of Greek influence but it predates Democritus (c. 430 BCE), because Pakda Kayayana, a contemporary of the Buddha, taught atomic theory around 580 BCE, according to Buddhist scriptures.

Let us now briefly return to the field of plant chemistry and the use of plants in medicine. Ancient Indian chemistry is full of references to medicinal plants (see, for example, *Indian Materia Medica* by Nadkarni, 1954). The chemistry and extraction of medicinally active ingredients from plants, which had lost much of its fascination for the organic chemists of the country, seems to have found an early spokesman for its revival in J. L. Simonsen (1928) of the Indian Institute of Science in his presidential address to the Indian Science Congress in 1928 (quoted in Chapter 8).

Several schools of research in this area have since flourished, including the famous schools of T. R. Seshadri at Andhra and Delhi Universities, K. Venkataraman at Bombay University Department of Chemical Technology (now renamed as Institute of Chemical Technology, ICT) and the NCL, S. C. Bhattacharya, Sukh Dev and Rama Rao at the NCL,

T. R. Govindachari at the Madras University, and Asima Chatterjee and U. R. Ghatak at the Indian Association for the Cultivation of Science in Kolkata. The NCL school made some signal contributions as we shall see in Chapter 8.

With respect to chemical manufacturing practices (for that is what they were; there was nothing like chemical technology or chemical engineering then), pre-Vedic cultures like the Harappan culture of 4000–4500 years ago were known to make mortars from gypsum, lime and sand, and brown bricks for construction from ordinary alluvial soil. There is also a history of pottery and metal working. Our inability so far to decipher the Harappan script has precluded any detailed understanding of the technological achievements of the intellectually versatile people of that ancient culture. The current belief (questioned by some) appears to be that the invading Aryans, instead of destroying the Harappan culture, probably assimilated it and gave it a new dimension. Their achievements were described under the names of *Vedas, Brahamanas, Aranyakas,* and *Upanishads,* which also included a glimpse of the chemical practices of that age. The following are representative of the many practices that have been recorded:

- The use of fermentation to manufacture alcoholic drinks such as *soma* (also called *amrita,* i.e. ambrosia) made from pounding the shoots of the *soma* plant (*Sarcostema viminalis*) to obtain the juice, filtering it through sheep's wool, and blending with milk or barley
- manufacture of soda-lime glass with a high percentage of aluminium oxide (7–8%) and some iron oxide, described, among other texts, in *Satapatha Brahmana, Brhatsamhita,* and *Caraka Samhita*
- preparation of perfumes, various hair oils, etc., by blending 16 components according to strictly defined proportions
- preparation of an adamantine composition like *vajra-lepa* by mixing extracts of plants, fruits, seeds, barks, gum *guggle,* etc., boiling the mixture in water, reducing the volume to a pre-determined level, mixing with plant exudates such as that of *deodar* (it may be mentioned here that in the early 1980s, an extract of medicinal value was prepared by Rama Rao and his colleagues at the NCL and passed on by me to T. T. Krishnamachari and Sons at an impressive ceremony in Madras) and formulating it into a glutinous paste
- preparation of pigments and colors from iron oxide, powdered rock, vegetables, fibers, and paddy husk
- the classification and use of aromatics in the manufacture of cosmetics and perfumes, the categories involving leaves, flowers, fruits, bark, wood, roots, and exudates, as described in several books such as *Gandhavada* (of uncertain authorship)
- manufacture of paper by techniques imported from China; preparation of gunpowder from saltpeter, sulphur, and charcoal in proportions depending on the type of gun.

The essential features of ancient Indian science and engineering, including chemistry, are covered in the Olaf Hougen Lecture I gave at Wisconsin (1987). A much more exhaustive account can be found, among other books, such as *Concise History of Science* *in India* by Bose, Sen and Subbarayappa (1971), and *Scientific Spirit in Ancient India* by Majumdar (1963). Of the many other books and articles available to the general reader on Indian mathematics, *Vedic Mathematics* by the Sankaracharya of Puri (1992) is conspicuous by its clarity and general appeal. He explains the Vedic methods of solving problems in multiplication, division, factorization, equations, calculus, analytical conics, etc. in the shortest time and the least number of steps possible. Another more secular work is *The Crest of the Peacock* by George Joseph (2000) which traces Indian mathematics from the age of the Mauryas in north India to the age of the Guptas all the way to the Kerala school in south India that began around 1430 CE and lasted well into the 17th century. A few other books are truly remarkable for their scholarship and fairness.[9]

Hellenistic vs. Other Cultures

From the viewpoint of the present book, two approaches to the history of science are noticeable: Eurocentric and Indocentric. One can quote several books by Western and Indian scholars to validate this point. Neither extreme is true. A brief excursion into the influence of another culture, the Zoroastrian (Parsi) culture, on India's life and science, through its assimilation of the Western culture, will also be very fitting. Several well known Parsi industrialists have had considerable influence on the planning of the NCL's research programs

MUCH ADO ABOUT NOTHING[10]

Among the great things that are found among us, the existence of Nothingness is the greatest.

Leonardo da Vinci
(in the *Notebook*, see Macurdy, 1954)

We have already noted the Western scholars' habit of rapidly disapproving / marginalizing the contributions of other cultures. Several more instances of this can be cited, but a little elaboration of the concept of the zero will not be out of place in the present book. After many hesitant starts, this concept, indeed of nothingness itself, finally came home to roost permanently in India. The concept of positional notation can be traced to early Sumerians and Babylonians around 3500 BCE. The basis of this concept is the positions of numerals in a number. Take, for example, the number 246. In its complete form, this should be expressed as:

$$(2 \times 100) + (4 \times 10) + (6 \times 1) = 246$$

The abbreviated form is far simpler and much more convenient to use in calculations. But when it came to a number like, say, 206, which has a zero in it, the Babylonians were clueless. The implied "nothingness" in the middle of the number baffled them, so they just ignored it and wrote the number simply as 26! It was not until the invention of zero by the ancient Indians that the correct analogous form of the earlier equation was found:

$$(2 \times 100) + (0 \times 10) + (6 \times 1) = 206$$

In this context, I find the following lines of Paul Dirac (1958) singularly expressive of the concept of zero:

> *A place is nothing: not even space, unless at its heart — a figure stands.*

This monumental advance, along with the use of the decimal system based on 10 (as opposed to the sexagesimal system based on 60, as used by the Babylonians) is given far less importance than its later adoption by the Greeks. Indeed, there was a great deal of hesitation in ascribing Indian authorship to the zero, notwithstanding the fact that the first reference to the zero (called *sunya*) appeared as far back as 400 CE as a black dot in the *Bakhshali* manuscript unearthed in 1881 in Gwalior and now in a library at Oxford University (Teresi, 2002). Based on an error of his dating of this manuscript, the English author G. R. Kaye was quick to debunk the Indian origin of the zero. This was at best unfortunate, particularly in light of the fact that the association of the zero with its well-known symbol can be clearly seen in the following Vedic description of the stars (Vasavadatta, c. 400 CE; see Flegg, 1989):

> *The stars shone forth like zero (sunya-bindu), scattered in the sky as if on the blue rug…*

The great Arab mathematician, Al-Khwarizmi, a Director of Bagdad's famous House of Wisdom, modified the Gwalior version of the Hindu numerals including zero and introduced them to the Islamic world around 830 CE. The discovery of zero *per se* is unquestionably a major watershed in the history of mathematics but the development of a logical place value system with zero in it is unequaled in its enormity. The construction of this new numeracy of surpassing originality, along with the early association of *sunya* with *nothingness*, is now generally accepted as fully Indian. According to Genevieve Guitel (1975)

> *The study of the numerations used in India is extremely important for the history of mathematics, since it is linked to the most perfect worldwide spreading of the written position numerations.*

And in his excellent book, *The Mystery of Numbers*, Marc-Alain Quankin (2004) notes that

> *Indian scholars decided that the term shunya was perfectly appropriate from a philosophical and mathematical viewpoint. Finally, in the midst of this unspoken, then written numeration, this term became the utterly strange and practical numerical creature we now call zero.*

Among the many ancient evidences to buttress this conclusion (see Joseph, 2000; Aveni, 1993), the following statement from a 12th century text *Manasollasa* is particularly revealing:

> *Basically there are only nine digits, starting from one and going to nine. By the adding of zero these are raised successively to tens, hundreds and beyond.*

Another is an allegorical reference to zero and the place value system that appeared in the 7th century CE.

> *Just as the same sign is called a hundred in the hundred's place, ten in the ten's place, and one in the unit's place, so is one and the same woman referred to (differently) as mother, daughter or sister.*
>
> Joseph, 2000

Yet another refers to a woman's beauty in mathematical terms that decisively brings out the ancient Indians' appreciation of the place value system, found in a piece of Sanskrit poetry:

> The dot on her forehead
> *Increases her beauty tenfold,*
> *Just as a zero dot (sunya-bindu)*
> *Increases a number tenfold.*
>
> Datta and Singh, 1962

Beyond all this, there is something inherently, almost inexorably, Indian about *sunya* or nothingness. The derivative term *Sunyata* is the Buddhist doctrine of emptiness, and conveys the meditational practice of emptying or cleansing the mind of all thought and impression. This was considered to be the most desirable pre-requisite for any creative effort such as painting, scientific contemplation, sculpturing, writing, etc.

FROM NOTHING TO SPECULATION AND MORE

The example of the zero just cited is by no means the only one, but certainly it is unique. Heralding the advent of the third millennium CE, the *Science* magazine, in collaboration with the American Association for the Advancement of Science (AAAS), brought out an article titled *Pathways of Discovery* (2000) which listed 96 most important discoveries in recorded history. Of these, only two were non-Western, and both had ancient Hindu associations: the discovery of the zero, and the astronomical observations of the Mayas and Hindus. Even here, credit, if one can call it that, was given to the Hindus not for the concept of the zero but for its symbol. As for astronomical observations, they did not wish to dignify the Maya-Hindu observations with the word astronomy, and called these *skywatching* used for agricultural and religious purposes only.

Mention was previously made of the dismissive attitude of the West to the ancient Indian speculation about gravity. I will cite just a few more. Take Carl Sagan, unquestionably one of the most scholarly, balanced, and admired modern day writers. Even he did not seem to take some Indian discoveries/predictions seriously. For example, he believed that the prediction of the age of the universe as 8.64 billion years, so incredibly close to the correct age of twice this figure (16.5 billion years), was no doubt by accident. It is well to recall here that this was the first time that any prediction of the age of the universe had broken from the early Western line of restricting it to a mere thousands of years. Another is the hasty dismissal of the concept of the cyclic universe in which one universe (formed by an expanding circle starting from a gradual or sudden appearance of a singularity at the center) is succeeded by alternate occurrences of Big Bang (the singularity) and collapse. The present theory accepts only one Big Bang and is silent or in denial on others (although the concept of one universe spawning another, the process continuing till an infinite number of universes are created, is gaining some ground — see Leslie, 1998).

As yet another example, the ancient Indians' belief in an all-pervading ether was also held by such famous latter-day Western (Greek based) thinkers as James Clark Maxwell and Isaac Newton, till Albert Einstein proposed that no such medium was needed for the propagation of light; just space would do. Then we have the Buddhist concept of *maya* which considers the material universe, i.e. the universe characterized by weight, as an illusion. This is not dissimilar to Higgs' boson (named after the Indian physicist Satyen Bose), the particle responsible for the universe's invisible field. Yet another heliocentric claim is with respect to the value of π. Robert Kaplan (1999) advocates that the Indians, along with the Babylonians and the Egyptians, had no clue that π and the square-root of two are irrational numbers. They just went on refining the value by adding more places after the decimal. The truth, however, is quite different. To quote from the *Aryabhatiyabbasya* of the reputed Kerala mathematician, Neelakantha:

> *Why is only the approximate value (of the circumference) given here? Let me explain. Because the real value cannot be found. Though we try very hard we can reduce the remainder to a small quantity but never achieve the state of "remainderlessness." That is the problem.*
>
> Quoted in Kaplan, 1999

And, as Joseph remarks, if that does not show some understanding of the irrationality of π, what does?

Calculus is accepted as a Western invention, the brainchild of Gottfried Leibnitz, a truly gifted German mathematician, and of Newton. According to Joseph, it was invented in India centuries earlier. If this is true, the Indian contribution to mathematics is much more than the zero and the decimal number system. It is an astounding fact that this claim has not been researched by Western scholars, the way they would any other challenge of such a magnitude, choosing instead to ignore it.

This tendency to promote Greek (Western) authorship is no surprise for, after all, much of history till recent times was written by the victor and his extended progeny. Indeed, the Greek fixation has been so dominant in Europe that entry into the British foreign service depended till recently on knowledge of Greek (and Latin). It is a fortunate circumstance that there are many Western scholars today who are prepared to look dispassionately at ancient science.

Thus the Greek contributions, basic and enormous as they are, seem to enjoy almost exclusive hegemony, to the near neglect of contributions from other civilizations. This situation is further exacerbated when it is claimed that much of present thought is the continuing result of two Greek explosions, the first which began 2500 years ago, and the second around 500 years ago, which was only partly Greek and unquestionably of mixed origin. There is reason to believe that both the explosions borrowed much from prior cultures, either knowingly or unknowingly. Some fundamental concepts pre-date the Greeks' but it is not clear whether the Greeks were aware of those. For example; the Arabs invented algebra and were the first to call it that (Joseph, 2000); even Aristotle conceded, though rather condescendingly, that

> *The mathematical sciences originated in the neighborhood of Egypt because there the priestly class were allowed leisure.*
>
> See Fowler, 1987

What is more, as mentioned previously, the interim period is regarded as the “dark age” of science and culture, as though the darkness or brightness of an entire age is determined solely by its European hue! The dark age, which began around 400 CE and lasted over a 1000 years, apparently included the Indian, Chinese, Arabic, and Egyptian civilizations. This darkness seems to have missed the light of Aryabhata, Brahmagupta, Bhaskara II, Varahamarahira, and other great intellectuals of ancient India who lived and discovered in those times, not to mention the innumerable names of other cultures! One wonders what would be the color of those centuries of darkness if the history of that time were written by cultures on the brighter side of the great divide. But they clearly did not influence the other side where cultural evolution proceeded smoothly. Their dark age was of a much lighter hue, and came later when Europe started on its blazing trail that became quite explosive a few centuries later. This period was labeled as the period of restoration of the world, of the renaissance of the social and industrial revolutions, the beginning of the second Greek explosion. Will this change and the cycle repeat itself? Probably not, for we are living in a shrinking world with an unprecedented international compulsion to level the ground and banish regional and cultural contrasts (albeit with no great success so far). I say all this with some asperity because the term “dark age” was used to describe a period when many cultures other than the Greek/Western were dominant, and is just not acceptable. And lastly, European dominance was not complete even as late as the 17th century, long after the dark age. This situation is nowhere better revealed than in Philip Cutin’s analysis of cross-cultural trade in world history:

> *The European Age in world history had not yet dawned. The Indian economy was still more productive than that of Europe. Even per-capita productivity of India or China was probably greater than that of Europe — though very low by recent standards.*
>
> See Curtin, 1984: 149

True, errors in Greek science have been recognized and corrected by Western scholars, but this has been done with subtle grace and not dismissively, much in the manner of one correcting the mistakes of an ancient forebearer of the same vintage. In fairness, the same can be said of Indian scholars too, albeit on rarer occasions. For instance, the legendary Aryabhata wrongly proposed in his *Aryabhatya* that the apparent rotation of the heavens was due to the axial rotation of the earth. Apparently, most latter-day editors of the *Aryabhatya* changed the text to save Aryabhata from embarrassment! Given that even the originals went largely unnoticed by the West, the corrections made little difference, even if the motive was clear.

To conclude this discussion of Hellenistic influence, there is little doubt that modern science, with all its incredible discoveries, has drawn heavily from ancient Greek science. This led to the Greek fixation, which is brought out with uncompromising fixity in the following words of wonder:

> *The great mystery of zero is that it escaped even the Greeks.*
>
> Logan, 1986

And yet it is instructive to note the words of a well-known philosopher-scientist of the first millenium CE. In 662 CE, Severus Sebokht, a Nestorian bishop who lived in Keneshra on the Euphrates river, wrote:

> *I will omit all discussion of the science of the Indians, …, of their subtle discoveries in astronomy, discoveries that are more ingenious than those of the Greeks and the Babylonians, and of their valuable methods of calculation which surpass description. I wish only to say that this computation is done by means of nine signs. If those who believe, because they speak Greek, that they have arrived at the limits of science, would read the Indian texts, they would be convinced, even if a little late in the day, that there are others who know something of value*
>
> Basham, 1954, rpt. 1981

THE PARSI INFLUENCE

The discussion presented so far might give the impression that only two cultures influenced Indian thought prior to British rule: Hindu and Muslim. This is by no means true. A third culture, though an insignificant fraction of the Indian population, around 80,000 (well within the margin of error in population statistics to be almost non-existent!), has influenced Indian science and societal involvement out of all proportion to its numerical strength. This culture is the gift of a group of Persians of the Zoroastrian faith who fled their country around 1200 CE to escape the persecution of the invading Arabs. Ever receptive to alien cultures, a Hindu king of Gujarat gave them land, where they constructed their first fire temple. India fully absorbed them, and allowed them to thrive as a distinct community known as Parsis, to denote the land of their origin — Persia (*Pars*). They have produced many thinkers over the centuries, as well as scholars, scientists, musicians, businessmen, and social reformers. Today they are perhaps the most philanthropic group in the country, committed to the health, education, and general social advancement of India's growing population.[11]

The Parsis can boast of many firsts in India, for example, the first newspaper in Bombay (*Bombay Samachar*), the early cotton mills of India (built by Cowasji Nanabhai Davar), the first ship builder of Bombay (Nusserwanji Wadia), and Cursetji who was the first Indian Fellow of the Royal Society of London.[12] Jamshedji Tata's invitation to Pittsburg's steel king to start the steel industry in India (see Chapter 4) marked the beginning of India's entry into the world of modern industry. Zubin Mehta, who immigrated to USA, is a world- renowned musician. Homi Bhabha established atomic energy research in India, and relevant to this book is the fact that the road leading to the NCL was renamed the Dr. Homi Bhabha Road in the 1970s. One of the best known Indians of the 20th century, J. R. D. Tata, was a Parsi who was recognized as one of the leading industrialists of the world, and who was also responsible for starting air travel in India (being himself a pilot). The Parsis were the first to make full use of Bombay's Native Education Society formed by the British in 1820. Two of India's foremost scientific research centers of more recent times, the Indian Institute of Science and the Tata Institute of Fundamental Research, were creations of Parsis, who were also responsible for establishing many hospitals and industries of various kinds.

The influence of Parsis on India's life and science, which started since they first landed in India over 800 years ago, continues unabated. It has become an inalienable part of India's dream and deed.

Historical and **Cultural Scotoma** *or* **Memory Holes**

From some of the instances cited before, it is clear that several ancient discoveries or observations were missed — wittingly or unwittingly. In my personal opinion, the prejudice part is now almost completely a thing of the past — although the debate will continue. In a critical essay on this aspect of science, Oliver Sacks (1995: 141–187) disarmingly invokes the medical term *scotoma* to describe this condition — *a disconnection or hiatus in perception, especially a gap in consciousness produced by a neurological lesion.* In his essay *Scotoma* (1995) he cites even more remarkable instances of forgetting. I have already referred to Lavoisier as the father of chemistry for his discovery of oxygen. This distinction, as it turns out, is probably dubious. According to Sacks, oxygen was all but discovered in the 1670s by an unknown individual named John Mayow. This was concealed from revelation by a century of obscurantism (and the preposterous flogiston theory) till it was rediscovered by Lavoisier, a mainstream chemist. Another instance is the discovery of muscular dystrophy by the physician G. B. A. Duchenne. It was actually reported around the same time by the son of the father-son team of astronomers John Frederick and Frederick Herschel, both of whom suffered from visual migraine, a rare syndrome of the disease, almost lost due to the inability of the patient to communicate it to the physician. Thus the discovery fell prey to scotoma. Yet another example of neglect or forgetting, made the more remarkable by the fame of the forgotten discoverer, concerns Goethe's rejection of Newton's theory of light, i.e. that white light consists of different colors. (The biased will probably see an opposite bias here, but the truly unprejudiced will, one hopes, pronounce a fairer judgment.) To the poetic mind of Goethe, reality was not just the simplifications of physics in terms of limited laws but a complex phenomenon that only personal experience could recognize and fully understand. However, the fate of this speculation, doomed at start, was not helped by Goethe's caustic tongue and pen, and was sealed for ever. Newton's theory continued its sway till the dazzling experiments of Edwin Land in 1957 (see Sacks, 1995), three centuries after Newton's splitting of light with a prism, revived Goethe's thinking but with no scientific encomiums to the great poet. His original speculations and his bold assertion that optical illusion is optical truth remained buried in his largely unread *Farbenlehre* of 1832. His great poetic achievements aside, he had so much wanted to be remembered for his thoughts on color — which had almost become an obsession with him in the later forty years of his life.

Prejudice and Straightjacketing

In addition to scotoma and other forms of neglect or selective amnesia in science, there has also been a bias against contributions from persons outside the mainstream of a profession or a formal disciplinary pursuit. There is also a strong inclination to straightjacket people on the basis of the jobs they do to earn a living regardless of their interest in other activities, such as science. To appreciate this point, one has only to recall the scientific achievements of many great men who did not begin their lives as scientists: Sir William Herschell who was a band leader, Lavoisier who was a tax collector, Thomas Edison who was a telegraph operator, Joule who was a brewer, Priestly who was a clergyman, Michael Faraday who was a book-binder, Albert Einstein who was a patent office clerk, and Srinivasa Ramanujan who was a clerk in the accounts section of the Madras Port Trust. Henry Cavendish was a formal scientist from the start but was a compulsive recluse who fled at the sight of company, and Willard Gibbs was almost pathologically shy and hardly ventured outside his Yale campus (in fact, he published his monumental works in the local *Transactions of the Connecticut Academy of Arts and Sciences*, which was largely unread even in Connecticut). When the great Max Plank came to know much later that his ideas on entropy had been anticipated by this reclusive genius, he accepted the truth hidden in the arcane language and messy nomenclature of Willard Gibbs. The non-scientific beginnings or peculiar personality traits of these great thinkers fortunately did not come in their way.

A unique case was C. V. Raman, who made his transition from a successful bureaucrat in the Indian Financial Service to the greatest modern-day physicist of India. Another stark example is the silent but active disapproval of research by scientists in the government surveys of the British days prior to the creation of universities. Sir Ronald Ross, the discoverer of the role of mosquitoes in the spread of malaria, was one such government employee. Although these employees were permitted to do research in their spare times, Ross was rebuked for spending all his spare time in malaria research! As the final example, I would like to cite the experience of my own late friend Vainu Bappu, India's greatest modern-day astronomer. He was a Government of Hyderabad scholar sent to Harvard for higher studies in physics. He took up astronomy (for that had been his passion since he was a boy and had the opportunity to play with astronomical telescopes in the government Nizamiah Observatory, where his father was an observer) and did some outstanding work which brought him instant fame (he was co-discoverer of the Bappu-Bok-Newkirk comet). When he returned to Hyderabad, they could not find a suitable position for him, which compelled him to take up a lecturer's position in physics, ignoring his Ph. D. in astronomy from Harvard. It was with the greatest difficulty that he obtained his release from the bond he had signed with the government and continued his work in astronomy elsewhere in India. Had he been forced to stay in Hyderabad, as appeared almost certain at one time, India would have lost a great astronomer. The point is: would all these scientists have succeeded if they were lesser men? They were recognized because their greatness transcended external prejudice/stubbornness. Those with lesser potential are apt to fall by the wayside.

There was also a reluctance to accept contributions from older cultures, along with a desire somehow to find a link with their own. Is this attitude still a concern? These are the questions history has left for scientists of the present to side step or answer. Where Indian discoveries are concerned, there is perhaps a touch of all these, abetted by a situation common to some ancient cultures where no specific name can be attached to a discovery. Take the case of indeterminate equations. Credit should probably go collectively to the Vedic and post-Vedic mathematicians. On the other hand, if the attachment of a name to a discovery gives it a greater credibility and a national recognition, Brahmagupta's claim would be foremost. I shall describe how the NCL dealt with the problem of authorship in Chapter 13.

5 + 1 = 6 Equations that Changed the World

In his book *Five Equations that Changed the World*, Michael Guillen rightly cites the five equations listed in Box 1.1.

His emphasis on equations is quite justified because mathematics is nature's language. Faraday was no mathematician and wrote down his findings in words in English. This was elevated to the natural status only after James Clark Maxwell translated it into

Box 1.1: Five-plus-one-equal-to-six equations that changed the world*

Apples and Oranges

Issac Newton and the Universal Law of Gravity

$$F = G\frac{Mm}{d^2}$$

Between a Rock and a Hard Life

Daniel Bernoulli and the Law of Hydrodynamic Pressure

$$\frac{P}{\rho} + GZ + \frac{1}{2}V^{2=constant}$$

Class Act

Michael Faraday and the Law of Electromagnetic Induction

$$E = -\frac{dB}{dt}$$

An Unprofitable Experience

Rudolf Clausius and the Second Law of Thermodynamics

$$\frac{dS}{dt} = 0$$

Curiosity Killed the Lights

Albert Einstein and the Theory of Special Relativity

$$E = mc^2$$

The Nothing That Meant Everything

Manipulations with zero, largely by Brahmagupta

$$\infty \pm a \text{ (or 0)} = \infty$$

$$0 \times \mathrm{a} = 0$$

$$0/\infty(\text{or a}) = 0$$

$$\mathrm{a}/0 = \text{indeterminate}$$

The Nothing that meant everything, manipulations with zero, presumably by unnamed Indian authors.

NOTATION:

Equation 1: F = earth's gravitational force; M = earth's mass; m = mass of any other body; d = distance between the earth and the body.

Equation 2: P = pressure; ρ = density; v = velocity.

Equation 3: left side stands for amount of electricity E produced, and right side for rate of increase or decrease of magnetism B

Equation 4:ΔS = change in entropy.

Equation 5: E = energy; m = mass; c = velocity of light.

Equation 6: ∞ = infinity; a = any number

*I have not included Paul Dirac's equation, which hás two types of solutions, one for matter (Einstein's equation) and the other for antimatter. It is the only equation etched in the stone of Westminster Abbey. It is mathematically the most beautiful, and beyond any other equation I can think of. Its appreciation is limited to the physics community, and is not as popular as those listed.

the language of mathematics and became famous doing so. That equations are the most important elements of a theory is further borne out by Stephen Hawking's fiery, unanswered question (1988): *What is it that breathes fire into the equations and makes a universe for them to describe?*

Kitty Ferguson, 1994, attempts a feeble answer. Each of these equations is most singularly deserving of this distinction. On the other hand, it is difficult to accept that humanity's greatest achievements all stand on their own foundations and all came in the last 200 years following upon a barren stretch of several millennia! It even suggests the rather absurd implication that after a few centuries, these equations, superseded by other, more contemporary ones, will go the way of their predecessors. It ignores the accomplishments of man over millennia of time, so eloquently expressed by the great poet W. B. Yeats (1923 Nobel Laureate in Literature) as "Monuments of unageing intellect" in his 'Sailing to Byzantium' (1928). Many equations from the distant past could be candidates for inclusion. My own choice, granted a sliver of bias in a narrative kept painstakingly clear of it, would be the concept of nothingness, expressed numerically by that unique "quantitative non-quantity" (as I am tempted to call it), zero. But this would not qualify for inclusion here, for it is not an equation, but only a commonly used number, such as when one integrates a differential equation between the limits zero and a finite quantity or infinity. However, the manipulations with zero, discovered by many unknown Indian mathematicians, and so succinctly expressed as

$$\infty \pm a \text{ (or 0)} = \infty$$
$$0 \times (a) = 0$$
$$a/\infty = 0$$
$$\infty \times 0 = \text{indeterminate (any finite number)}$$ [13]

form a set of the most important equations coming down from ancient times, unauthored and unsung, but accepted almost as a natural fact needing no name attachment. It is the basic underpinning of counting and, in the words of Einstein:

> *We owe a lot to the Indians, who taught us how to count, without which no worthwhile scientific discovery could have been made.*
>
> Pramod Kumar in *Meri Khoj Ek Bharat Ki*, 2008

If authorship is to be assigned to these equations, it would almost certainly be Brahmagupta. These equations brought out for the first time the centrality of zero in mathematics. A few other equations and principles are also very powerful candidates for number six, but this is my choice, considering its role in the beginnings of arithmetic and the thought that some of the most fundamental equations of today are based on these robust roots that are taken for granted and that even transcend the limitations of mere equations.

From equations we now move on to experimental observations. Freeman Dyson (1998) suggests 20 experiments that have defined the basics of science and fostered its evolution. While many cultures were involved in developing rigorous, and sometimes far-reaching, theories of science, of which we have selected six earlier, the task with respect to experimental equivalents in importance is even more difficult (with the same qualifying inadequacy of language). It is the British who introduced experimental science in a major way in research, particularly to India. This has led to results of explosive importance with or without the support of theory. Practically all Indian science today is tool-driven, except in places like the Indian Institute of Science, Bangalore; Tata Institute of Fundamental Research, Mumbai; and the NCL. This is particularly true in chemistry, as J. C. Ghosh so clearly stated with little concession to subtlety (see Chapter 2).

Lessons From Big History

The set of equations for manipulations with zero may not be the universal choice but its place as a serious contender is undeniable. Indian science of today has a strong base to stand on. All scientists, engineers and scientific institutions must be aware of this cultural heritage. The NCL and its scientists should exploit this base, notwithstanding the torpor into which Indian science had fallen prior to and during the early part of British rule. The world of science has progressed through revolutions in concept and in the tools of research. India has not been home to concept-driven revolutions for over a millennium. The Raman effect was the most spectacular tool-driven research of more recent times. Therefore, it would seem desirable to foster a mode of thinking where thinking itself is supreme.

Indian science has had its own less spectacular discoveries and concepts in times past, and it is only apt that today we are firmly anchored to modern science, product as it is of all cultures. In the rapidly changing world of today where cultural pluralism will increasingly determine demography, Western science will only be Western in region. Cultural backgrounds do come into play, but only in a subtle, indefinable way, as transmittals from the past (not excluding genetic continuity) embedded in current thinking. It is for laboratories like the NCL to ensure that these are preserved enough to make a difference.

This excursion into a bygone age of India and a brief peep into big history were undertaken with the object of generating a feeling of evolution. The word evolution was just another word in the English language till Charles Darwin used it to denote transformation. Even he desisted from using it in his *The Origin of Species* (1859), for fear that it might inherently indicate progress as we conceive it, preferring rather to use the safer term “descent with modification.” If survival is the test of evolution, it is also the test of a scientific theory. The fact that theories are born and die with amazing rapidity lends a sense of randomness to the evolution of science, in consonance with the evolution of life. But over time it seems to follow the success curve, in the sense that what survives is the fittest. Theory has been India’s strength. While recognizing its weaknesses, it should not be sacrificed at the altar of expedient empiricism. We have seen how scotoma has prevented encouragement of scientists or thinkers from outside mainstream disciplines. True to tradition, the NCL has been free from this. Professor John Barnabas, an evolutionary biologist who did some outstanding research at Yale University, was appointed as head of the Biosciences Division, much to the disappointment and dismay of many experts who felt that evolutionary biology had no place in the NCL's program. Barnabas belied all their fears and produced work of even greater merit at the NCL, an almost defiant testament to the old Indian tradition of respecting talent and the interdependence of the sciences. There have been many more fine theoreticians at the laboratory, exemplified by two contemporary thinkers, Sourav Pal and B. D. Kulkarni, the recently retired P. Ganguly, Sumit Mazumdar, who went back to the USA after a brief stay, and K. P. Sinha, a stalwart of the 1960s. It is only fitting that the NCL's story has been inlaid into a mosaic of big history.

To loosely quote P.C. Ray (1920), an enduring lesson from the past is that no discovery stands on its own feet, alone and apart from all other researches. To give this statement the credibility and force it deserves, I can do no better than recall Sir William Bragg's (1862–1942) assessment of a discovery. Referring to wireless telegraphy, Bragg is said to have remarked that all discoveries are a by-product of a consistent and consecutive system of enquiries...the fruit of many men's work.

In a similar vein but with much less loftiness, the success of many of the NCL's projects were the fruit of work from different disciplines, during and even before they became full grown projects (like methylchlorosilanes). Where this cardinal principle was not recognized and internal squabbles were allowed to dominate, there was failure. We will see examples of both in later chapters.

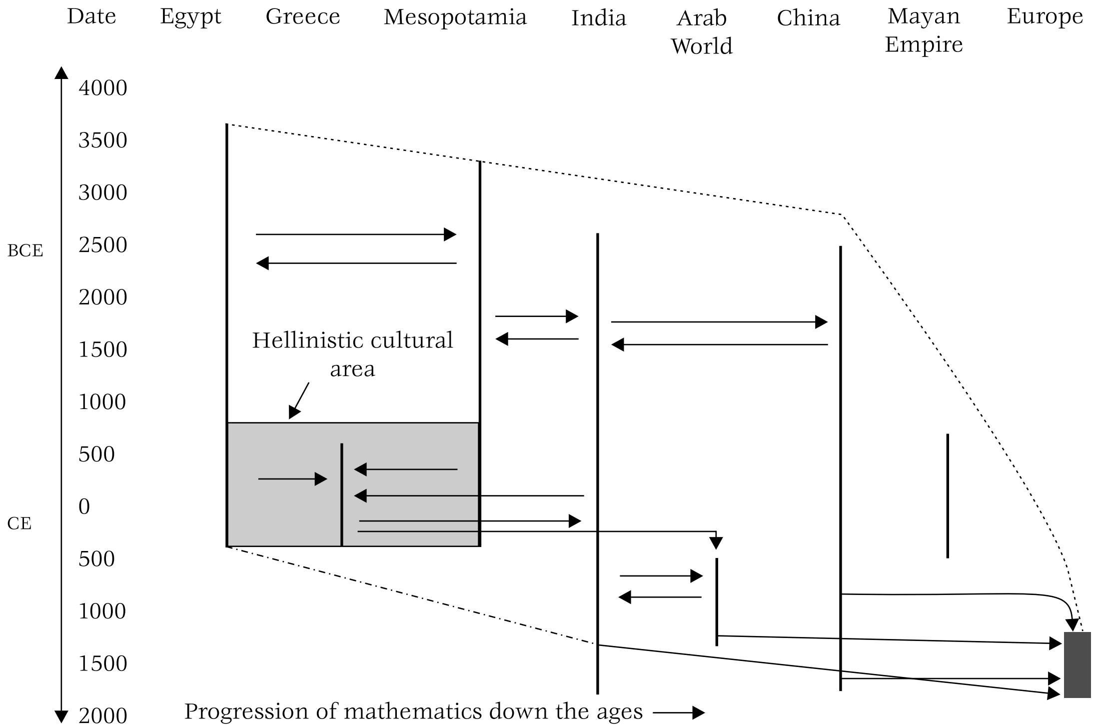
Teasing a Coherent Story

It is difficult to tease a coherent story out of the creative synergy of interacting cultures. History tells us that no single culture will be permanently dominant. Different cultures dominated at different periods of time, sometimes overlappingly. No culture has been subsumed by another. They all profited by mutual dissolution and somewhere along the line became one, each disappearing into the mainstream, directly or through other cultures, in its own time. This is roughly illustrated in Figure 1.2.

It is also true that non-Western cultures dominated till about 1400 CE. This is clearly illustrated by Murray (2003) in a special plot prepared by him. This plot shows significant figures as a function of historic time. By significant figures is meant the numbers of truly outstanding personalities identified by him through a logical but complex system of ranking. Based on this ranking, 4002 significant figures were identified as falling between 8000 BCE and 1950. From this inventory of the greats, only 690 belonged to the period 8000 BCE to 1400 CE, and only 226, constituting less than 6% of the total, were identified as giants. It is a remarkable fact that 120 of the 226, i.e. almost 50% of the giants, adorned the period between 8000 BCE and 1400 CE. Thus a large proportion of the giants of the world up to 1950 CE came from non-Western civilizations. Murray's plot referred to previously is reproduced in Figure 1.3.

Selected best-known names of the period prior to 1400 are marked on the figure in the columns representing the periods when they lived. I have highlighted the Indian names in bold letters. In terms of numbers, there was no great Indian domination, but Indian involvement in groundbreaking inventions was the highest. As mentioned previously,

Figure 1.2: Broad illustration of fusion of cultures



Source: Modified from Joseph, 2000

four of the 14 epochal thoughts of mankind came from the Indians of this period. But meta-inventions seem to have evaded the ancient Indians in the field of science.

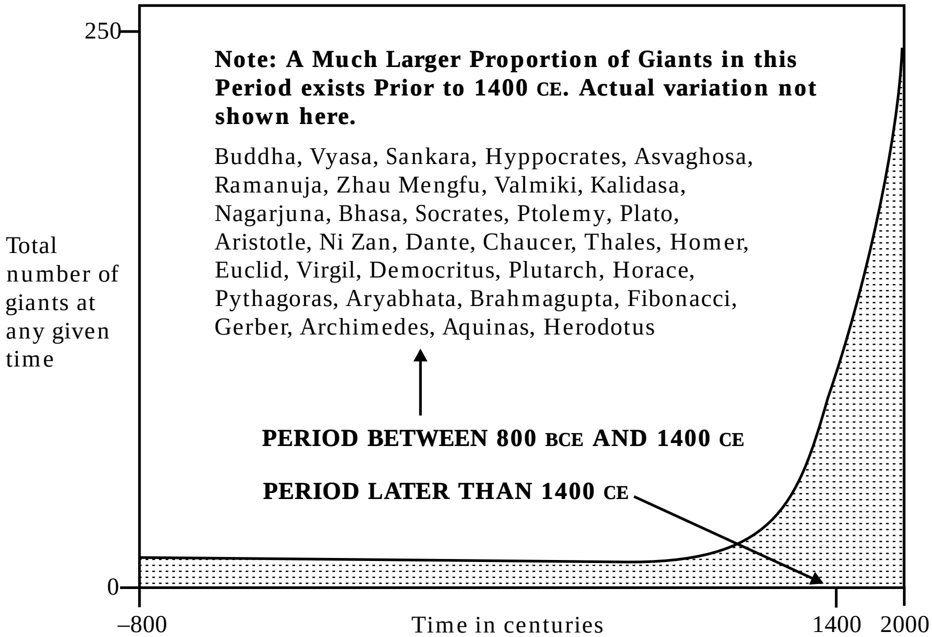
Apart from the highly scientific numbers game, devised by Murray, largely divested of personal views, many historians seem to set their own rules, somewhat arbitrarily, for judging ancient contributions. And these rules change depending on what they wish to conclude and convey. For instance, talking about the Egyptian and Babylonian concept of numbers, the renowned historian Morris Kline (1962) comments that

> *like young children of our civilization, they hardly recognized that they were dealing with abstract quantities.*

and claimed that the Greeks were the first to recognize numbers as ideas. Compare this with the strongly held Western belief that ancient Indian physics was meaningless because it was abstract, presumably no more than a set of ideas! As the popular saying goes, it is a no-win situation for ancient cultures. On the other hand, there seems to be an increasing awareness among some leading Western historians today of the contributions of ancient cultures, hopefully the beginnings of a counterweight to the rigid views of many earlier historians of science.

Another historical event, narrated by Teresi (2002), concerns the naming of discoveries. Pythagoras brought back to his homeland the famous eponymous theorem from his travels

Figure 1.3: Spread of giants before and during the Common Era



Source: Modified from Murray, 2003

in the East, but once home he had to adduce proof to convince a skeptical audience to stake his claim. This done, it indisputably became the Pythagoras theorem almost naturally, without question or debate. The Pythagoras theorem, which Jacob Bronowski (1973) calls "the most important theorem in the whole of mathematics," could well have been named after an Indian or an Egyptian mathematician (if a clear name could be identified)! But apparently Pythagoras himself was quite blameless in this name game. His disciples were vociferously parochial and tended to deify him, as was the wont with the Greeks of the time.

On the other hand, when Andrew Wile of Princeton University supplied the proof to Fermat's last theorem, there was no cultural conflict in names and hence the original name continued. Very recently (in 2006), when the Russian mathematical genius Grigory Perelman of St. Petersberg supplied proof to the famous Poincare conjecture, in view of no cultural conflict in names, the conundrum will perhaps continue in Poincare's name.[14]

I will end this section by quoting two opposite points of view and a third of wonder and happy remorse, which together must provide a measure of justification to the title of the section.

> Morris Kline (1962): *The history of mathematics cannot with certainty be traced back to any school or period other than the Ionian Greeks. [It] finally secured a new grip on life in the highly congenial soil of Greece and waxed strongly for a short period...With the decline of Greek civilization, the plant remained dormant for a thousand years* [until it was] *transported to Europe proper and once more embedded in fertile soil.*

Glen Bowersock (1996): *The porousness of Greek culture and the parallels to its achievements in other cultures have never been a secret…An expression like the "Greek miracle" was a catchy phrase for great drama, heroic statues, and the Parthenon, but all this had its historical context. For the Greeks themselves, the context was Phoenicia and Egyp*t [two cultures from where Greece imported many of its concepts].

Dick Teresi (2002): *My embarrassment at having undertaken an assignment with the assumption that non-Europeans contributed little to science has been overtaken by the pleasure of discovering mountains of unprecedented human industry, four thousand years of scientific discoveries by peoples I had been taught to disregard.*

Some Sobering Facts

There is, among Indophiles, a tendency to ascribe more to Vedic science than reality demands. Certainly, many Western writers till recently never attempted to recognize the contributions of other civilizations. While this is not true of some of the greatest Western minds, it is an unfortunate fact that the common writer is often almost irrationally committed to the singleness of the Western contribution. As is often the case, the reality lies somewhere in between; in this case, skewed rather heavily towards Western science. Over 95% of science was from the West but 50% of the giants were from other civilizations prior to 1400 CE.

I have already dealt with the merging roles of various civilizations in the creation of a single science that recognizes neither region, religion, nor remoteness. But, for the emotional proponents of Vedic science, they might do well to pause and ponder over some of the comments of one of the two greatest traveler scientists who spent years in India, the Arabic scholar Al-Biruni and the Chinese scholar Heun Tsang. To be sure, *Alberuni's India* (see translation, 1910) is an odd mixture of comments, some correct and some outright wrong. Some of his comments particularly pertinent to writers of science, are worth quoting here:

In consequence the highest results of the author's mental development are lost by their negligence, and his book becomes already in the first or second copy so full of faults, that the text appears as something else. Add to this that the Indian scribes are careless and do not take pains to produce corrected and well-collated copies, entirely new, which neither a scholar nor one familiar with the subject, whether Hindu or Muslim, could any longer understand…Besides, the scientific works of the Hindus are composed in various favorite meters…Now, it is well known that in all metrical compositions there is much misty and constrained phraseology merely intended to fill up the meter and serving as a kind of patchwork, and this necessitates a certain amount of verbosity. This is also the reason why a word sometimes has one meaning and sometimes another.

One cannot agree with two of his three comments. The charge of verbosity is only partially correct since, as is well known, Aryabhata compressed his many lofty mathematical concepts in just 33 terse verses. Further, verbosity is not peculiar to the Indian scribe. Other writers, such as the Chinese, also exhibit similar traits. Regarding the charge that the same word has different meanings in different places, this is a common feature of many languages, such as even Arabic and English, and therefore cannot be taken seriously. The non-Hindu parallels to these traits are fairly common and hence the criticism loses its force in what was perhaps meant to be specific to Hindu writers.

There is some truth in the criticism that the Hindu scribe was generally careless and committed errors that accumulated with reproduction. What is more, one sees a lack of attention to grammar in the articles, speeches, and even research papers of many senior present-day scientists of the country. Some are very adept at using popular terms, current jargon, and emerging scientific terms, but give themselves away in the use of connecting sentences. These sentences often contain passable errors but are sometimes loaded with serious ones. I can personally attest to this failing in the NCL of earlier years. Within a few years of taking charge as Director, I realized that the Division of Technical Services (DTS) not only did not communicate well, it was prone to serious errors in its writing. Being in many ways the NCL's mouthpiece, there was no scope for error in its reports, communications, and bulletins. How the NCL dealt with this problem is described in Chapter 13.

Another sobering thought — a very sad one — is that while Indian thought was part of the foundation on which Europe's resurgence was built, this is never explicitly recognized. Europe's revival is based on the blending of two great mathematical cultures, Greek (geometric and axiomatic) and Indian (algebraic and computational), but soon the Indians went through a phase of stagnation during the 17th–19th centuries. Thus, Indian algebra and geometry remained at a level which we today associate with high-school mathematics, and never reached the college or university stage (Dutta, 2002). The recent revival is heartening but noticed only in special circles.

Concluding Thoughts

In conclusion, it is emphasized that this brief excursion into the past of Indian science was not restricted to Hindu science, although the emphasis on Hindu science has been greater. Arab science was as much a part of this evolution. Indian science was greatly influenced by mutual interaction with Arab science during the Middle Ages, particularly the Mughal period. Together they provided the latent underpinnings of the scientific ethos and culture of the land. Their influence, particularly from the Vedic period up to c. 1500 CE, on the growth of modern science is not visible but, like the dark matter pervading the universe, exerts an invisible influence.

Abandoning the past leads to a society with no depth, one that totters on the brink of one-dimensional inadequacy. In the words of Alexander Stille's Brahmin scientist Veer Bhadra Mishra of Varanasi, immersed in Vedic lore (with whose actual words this chapter began), so admirably brought to life by Alexander Stille in *The Future of the Past (2002):*

> *Life is like a stream: one bank is the Vedas and the other bank is the contemporary world, which includes science and technology. If both banks are not firm, the water will scatter. If both banks are firm, the river will run its course.*

Laboratories like the NCL were created to keep the bank of contemporary science firm and growing in India, drawing from the other bank's alluvial soil nourished by centuries of daring thought and absorbed knowledge.

Tread Softly!

It is good to place in front what is behind, not as a hidden screen from which to read (as modern day politicians do) and follow, but as an occasional flashing light that cautions and provokes. How true it is that

> *The past should be culled like a box of fresh strawberries, rinsed of debris, sweetened judiciously and served in small portions, **not very often**.* (Emphasis mine.)
>
> Laura Palmer, 2000

Even the great French philosopher Benoit de Maillet (1797) tread softly when he captioned his book *Telliamed*, an epigram of his name, for fear that he would be openly violating the church's beliefs and could face retribution. He preferred instead to associate his ideas with those of a fictitious Indian philosopher, and subtitled it:

> *Or the World Explained: Containing Discourse Between an Indian Philosopher and a Missionary, on the Diminution of the Sea — the Formation of the Earth — the Origin of Men and Animals — and other Singular Subjects relating to Natural History and Philosophy.*

This supports, as few other statements do, the high esteem in which Indian thinkers were held for their daring concepts, by philosophers of an earlier age.

❄

2

THE EMPIRE OF ARISTOTELIAN REASON

THE PRELUDE TO THE BEGINNING

The East bowed low before the blast
In patient deep disdain
She let the legions thunder past
And plunged in thought again

Mathew Arnold
(see *The Pagan World*, 4th Para, in *Poetry and Criticism of Mathew Arnold*, 1961)

Adopting adaptation.[1] Indian culture has been known to absorb elements of new cultures, indeed, to adapt to them. This was manifest during the Mughal rule, and became a noticeable feature of the British. Indian politics and science began to adapt themselves to the new cultural environment, thus heralding a bicultural approach to science. This adaptation culminated eventually in the near total eclipse of Vedic science and designated a role to science that was to become a major factor in India's resurgence. This chapter attempts to show that India did not just *let the legions thunder past*, but adapted itself to them through a dual process of imposition by the conqueror and absorption by the conquered. A highly satisfying result (described in the next chapter) was the emergence of scientific agencies like the CSIR and laboratories like the NCL.

Western science is based mainly on the concepts of Aristotle (c. 384 BCE) and Democritus (c. 460 BCE). As these concepts established their sway in Europe, the rulers of the West took them to the lands they conquered. And so it was that Vedic and Arab sciences in India were slowly replaced by Western science. This chapter is concerned with the beginnings of this paradigm shift in India's scientific thinking and progress — the dawn of the empire of Aristotelian reason, as so eloquently expressed by some writers.

The Rise of British Influence

SCIENCE IN BRITISH INDIA

Around 1600 CE, two East India Companies were formed, one in the Netherlands and the other in Britain. Soon the former ceased to exist and the British company formed a number of scientific organizations in India, promoting scientific inquiry in the country. The subsequent formation of more such institutions can in part be traced to this early action.

Over the last 300–400 years, particularly with the ascent of Greek science, complete with other influences, accompanied unfortunately by the neglect, decline, and dismissal of ancient Vedic science, and even more so since the decline of Buddhism in India, Indian science was submerged in a quagmire of religion and dogma. Instead of being a tool for creating a better life for humankind, it fully lost its tenuous identity and became the handmaiden of priests. For instance, the highest form of mathematics of the Vedic Indians, indeterminate numbers, developed to construct sacrificial altars to the rigid specifications of the *Shastras*, was subsumed by the new culture of the day. All that remained of the old was the altar and the sacrifice, with no intellectual content. The rule of the *Shastras* prevailed and clouded intellectual inquiry. This state of torpor lasted for centuries, getting worse in the later years. This was also the time of the second Greek explosion, when Western science was getting back on its wheels. Because it too did not flourish during the period starting from the 4th or 5th century CE and stretching into the 15th century CE, Western scholars self-importantly called it the dark age of the world (as mentioned previously). Even ignoring this slanted view of science of the past, it is unfortunately true that Indian science did go into a slumber for a few centuries immediately following the dark age. As a result of the conquest of India by Britain, there was a steady ascendancy of Western science in the country, and local science, or whatever was left of it, disappeared from the scene. The attitude of the Indian mind towards the study of the laws of the physical world and the incessant activity of the West is summed up in the lines of Mathew Arnold, with which this chapter began.

But this transition was not painless. There was the famous controversy between the Orientalists and the Anglicists in the days of Lord Macaulay. Although the Anglicists seem to have triumphed, their creed could not be firmly established in India till it was publicly embraced by prominent Indians. Such an endorsement soon came from a well-loved and respected Indian reformer, Raja Ram Mohan Ray (P. C. Ray, 1920).[2] One of the greatest Indians to reshape Indian thinking almost two centuries ago, a Sanskrit scholar *par excellence* brought up in the *Vedanta* tradition, and the first to resuscitate the *Upanishads* in an Indian language (Bengali), Ray came out strongly in favor of Western based education, going so far as to say that Sanskrit caused a

> *lamentable check to the diffusion of knowledge…Nor will youths be fitted to be better members of society by the Vedantic doctrines which teach them to believe that all visible living things have no real existence, that as father, brother, etc. have no real entity, they consequently deserve no real affection and therefore the sooner we escape from them and leave the world the better.*
>
> See Ray, 1920

He then went on to write a letter to the then Governor-General of India, Lord Amherst, in which he appealed to him

> *to employ European gentlemen of talent and education to instruct the natives of India in Mathematics, Natural Philosophy, Chemistry, Anatomy, and other useful sciences, which the natives of Europe carried to a degree of perfection that has raised them above the inhabitants of other parts of the world.*
>
> Mohanram and Rajan

One sees a revivalist trend today encouraged by government, with emphasis, for example, on benign cures through the active principles of plants and herbs from Vedic times, on physical and mental exercises through *yoga*, and on a holistic approach to health care.

The fact is that during the days of the Raj, modern science, dominated as it was by Aristotelian reason, came to stay in India. How the British brought it here and a quick walk through the lives and times of some of our great scientists and technologists of pre-independence India would be a logical bridge between the vanished past and the surging present — one that would be locally unique but generally in tune with the developed world at large.

The British did not introduce science in India to create a love for modern (Western) science in the country. As policy, they brought in science and technology to train Indians and use them to govern India. When they first set foot in the country and established the East India Company in Calcutta (now Kolkata) in mid-18th century, there was no modern (post-Galilean) science. According to some experts (for instance, Kocchar, 2004), the earlier part of modern science and technology grew hand in hand with colonial expansion, such as the development of armaments, steam navigation, telegraphy, and railways. War also was (and continues to be) a great accelerator of science. Indeed, one is inclined to agree with Bernal (1954) that

> *the great developments of the eighteenth and nineteenth centuries, particularly the large scale smelting of iron by means of coal, and the introduction of the steam engine, were directly due to the needs of artillery which the increasingly large scale of war demanded.*

Thus the agenda was utilitarian — in large measure, colonial, as illustrated by the following occurrence, which may be regarded as a natural effect of science (Kocchar, 2004). During the famous mutiny of 1857, a telegraphic message was sent by the British from Calcutta to Bombay to rush reinforcements by train to what is now Uttar Pradesh. These forces reached there in time to crush the rebellion. The technological point here is that if the mutiny had occurred 10 years earlier when there was no railway and no telegraph, it might have been a different story altogether.

THE ROLE OF ENGLISH SCIENTISTS

Having brought modern science and the scientific methods to India, the British created several scientific departments in the government, such as the

- Botanical Survey of India
- Geological Survey of India
- Zoological Survey of India
- Survey of India
- Agricultural Service
- Forest Service
- Trigonometric Survey of India
- Meteorological Department
- Medical and Bacteriological Service

- Veterinary Department
- Educational Service

The heads and senior scientists of most of these departments were from England (many of them quite famous), with a few being Fellows of the Royal Society. Some important names are: Colonel Everest of the Trigonometric Survey, after whom the highest peak of the Himalayas was named; G. T. Walker, a distinguished Director-General of Observatories; Alfred Hay in electrical engineering at the Indian Institute of Science; W. H. Harrison and Mr. and Mrs. Howard in agriculture at the Agricultural Research Institute at Pusa in Delhi; Harold Mann of the Agricultural College of Pune; John Marshall in archeology at the Archeological Survey of India; N. Annandale in zoology; J. H. Hutton in anthropology; and John Evershed in astrophysics at the Kodaikanal observatory (since named The Vainu Bappu Astronomical Laboratory, after my late friend of college days in Hyderabad; both of us went to USA on the Nizam's government scholarships, he to Harvard and I to Wisconsin). It was partly due to the efforts of Sir Thomas Holland, a Director of the Geological Survey of India, that the first major Indian enterprise, the Tata Iron and Steel Works, was started at Jamshedpur in the iron-rich state of Jharkhand.

Many famous English scientists who were not in any way connected with India also had a great attachment to science in the country. A particularly noteworthy example is the acceptance by Lord Rutherford, Nobel Laureate and one of the greatest experimental scientists ever, along with Michael Faraday, of the invitation to preside over the Silver Jubilee of the Indian Science Congress in 1928. His sudden death before he could come deprived the Congress of his address, but his place was worthily filled by the brilliant Sir James Jeans, who was elected to the Royal Society at the age of 28. Another Englishman who should be gratefully remembered is Sir William Jones who, in the words of Sir Ashutosh Mukherjee (1914):

> *was one of the most gifted of the many noble sons of Britain who have devoted their lives to the cause of the advancement of knowledge amongst the people of this land (*India*).*

The Englishmen who came to India did not all retire and fade away after their service here. Many of them went back to do even more outstanding work in their own country, some were even appointed to very prestigious positions. A striking example is the appointment of the Superintendent of the Department of Geodesy in the Government of India, Sir Gerald Lenox Coyningham, as the Head of the Department of Geodesy at Cambridge. Sir George Simpson, a member of the Indian Department of Meteorology, became the distinguished head of the Meteorological Office of Great Britain after his return home.

The British established in India what is one of the finest research laboratories in forestry in the world. The Forest Research Laboratories in Dehra Dun had some of the most outstanding scientists of the day among its ranks. It provided the first two Directors of the Forest Products Laboratory of Great Britain, namely Sir Ralph Pearson and

W. A. Robertson. One of its scientists, R. S. Troup, became a distinguished professor of forestry at Oxford. Not a negligible number also enjoyed imposing titles, e.g. Imperial Economic Botanist to the Viceroy of India.

It is important to stress that there were foresighted Englishmen who were keen on starting a culture of intellectual discourse and free discussion in the country along modern lines. The formation of the Asiatik Society of Bengal in 1784 by Sir William Jones (later called the Asiatic Society), with the full support of Governor-General Warren Hastings, is an outstanding practical expression of this foresightedness.[3] The scope of this society's work covered the fields of literature, art, and science. It also participated, at the behest of Professors P. S. Macmohan and J. L. Simonsen, two well known scientists of the day, in the creation in 1914 of India's most popular scientific body, the Indian Science Congress Association. The annual meetings of this Association (called the Indian Science Congress) have invariably been inaugurated by the reigning Prime Minister of India since the country's independence. In fact, Prime Minister Jawaharlal Nehru also gave the presidential address of the Congress in 1947, the year of India's independence, on a subject close to his heart, Science in the Service of the Nation.

An unfortunate fact is that, notwithstanding the close association of many famous English scientists with India and their attachment to Indian science, the proportion of Indians to Europeans (calculated from the details given by Ray, 1920) in the various scientific services of India varied from 0 to about 25% (particularly in the 18th and 19th centuries), a lamentably low figure. The salaries of Indians in corresponding positions were also low, only 40 to 75% of their British counterparts. Appointments were made not by selection committees consisting of distinguished scientists but by the immediate superiors, who were invariably bureaucrats with no scientific credentials, who sometimes sought the help of committees consisting of men of their own bureaucratic ilk. This is perhaps more a reflection of policy than of the conduct and disposition of many of the Englishmen who served in India. In any case, the number rose with the years, as will be discussed in the next section. But the decadence of the Indians was not entirely the fault of the English, even though they ruled India for close to 150 years (excluding the East India Company era) but a reflection of the degeneration of the Indian mind and attitude over a much longer period, during which no notable contributions were made. This was also the period when the average educated Indian had lost his identity. Eager to please his English bosses and reluctant to leave his own way of life, he became a confused figure — neither serf nor equal. But attitudes changed as the years passed.

THE INCREASING ROLE OF INDIAN SCIENTISTS

In general, the tools of science and technology, aided by the Indians themselves in some measure, became an effective ally of the British to control and administer the country. Also, science as a knowledge system coupled with the Indians' natural propensity for learning, gave the West the opportunity to extract some of the legitimacy it lacked. Simultaneously, it encouraged many Indians to see themselves as allies of the British and to demand things within the broadening framework of the British rule. While all this was going on, Britain crushed the last remnants of resistance spearheaded by the Marathas in Western India. This gave rise to a situation where the British felt increasingly safe in appointing even more Indians to subordinate positions by teaching them English and the basic sciences. Thus began a curious relationship between the ruler and the ruled.

The first concrete evidence of this relationship was the appointment of an increasing number of Indians to subordinate positions in the Survey of India, mostly as mathematicians. Considering the pre-eminence of Indians in the area of computers today, it is almost clairvoyant that these subordinate Indians in the Survey of India were called “computers” (Ray, 1920)! (I am not sure if this was a compliment or an indifferent admission that Indians could do their numbers right!) In a further display of effective governance, Britain trained Indians in medicine and law. These initiatives, along with many others, helped create a strong middle-class in India. What happened as a consequence of this strategy is historically relevant to India’s present position in science, and indeed to the creation of scientific agencies like the Council of Scientific and Industrial Research (CSIR) and the early British-era universities like those of Calcutta, Madras, and Bombay.

A major offshoot of the induction of Indians to scientific and technological positions in British India was that it created a momentum of its own, and slowly but surely implanted in the Indian mind a renewed reverence for science, which had almost disappeared following the collapse of Vedic science. The burgeoning middle class became stronger and more demanding, and began to take major initiatives on their own. A particularly important outcome of this was the establishment in 1869 of the Indian Association for the Cultivation of Science (IACS) by Mahindra Lal Sarkar in Calcutta. Known primarily for C. V. Raman’s Nobel Prize winning research 50 years later, this was the first All-India organization of the middle class and it was in the name of science. This Association was instrumental in advocating and establishing the teaching of science in India. It was not a center of research when it was created but has been active in the area since 1907. Indeed, research in science was all but absent in India before the dawn of the 20th century. The CSIR and NCL, also created during the British rule, came 75 years after the IACS was formed. Indubitably, the IACS enjoys a place of its own among Indian laboratories, in spite of being overshadowed by others following independence, for it was the first scientific institute in India (excluding the more general Asiatic Society).

Notwithstanding these earlier scientific events in India, the real beginnings of sustained research can be traced to the Indian Institute of Science in Bangalore, established by the Tata Group, and the University College in Calcutta. The Iron Institute at Jamshedpur (named after the founder of the iron and steel industry in India, Jamshedji Tata), the South Indian Planters Association, the C. V. D. Institute for Animal Diseases at Muktesar in the then United Provinces, the government Testing House at Alipore, along with the various other government departments (or Surveys) mentioned previously in this chapter are some of the other centers where scientific work, including applied scientific research, was carried out during the British rule.

It is noteworthy that the initiative for modern scientific research by Indians came only from those who were educated abroad in countries like England, Germany, and the USA, or who had a strong foreign connection.

The most famous scientists of those days (1890–1940) were J. C. Bose, P. C. Ray, Satyen Bose, Meghnath Saha, C. V. Raman (known all over the world for his Raman Effect and the only Indian citizen to have won the Nobel Prize in a scientific subject, physics), M. Visveswarayya (an outstanding engineer), D. M. Bose, and Ashutosh Mukherjee. Of these, Raman and Visveswarayya belonged to the time immediately preceding independence. From the point of view of promoting science and education in India, Ashutosh Mukherjee was one of a kind. A distinguished polymath, he was a particularly gifted individual who combined vision and accomplishment with a forceful personality. His role can be prominently seen in a variety of educational and research activities of his time, a striking example being the establishment in 1914 of the Indian Science Congress Association. Like him, Meghnath Saha also vigorously promoted Indian science. He was instrumental in founding the National Institute of Sciences (since renamed as the Indian National Science Academy) and obtaining recognition for it as the representative national scientific body of the country. The Indian Physical Society too owes its origin to his vision.

J. C. Bose and P. C. Ray were the first Indian scientists to be recognized internationally. Bose worked on the propagation of radio waves but, according to Kocchar (2004), discontinued his research in this area as the humid climate of Calcutta (in the absence of air conditioners) was not conducive to using metal detectors and receivers. He started work on natural products and found very useful properties in some of them. In fact, a US patent was obtained in his name by Sister Nivedita, a product of Western civilization, but Bose refused to accept any monetary benefit from it. This is also true of P. C. Ray, who became famous through his work on mercurous salts. In fact, one sees this as a general attitude in the practice of science in pre-independence India, an attitude that one also saw in the early years of the NCL till S. Varadarajan (Director-General, CSIR, 1984–86) emphasized the need for patent consciousness and for laboratories to earn their keep. Unfortunately, he was not very successful. Another name, already mentioned, that has a permanent niche in India's science and engineering in the pre-independence and transition periods is that of Mokshagandam Visveswarayya, the only engineer so far, besides the former President of India, Dr. Abdul Kalam, to have been honored with India's highest award, the Bharat Ratna, for his massive accomplishments and sustained advice to governments.

Any account of science in pre-independence India would be incomplete without a mention of the role of many far-sighted administrators. Sir Ardeshir Dalal, ICS (Indian Civil Service, the prestigious British-day predecessor of the present Indian Administrative Service, IAS), was a particularly gifted individual who helped the Tata Group in many of their pioneering endeavors. Of these, the most pertinent to us is his stewardship of the Tata Iron and Steel Works and his membership of the Board of Scientific Research which created the National Chemical Laboratory. Another administrative luminary was Sir Arcot Ramaswami Mudaliar, who played a major role in creating the Council of Scientific and Industrial Research.

Stressless scholarship, a feature of Vedic times, and disregard for market-driven science have been the central tenets of the Indian science of earlier centuries (some dispute this). Indeed there was an indefinable sense of pride, not unspoiled by a feeling of elitism, in studying science for the sake of science. But the demands of modern life have caused a motivational shift towards utilitarian science that seems quite irreversible. The only notable scientist of pre-independence India who also excelled in applied chemistry and used this ability to set up a chemical manufacturing company was P. C. Ray.

No attempt to put the NCL in a historical context will be complete without reference to another attitude that, to some extent, persists to this day. Expressed simply and plainly, Indian scientists have considered recognition from the West almost as a *sine qua non* for recognition within the country, even if it meant placing the West on a pedestal of their own creation. Even the Nobel Prize-winning Rabindranath Tagore, expressing his admiration for Bose, wrote (Kocchar, 2004), *You are God's way of removing India's shame.*

Another example that cannot be omitted is that of Srinivasa Ramanujan, one of the greatest unconventional mathematical geniuses the world has known. Nobody bothered about him till he was recognized by Professor G. H. Hardy of Cambridge. But for Hardy he might have languished as a clerk in an Indian government office on a pittance of a salary, unknown and unsung, an unwitting victim of anticipatory plagiarism.[4] A more common example is the spirited revival of *yoga* following its unexpected popularity in the West. It may be argued that such an attitude was no more than an unavoidable product of the times, since Indian scientists were simply unable to recognize a great piece of work when they did or saw one. A striking example of this is the early work of J. C. Bose on radio waves. Its importance was not recognized by him or his Indian colleagues till it was pointed out by his former teachers in England, Cavin and Riley (Kocchar, 2004). It is now well known how Bose held a public demonstration in 1895 at which he used radio waves to remotely ring a bell and explode some gunpowder.

There are exceptions, of course, where other considerations have prevailed. A strange example of this is the experience of Satyen Bose who, along with Albert Einstein, formulated the well known Bose-Einstein statistics, but did not have a Ph.D. degree. When he applied for a faculty position in Dhaka (now in Bangladesh), he was asked to produce a letter from Einstein. *Do you still need a letter?* asked a bewildered Einstein, but wrote a strong one all the same. Bose was still rejected. Lack of a Ph.D. and not many publications seem to have weighed more heavily than Einstein's letter!

An important development during this period was the political recognition of scientists and other professionals. Among the other professionals were the officers of the Indian Civil Service (ICS) for which Indians had to pass a tough competitive exam in England (along with Englishmen) as an ordeal of fire, and membership of this exclusive club was regarded as the acme of achievement. The ICS officers were the bureaucratic elite of the country. The ICS has now been replaced by the Indian Administrative Service (IAS), the Indian Police Service (IPS), the Indian Revenue Service (IRS), etc., all very elite (particularly the first two) and the hallmarks of power in independent India. Examples of such political recognition in pre-independence India are contained in a resolution read by Anand Mohan Bose at the 1897 session of the Indian National Congress (to be differentiated from the Indian Science Congress), which paid rich tributes to J. C. Bose, P. C. Ray, and Atul Chatterjee, who had topped the ICS examination conducted in England. (C.V. Raman had done equally well but chose to leave the service in favor of science. Jawaharlal Nehru had also seriously contemplated appearing for it after passing the Tripos in science from Cambridge in 1910, but his strong-willed father Motilal Nehru would not have it.)

A feature of pre-independence India that cannot be overlooked is the clever use of science. While the British introduced modern science to India, they did so to streamline and modernize their system of government. If some Indians did good research and prospered as a result, that was fine. It is generally mentioned that science was never a professed instrument of social change in India, and that it was not until different scientific agencies were established following independence that the social purpose of science was truly articulated and practiced. In this connection, it is instructive to note that the very subject of this book, the NCL (and the CSIR), with far-reaching futuristic influence, was created at the transition to self-rule. In other words, the exploitation of science for the good of the people was not entirely a post-independence phenomenon, though it was largely so. But education in its modern form was certainly one of the finest legacies of British rule, starting with the University of Calcutta in 1857 (with Ashutosh Mukherjee as a future Vice-Chancellor), and followed by the Universities of Bombay and Madras the same year.

Organized research is different from research by professors in their specific areas with the help of students working towards their degrees, and is undertaken for the social good, and often for profit too. In other words, cooperative research is quite a different proposition. It is difficult to say when and where this modern version of high quality research started in India. The Council of Scientific and Industrial Research, started in 1940, is perhaps the best candidate for this distinction where industrial research is concerned. An important event was the establishment of the Indian Science Congress Association in Calcutta in 1914 with the object of promoting interaction between scientists from a variety of disciplines across the board, cooperation between officials and non-officials, between Englishmen and Indians, between laboratories maintained by private effort and those managed by government or universities and other public institutions, between trained senior workers who have attained an established position and junior workers and raw graduates just beginning original research. There is probably no parallel to such a broad based congress anywhere else in the world. The Science Congress, by its very nature, promotes contacts, discussions, mutual visits, and horizontal cooperation between scientists — even if loosely and informally. It does not envisage or promote vertical cooperation between scientists and engineers and, rightly, is not project oriented. The CSIR is perhaps the first institute to make a beginning in this challenging task of formal vertical cooperation between research scientists and engineers, between research organizations and industry, and between universities and research organizations. It was also perhaps the first to introduce the concept of projects with well-defined goals. Horizontal cooperation, formal or informal, was by no means excluded.

We shall briefly examine the beginnings of research in different areas of science in British India. Since the NCL is concerned with chemistry and chemical engineering, we begin with these areas and then lightly touch upon other branches of science.

CHEMISTRY AND CHEMICAL ENGINEERING IN BRITISH INDIA

Chemistry

As will be evident from the preponderance of Bengali names among those mentioned above, the credit for ushering in the dawn of intellectual renaissance in India belongs largely to Bengal. In particular the credit must go to the Serampur missionaries and the old Hindu School at Calcutta. John Mack of the University of Edinburgh who came to India in 1821 as Professor of Chemistry at the College of Serampur was perhaps the first to make a systematic attempt to teach chemistry in India, and his book on chemistry in Bengali in 1834 was by all accounts the first rendering of the subject in an Indian language. According to P. C. Ray (1920), the study of chemistry was further promoted when it became part of the curriculum of the Medical College established at Calcutta in 1835. A great teacher of chemistry at that time was O'Shaughnessy who wrote the then popular *Manual of Chemistry* in 1842. He was also a great spokesman for India, an enthusiast of the youth, and an articulate champion of science in general, and chemistry in particular, in the country. His constant refrain to students, delivered on many occasions, was:

> *Difficulties will beset his* [student's] *progress, it is true, but to overcome them all, he requires only the qualities which the Indian student possesses in the most pre-eminent degree. He is quick of perception, patient in reflection, adroit and diligent in experimental manipulation.* (Ray,1920)

My own interaction with professors in the USA and Europe confirms this view of the Indian student in Western eyes, except perhaps O'Shaugnessy's enthusiasm for the students' *adroitness* in experiment! Some other early names that deserve mention are: Kannailal Dey, who was perhaps the first Indian to acquire fame as a pharmacologist, being elected a member of the Pharmaceutical Society of Great Britain; Alexander Pedler, who was appointed Professor of Chemistry at the Presidency College in Calcutta; J. C. Sudborough in chemistry and Dr. Gilbert Fowler in biochemistry at the Indian Institute of Science in Bangalore; and J. L. Simonsen in natural products chemistry at the Forest Research Institute in Dehra Dun and at the Indian Institute of Science in Bangalore.

An event that merits mention concerns the Royal Commission for the Exhibition of 1851 which each year sanctioned a number of overseas scholarships to Great Britain's Dominions, as well as senior research studentships open to competition in England by all members of the British Commonwealth (Rutherford, 1938). This provided the best opportunity for the most outstanding investigators from the Commonwealth to continue their research in England. It was a very tough competition and Lord Rutherford was one of the early winners of such a scholarship. The first and only Indian to win it was N. S. Nagendra Nath of the Indian Institute of Science for research in theoretical physics at Cambridge.

A prominent figure in chemistry in early 20th century was J. C. Ghosh, who held many important positions in the academia and government.[5] He was a well known chemist who worked in a variety of areas. In his presidential address to the Indian Science Congress in 1939, after deploring the weak state of chemistry in India compared to that of physics and mathematics, he went on to say:

> *Chemists are apt to describe themselves as the most painstaking of all animals not even the ass excepted. It is more true of their science than that of any other that innumerable experiments must be performed, innumerable facts observed, catalogued, correlated and classified before an important generalization can be made or the structure of a new conception of the phenomenal world can be raised.*

He then offered the view that this limitation could only be overcome by team effort. One may or may not agree with this assessment of chemistry of Ghosh, expressed in rather unsubtle language. Nonetheless, it is a fact that truly outstanding work in chemistry was much rarer than in physics or mathematics. An important milestone in chemistry was the appeal by Professor J. L. Simonsen of the Indian Institute of Science in his presidential address to the Indian Science Congress in 1935, that the chemists of India should study the wealth of natural materials that lay at their doors more intensively and devote less time to the study of problems of only theoretical interest. This advice did not fall on deaf ears, for many schools of research on the chemistry of natural products have since flourished, including the famous schools at the NCL under K. Venkataraman, S.C. Bhattacharya and Sukh Dev (see Chapter 8).

Among those who did outstanding research in chemistry in those years were T. K. Seshadri, FRS, at Andhra University and then at Delhi University, K. Venkataraman and Wheeler at Bombay University, P. C. Guha at the Indian Institute of Science, and S. Siddiqui at Allahabad University. As will be described later in Chapter 3, Siddiqui was offered the first directorship of the NCL but he chose to go to Pakistan, and Venkataraman became the third (and the first Indian) Director of the NCL.

An important development in chemistry during this period was the formation of the Indian Chemical Society in 1924 by S. S. Bhatnagar, J. C. Ghosh, and J. N. Mukherjee.

Chemical Engineering

Following Norton's lectures on chemical technology at MIT towards the end of the 19th century (Peppas, 1989), chemical engineering established a strong foothold a few decades later in USA and Europe, with stalwarts like W. H. Walker, W. K. Lewis, O. A. Hougen, Peter Danckwerts, D. van Krevelan, M. Kramers, Neil Amundson, Richard Wilhelm, Kenneth Watson, and, a little later, Byron Bird, Edwin Lightfoot, Warren Stewart, Rutherford Aris, and Andreas Acrivos, giving it a respectable place in industry and academia (Bird, Lightfoot and Stewart taking it to a new era of analysis and thinking).[6] Their many original concepts and books, including those of the contemporary scientific contributors, USA's Edwin Lightfoot, Robert Langer, and Nicholas Peppas, England's John Davidson, Belgium's Gilbert Froment, France's Jack Villermaux, Japan's Diazo Kunii, and India's Manmohan Sharma and R. A. Mashelkar, not to mention the many more from these and other countries, have contributed greatly to today's chemical engineering — science and practice.

It did not take long for it to become a sustained presence in India. Actually, it did even a few years before independence. Among the best known chemical engineers of those years were Professor H. L. Roy (a chemical engineer with nationalistic fervor, generally known as the father of Indian chemical engineering), G. D. Parekh (the first Indian Sc.D. in chemical engineering from MIT), J. J. Mehta (who became the first CMD of the IPCL, and with whom I had very close connections as advisor to the R & D Department of the IPCL), Professor G. P. Kane (a UDCT Professor who became a technocrat in New Delhi), Professor N. R. Kamath (a UDCT professor who became the Deputy Director of IIT, Bombay, and whose Ph.D. papers were reportedly burnt in a fire in his department in England, thus depriving him of his doctorate), Professor M. Govinda Rao (a physical chemist with intense exposure to chemical engineering, who started the A.C. College of Technology in Madras in 1945), T. K. Roy (who started one of the first project engineering companies in India, one with which the NCL was later associated), Professors C. Venkata Rao and M. N. Rao (both of Andhra University; M. N. Rao later joined IIT, Kharagpur, as Chairman of the Chemical Engineering Department, before leaving several years later for Venuzuela to take up permanent residence there); Professors Ernest Weingaertner and N. R. Kuloor, Chairmen of the Chemical Engineering Department of the Indian Institute of Science in Bangalore (the former was on the committee that selected me as Senior Scientific Officer of the NCL), and H.E. Eduljee (an industrialist with a keen interest in research). Many of them continued to be active long after the British left India.[7] Bombay University was the first to start a course in chemical engineering in 1934. It was followed by the Alagappa Chettiar College of Technology of the Madras University in 1945. A few other centers quickly appeared, such as the Chemical Engineering Department at the Andhra University in Waltair, and the Laxminarayan Institute in Nagpur, under the leadership of C. Venkata Rao and P. S. Mene, respectively. Then came the Department at the Jadavpur University in 1955.

These centers were largely devoted to teaching, although Venkata Rao and Mene published a series of papers on vapor-liquid equilibria. The Lala Sri Ram Research Institute at Delhi, engaged essentially in industrial research, published several papers under the authorship of N. R. Kuloor. Kuloor subsequently moved to the Indian Institute of Science in Bangalore, devoted essentially to graduate education, and published a series of papers on physico-chemical analysis of a number of organic reactions. The period between the 70s and the 90s saw the rise of R. Kumar of the Indian Institute of Science and R. A. Mashelkar of the NCL. Mashelkar in particular has left a lasting impact, both as a researcher and administrator. As far as sheer brilliance goes, B. D. Kulkarni of the NCL stands out. J. B. Joshi of UICT has shown a remarkable talent for institution building, in addition to being a great researcher and in great demand for consultation. G. D. Yadav, the present Director of Mumbai's Institute of Chemical Technology, is a highly regarded researcher and consultant.

The Indian Institute of Chemical Engineers was founded in 1947 at Calcutta, and Professor H. L. Roy deserves a large share of the credit for starting the Institute and for fostering chemical engineering in the country in its early years of growth.

If Walker and Lewis' book from MIT on unit operations, and Hougen and Watson's book from Wisconsin on chemical process principles sowed the seeds of chemical engineering during that period, about a decade later Bird, Stewart and Lightfoot's tome from Wisconsin on transport phenomena opened new vistas and gave a new direction to chemical engineering. Amundson, Aris, Acrivos, Kramers, van Krevelan, and Danckwerts' books and papers from Minnesota, California, and Europe implanted the mathematical method firmly into the body scientific of chemical engineering. However, there were no equivalent books by Indian authors till long after the British had left India. The first book came (over three decades after independence) in 1984, under the joint authorship of chemical engineers from the NCL (LKD) and UDCT (M. M. Sharma), a comprehensive exposition of reaction/reactor analysis with copious examples, the first of its kind.

OTHER SCIENCES

Many of the areas of research today were non-existent up to the dawn of independence. The areas then known were few, and the British should be credited for introducing practically all of them in India. These include, besides chemistry: agriculture, forestry, botany, zoology, survey, biochemistry, medicine, physics, astronomy, geology, geography, and industrial research. An excellent survey of these appears in *Science in India* edited by C. N. R. Rao and H. Y. Mohan Ram (1958). A few lines on each should suffice to indicate the extent to which these areas were encouraged, for reasons that were perhaps not always altruistic.

Physics was unquestionably India's forte in pre-independence scientific endeavors. This is not the occasion to delve into the details of the Indian contribution, but a few examples should suffice to emphasize this fact. Ever since Vedic times the Indian mind has shown an unusual fascination for the abstract (see Chapter 1). After the centuries of darkness referred to in that chapter, contact with the West helped revive this dormant strength, which, before independence, had found its best expression in discoveries related to physics. Of the fundamental classes of particles known in nature, one is named after Enrico Fermi, the discoverer of the atom bomb, and is called the fermion. The other is known after Satyendar Nath Bose, the only Indian honored by the naming of a fundamental particle after him, the boson. Another Bose before him, Jagadish Chandra, was able to demonstrate the power of feeling in plants. His assertion that the response to electric stimuli even of inorganic matter is similar to that of living tissues is, however, yet to be proved. And then of course we have the well known Raman Effect, for which C. V. Raman was awarded the Nobel Prize. The Raman Effect is now routinely used in a variety of fields, independently or in combination with other measurements. Among the other well known physicists of British India were K. S. Krishnan (first Director of the NPL), K. R. Ramanathan, and D. S. Kothari.

Since the discovery of the place value system, India's pre-eminent position in mathematics has never been in question. This was emphasized by the remarkable achievements of Srinivasa Ramanujan (1887–1920) in number theory. Some of his identities remain unsolved to this day. Schools of classical analysis, differential equations, and analytic number theory flourished in South India and Allahabad. Since it is impossible to explain mathematical achievements in words, we will just name the areas in which mathematics flowered in the country over a couple of decades straddling independence (Rao and Mohan Ram, 1985): numbers, algebra, combinatories, algebraic geometry, differential geometry, Lie groups and algebraic groups, probability, topology, several complex variables, functional analysis. Applied mathematics developed only after independence.

India's contributions in astrophysics and astronomy, though quantitatively not comparable to those in some other areas, were qualitatively quite profound. The first name that comes to mind is that of Megnath Saha. His theory that the ionization of a gas by thermal excitation is a natural extension of what is happening in the stars was a great discovery. The Saha ionization formula finds extensive use in modern astrophysics as well as in terrestrial applications. S. K. Mitra, A. P. Mitra (a former Director-General of CSIR), and K. R. Ramanathan laid the foundations for upper atmosphere research in India. Homi Bhabha is another prominent name in Indian astrophysics known for his researches in cosmic rays (electron-photon showers). Subramanyan Chandrasekhar proposed his famous theory of stellar structure in 1939, for which (due to opposition from Lord Eddington, England's powerful Astronomer Royal, whose brilliant experiments supplied proof for Einstein's prediction of the bending of light rays) he had to wait for almost half a century before he was awarded the Nobel Prize.[8] In terms of practical astronomy, there was an observatory in Trivandrum in 1836, and another in 1898 in Puna (now Pune) which had the largest telescope in the country (20 inches), the Grubb reflector. The beginning of the last century saw an observatory in Kodaikanal, which assumed great prominence in post-independence India.

Agriculture received very strong support from the British, not so much to promote it in India as a science but to satisfy their own commercial needs; but soon it became a mixed blessing. The first step was the setting up of the Department of Revenue, Agriculture, and Commerce in 1871. Soon thereafter, agricultural colleges were established in Coimbatore and Pune. This was followed by several more colleges and institutes, such as the Imperial Veterinary Research Institute (now Indian Veterinary Research Institute) at Izzatnagar in 1898, and Imperial Institute of Animal Husbandry and Dairying (precursor to the present National Dairy Research Institutes at Karnal and Bangalore) in 1923. The last major act of the departing British was the establishment of the Imperial Council of Agricultural Research (forerunner of the Indian Council of Agricultural Research) following upon the recommendation of the Linlithgow Commission in 1928. Although there was an overall improvement of sorts in agriculture as a result of this recommendation, the progress during the period up to independence was unsteady.

Botany in British India received a big boost by the establishment in 1787 of the Royal Botanic Garden in Sibpur in Bengal. Its herbarium, the latter-day Central National Herbarium, was a repository of practically all the dried plant materials of the whole of the subcontinent, South East Asia, Japan, Persia and Asia Minor, Europe, and Australia, and of high quality plywood and pulp from bamboo. It conducted research in entomology, silviculture, wood anatomy, etc. Another major occurrence was the enunciation of a National Forest Policy in 1894, resulting in a steady development of forests and conservation practices.

The importance of zoology was recognized fairly late into British rule, in fact not until 1916, when the Zoological Survey of India was established, notwithstanding the establishment of the Bombay Natural History Society a few decades earlier in 1883. Detailed investigations of Indian fauna were then carried out, including several hundred intensive surveys. A series of 34 volumes titled *Fauna of India* (formerly British India) was brought out. Ornithology evoked national interest with the publication by the self-effacing Salim Ali (with Dillon Ripley), soon after independence, of his classic book *Handbook of Birds of India and Pakistan* (1987). Marine biology received a great boost with the establishment of the Marine Survey of India (MSI) and the appointment of J. Armstrong as the first Surgeon Naturalist (I have already talked about imposing designations in Chapter 1). A number of expeditions by the MSI resulted in the collection of a vast volume of data on marine life. Fisheries research occupied a prominent position in marine life investigations, and an important event was the passing of the Indian Fisheries Act in 1897, by which fisheries became a state subject, thus hastening their growth.

Indian geology held a great fascination for European geologists for the richness of the country's mineral wealth. In 1846, D. H. Williams explored the coal fields of Dhanbad and surrounding areas, which five years later led to the establishment of the Geological Survey of India (GSI). Based on extensive studies in India, J. H. Pratt and G. B. Airy formulated the theory of mountain compensation. Then, with the geology departments of many universities joining forces with GSI, there was a marked increase in the study of the geology of India.

One of the Vedic scientific practices that did not fully disappear during the centuries of scientific inactivity in India was Ayurveda, the science of medicine. However, when the British brought Western medicine to India, the practice of Ayurveda seemed to decline till desultory attempts to revive it soon after independence, followed by more sustained efforts, gave it a permanent niche in the practice of medicine as a whole in India. However, Western medicine had, in the meantime, taken a strong foothold from which there was no retreat. The beginnings of Western medicine in India can be traced to the work of Ronald Ross on malaria. Other important works were those on the development of a vaccine for plague by Haffkine, studies on filaria (very common in Kerala) by Lewis, and on cholera by Macnamara and Cunningham, and the discovery of treatment for kala-azar by Brahamachari. British India was perhaps the first to establish a series of institutes named after Louis Pasteur in any country. The following actions were also noteworthy: the creation in 1921 of the Indian Research Fund Association to promote research in medicine; the setting up in 1926 of the Malaria Research Institute in Madras; the appointment in 1942 of the Bhore Committee to recommend steps for undertaking further medical research. From here forward, one moves into the post-British era.

This brief summary is just a sampling of what was done during the British era in India. No mention has been made of developments in a number of other areas such as biochemistry, archeology, architecture, statistics, etc.

RESEARCH EXPENDITURE IN BRITISH INDIA

We have already referred to the first state policy on science in India during the Mauryan period, but there is no indication of the amount of money allotted by the state for scientific work — indeed, of the definition of science itself. The first recorded accounts of expenditure on science, however piecemeal, start with the British era. The figures on science education in schools, colleges and universities (teaching, and research if any, were largely restricted to colleges affiliated to universities which were no more than central administrative authorities) are somewhat hazy, but from the data available from the education departments of the center and the various provinces and princely states, some facts emerge regarding science education and research in British India. These can form a valuable basis for assessing the change since independence.

The chief difficulty in arriving at a reliable figure for expenditure on scientific research is the lack of a separate budgetary identity for research and the absence of ministries or departments devoted exclusively to research and development. There were many government surveys, but research was only a small part of these. One has to piece together figures for research allotted by various departments/ministries of government to arrive at even a semblance of a figure (Bourne, 1917). Thus one sees an allotment of Rs. 4 lakhs for a Forest Research Institute and College at Dehra Dun, 5.5 lakhs for an Agricultural Research Institute at Pusa, Rs. 87,500 for the Indian Institute of Science in Bangalore (with the promise that a matching amount would be forthcoming from government for any private grant so long as the total grant did not exceed 1.5 lakhs). With all the uncertainties about division of funds between technical/administrative activities and scientific research, the amounts contributed from state governments and other channels of providing funds for research, however limited, no firm figures on expenditure on scientific research even in the British years are available. It has been estimated (Bourne, 1917) that the total amount, excluding buildings, could be around Rs. 70–80 lakhs. At any rate, it was less than Rs. 100 lakhs (or $ 2.5 million, using the approximate conversion rate of those years). To put these expenditures in perspective, it may be noted that the National Physical Laboratory in England started out in 1902 with a capital grant of $13,000 (about Rs. 80,000) and that the Imperial College of Science and Technology received a subsidy of $20,000 (about Rs. 150,000) (Dalal, 1941). The government perhaps did not spend much more on research.`

Education in Pre-Independence India

The present university system of education in India had its roots well over a century ago in the British period. In 1835, Lord Macaulay proposed teaching English to the “natives” of India. This was followed in 1854 by a clear recommendation by Sir Charles Woods, in what is frequently referred to as the “Magna Carta” of English Education in India, from which a coherent system of education from primary school to the university was established in the country. The first modern university in India was the University of Calcutta and was established in 1857, followed by the Universities of Madras and Bombay.

For a number of years, these universities continued without mutual interaction till an Inter-University Board (later known as the Association of Indian Universities) was established in 1925 to share information in the fields of education, culture, and sports. Then came the first attempt to establish a national system of education when a report known as the Sargeant Report recommended the establishment of a University Grants Committee (see UGC website). By that time two more central universities were in place, one at Banaras and the other at Delhi, and in 1945 this Committee was entrusted with the responsibility of overseeing all the three central universities. Soon, almost coinciding with independence in 1947, the then existing universities were entrusted to this Committee's supervision.

The teaching of chemistry in the early years of the Indian universities was largely confined to inorganic or mineral chemistry (Dey, 1957). Sometimes physical chemistry was also taught but organic chemistry almost never. Another feature of the early years was that the universities did not take any active part in teaching and were content with merely laying down curricula and conducting examinations. The teaching was left exclusively to the many colleges affiliated to the universities. Of these, the Presidency Colleges at Calcutta and Madras were perhaps the best in the country and were unique in many ways. They attracted some of the best professors available, among them Sir Alexander Pedler at the Calcutta college and Dr. W. H. Wilson at Madras. Pedler was a student at the old Royal College of Science in London and Wilson was trained under Bunsen in Heidelberg. But they too belonged to the old school and taught only inorganic chemistry. As a tribute to their excellence many of the apparatus used by them are still preserved at the two colleges. They both were succeeded by equally outstanding men, P. C. Ray at Calcutta and Erlam Smith at Madras, again inorganic chemists. Following a few other happenings, all the main branches of chemistry were assigned their legitimate places of importance in the field of chemistry.

A notable event now occurred that signaled a great improvement in the university system. It was at this stage that a purely British initiative on the structure of education in India took on a nationalistic flavor, when Sir Ashutosh Mukherjee, the polymath educator, stepped into the scene. Soon recommendation became reality, hope became fact, and what hovered lazily on the edges came rushing to the center to materialize as the first school of higher education in the country. The locale of action was the University of Calcutta. The university changed over from an examining to a teaching university, a change in the way universities operated in India. The real turning point came when India's two great lawyers from Bengal, Sir Rashbehari Ghosh and Sir Taraknath Palit, gave their entire life savings to establish a College of Science and Technology at the university (Dey, 1957). A post-graduate council in science was established next, and teaching and research for the Master's and other higher degrees were undertaken by the university for the first time in India, in cooperation with the Presidency College and the other larger colleges in Calcutta. Once again, Calcutta had shown the way and other universities, notably Madras, followed suit.

Another event of some importance occurred in 1904, when the Curzon Commission on Education recommended the introduction of a three-year honors course. Only the brightest students were admitted to this course. The students took a big risk in opting for B.Sc. (Honors), for they then forfeited any claim to the lower B.Sc. degree if they were unsuccessful in attaining this. In view of the high standard of admission, usually not more than four students were admitted to this course every year. The M.Sc. degree course was introduced simultaneously and was an entirely research-based one. Usually only honors graduates were admitted to this course. The introduction of this degree brought in its wake new facilities and equipment and a general improvement in the university atmosphere.

Among the two outstanding universities of the time at Calcutta and Madras, a culture of research was built up in Calcutta in the early 1900s, mainly thanks to the efforts of J. C. Bose and P.C. Ray, who were perhaps the first Indians to establish a tradition of modern research in India. They occupied, respectively, the chairs of physics and chemistry at the Presidency College from 1890 to 1915, and developed their own lines of research and trained students. Madras did not have a similar tradition since W. H. Wilson, who joined the Presidency College at Madras at about the same time as Bose and Ray joined the Calcutta College, did not engage in research. But Simonsen, who also joined at the same time, though he did not immediately engage in research, soon resumed it from his English years and did some outstanding work in organic chemistry which resulted in the treatise, *The Terpenes* (Volumes 1 and 2) in 1931 (an enlarged edition was published in five volumes from 1947 to 1957).

Several things then occurred which changed the face of education and research in India, at least in the field of chemistry. Some of the professors who came to India during this period were organic chemists, such as J. L. Simonsen who came to Madras, E. R. Watson who came to Dhaka, A. N. Meldrum who came to Bombay, and several others in different fields. The building up of schools in physical chemistry was largely left to young Indian chemists educated in England, such as J. C. Ghosh at the University of Dhaka and then the Indian Institute of Science in Bangalore, J. N. Mukherjee at the University of Calcutta, and S. S. Bhatnagar at the Universities of Banaras and Lahore. As mentioned previously, two other events during this period were of great historic significance. The first was the establishment of the Indian Institute of Science by Jamshedji Nowroji Tata in Bangalore. He invited Sir William Ramsay, Nobel Laureate, to select a suitable site for the Institute. Ramsay chose Bangalore and deputed his co-worker M. W. Traverse to be the first Director. Several other distinguished scientists such as J. J. Sudburough, G. J. Fowler, H. E. Watson and A. Hayes also arrived in India at about the same time. The second event was the inauguration of the Indian Science Congress in 1914, thanks to the untiring efforts of J. L. Simonsen, Ashutosh Mukherjee and Macmohan. These developments signaled the arrival of a new age of education and research in India. Following these, how education grew at a phenomenal pace in independent India, with its influence on the evolution of NCL, is described in Chapter 4.

Chemical engineering education in India did not start till the mid-1930s. Since education and research in chemical engineering went hand-in-hand at that time in India, and neither merits individual attention, they were discussed together in the previous section on research. Since the industrial situation in general was bleak, engineering education was correspondingly weak. This entire situation with respect to engineering education and industry improved only after independence, and is briefly considered in Chapter 4.

Industries in Pre-Independence India

Will you come with me to India? asked Jamsedji Tata, *that strange man in a strange garb* (quoted in Lala, 1981). Charles Page Perin, the great Pittsburgh steel maker (those were the days when Pittsburg was the steel capital of the world) to whom the question was addressed, replied, *Yes, I will go*.

And he did. Thus was born the first major modern industry in India, the Tata Iron and Steel Works.

Though the Tatas were a highly nationalistic group, they realized that, such as things were in those years in India, foreign expertise was imperative for even a semblance of modern industrial development. This was also true in many other fields of endeavor, such as education and research. Thus most of the universities started in those early years bore the welcome patronage of the British. Even the Tatas enlisted the help of Englishmen to start the Indian Institute of Science in Bangalore. As we shall see in Chapter 3, the CSIR was also a creation of the British days. As independence came and with it an upsurge of national pride, resort to local sources for advancement became more prominent, and the word “indigenous” became one of the most commonly used words in any developmental context. The NCL was one of the first major instances of this transition in the field of science. I shall defer a discussion of this till after completing a brief review of the pre-independence chemical industry.

THE CHEMICAL INDUSTRY

As a major objective of the NCL was to help the growth of the chemical industry in India, it is important to appreciate the extant base structure of the industry at the dawn of independence. This is best done by briefly tracing the growth of this industry during the British period. Several accounts of this have been written, many of them in the form of articles in the *Chemical Age of India* and in other journals published by the Colour Publications Group of journals headed by the late K. V. Raghavan, one of the most honest and scrupulously straightforward journalists/editors of the country.

As mentioned previously, ancient Indians were not particularly strong in technology of any kind. There were some notable exceptions, such as the plants for extracting metals like zinc, copper, and iron. Although there was nothing like a chemical industry, the ancient Indians did have a large number of manufacturing units that produced a variety of chemicals, mostly chemical formulations with no precise specifications (in the manner of many old-time chemicals), including pharmaceuticals, dyes, auxiliary chemicals, and biochemical products such as alcoholic drinks. Mercury for alchemy was one of the few items produced to a high level of purity. As these units began to disappear and India went into that dreadful period of hibernation referred to previously, the chemical industry also waned considerably.

The first signs of resurgence along Western lines were seen in the establishment of a distillery for potable liquors by Carew and Company at Rosa in the United Provinces (now Uttar Pradesh) around 1835. This was followed over a decade later by another distillery, also for potable liquors, by Parry and Company in Nellikuppam in Madras (now Chennai). But there was no production of industrial alcohol, rectified or absolute. By about the beginning of the 20th century, a few more chemical companies were started, for example: factories for the recovery of quinine in Madras and Bengal in 1871, the Shalimar Paints, Colour and Varnish Company in 1902 in Calcutta, and the government Cordite Factory in Aravankadu, Madras, in 1904.

According to G. P. Kane (1990), the production of nitroglycerine, nitrocellulose and acetone at the Aravankadu defense factory marked the beginning of the organic chemical industry in India. This was quickly followed by the setting up of coal-tar distillation factories in several places, but benzene was recovered for the first time only in 1920. At this stage, realizing the importance of the organic chemicals industry, the central government stepped in for the first time by enacting the Heavy Chemicals Protection Act of 1931, thus stripping the Provincial Governments of sole authority in the matter. The first major result of this move was the establishment of distilleries for the production of absolute alcohol for use as a source of organic intermediates and for making what came to be known as "power alcohol" by admixture with gasoline (petrol) for automobiles. Facilities were subsequently created for producing benzol from coke-oven gases and coal-tar, and for glycerine from soap-making plants. These three chemicals appear to have been the only basic raw materials available for the organic chemicals industry during that period. Washing and toilet soaps associated with the glycerine industry, and a prosperous vegetable oil industry, including hydrogenated edible oils known by the brand name *Vanaspati* (familiar to every Indian housewife), were established in a major way during this period.

The inorganic chemicals industry too had dug its own roots in those British years. Heavy chemicals like acids and alkalis, soda ash, fertilizers, and salts such as sodium and magnesium chlorides, were the most notable inorganic chemicals produced then. The credit for organizing the soda ash industry in India goes to Kapilram Vakil, perhaps the first outstanding modern Indian chemical technologist. The first soda-ash unit was set up by Sri Shakti Alkali Works at Dhrangadhra around 1925. This was followed by Tata Chemicals at Mithapur in Gujarat. Even today Tata Chemicals is the largest soda-ash producer in the country. Dharamsi Morarji Chemicals was another major producer of inorganic chemicals in pre-independence India. It started with a Chamber plant for sulfuric acid, and produced nitric and hydrochloric acids, epsom salt, and copper sulfate. It then added many other processes such as for sulfuric acid (by the contact process), superphosphate, ferric alum and iron-free alum, borax, boric acid, chlorosulfonic acid, etc., many of them in association with sister companies. It continues to be an important producer of inorganic chemicals in the country today. Another company that was a major producer of inorganic chemicals like sulfuric acid (by the contact process) and superphosphate was Parry and Co., whose operations continue to this day at Ennore at Madras. Fertilizers and Chemicals of Travancore (FACT) was another major fertilizer manufacturer of the British days (established in 1936) that has expanded its activities and continues to this day. Two other companies of the British days that have grown over the years are worth mentioning — Associated Cement Companies (ACC), which more recently expanded into zeolite-based adsorbents and catalysts but quickly stopped this operation, and the Dalmia Cement Works.

It is interesting that the only British period company with which NCL later collaborated was, of all companies, a cement manufacturing company, ACC, which for a short interval entered the zeolites field. In that short period, it made history in the field of catalysis in India by collaborating with the NCL to produce the catalyst for IPCL's isomerizer on an industrial scale and thus help India enter the high-tech field of industrial catalysis. Soon, however, this facility was bought over by the IPCL. Ironically, the IPCL was later bought over by its one-time competitor, Reliance Industries, that soon was no longer a competitor but India's largest manufacturing giant. The NCL, which had an excellent relationship with the IPCL, managed to extend this relationship with Reliance later, as will be seen in Chapter 12.

The allopathic system of medicine came to India in 1797 when Lord Cornwallis introduced the first state monopoly for the production of opium and by 1820, two government opium factories were established, one at Ghazipur in Uttar Pradesh, and the other at Patna in Orissa. Over a century and a half later, the NCL was to be involved in modernizing the Ghazipur factory and setting up a modern plant at Neemuch in Madhya Pradesh. This story will be recounted in Chapter 10. Around 1870, the British set up the so-called Medical Stores Departments which later began to produce pharmaceuticals. These pharmaceuticals were all made from medicinal plants which were exported to England, where they were treated to extract the active principles which were sent back to India as finished products, an all too familiar pattern.

Acharya P. C. Ray, inspired by national considerations, started the Bengal Chemical and Pharmaceutical Works in 1907. This is normally regarded as the birth of the Indian pharmaceuticals industry. Almost immediately thereafter, T. K. Gajjar and Rajmitra B. D. Amin, inspired by similar considerations, set up the Alembic Chemical Works in Bombay (which later moved to Baroda). These developments notwithstanding, there was hardly any pharmaceuticals industry worth the name in the years immediately preceding and following independence. The dependence of the organic intermediates industry, so essential for the pharmaceuticals industry, on petroleum or coal-tar was not generally appreciated, neither was the fact that some of the higher order intermediates could be directly used as medicinal chemicals, such as phenol, resorcinol, sodium salicylate, benzoic acid, saccharin, sulfanilamide, sulfathiazole and other arsenicals, atebrin, and stilbosterol. The value of sulfathiazole against plague and as a general bactericide was established by the Haffkine Institute, Bombay, in the late 1930s. It was in great demand and the cost of the imported product was prohibitive, and yet no attempt was made to produce or permit production of the chemical within the country. Venkataraman presents a critical discussion of this situation in his article *Manufacture of Synthetic Drugs and Fine Chemicals* (1942).

The following decades saw phenomenal developments the world over in the pharmaceuticals industry. India, being a dependent country, had no role in it. Even in production, it produced only what it was allowed to by the British. Activity was largely restricted to formulations of drugs imported by multinational companies from their principals abroad. Even here, they were largely confined to tinctures, extracts, galenicals, etc. In the rare cases where drugs were manufactured within India, they were from the penultimate intermediates imported from abroad, also by multinationals. All this amounted to a total production of just about Rs. 10 crores or so.

The paints industry also made a beginning in the British period. To start with, there were several small-scale units. Then came Shalimar Paints (in collaboration with Pinchin Johnson Ltd. of England), which is the oldest paints company and was started in Calcutta in 1902. This was followed by Jensen Nicholson Ltd., Goodlass Wall Ltd., British Paints Ltd., Blundell Eomite Ltd., ICI Ltd., and in 1942, by Asian Paints Ltd. The industry continued to grow at a very fast rate after independence.

OTHER INDUSTRIES

Outside the chemical, industries were not very many in India, with the exception of the Tata Iron and Steel Company, the Indian Iron and Steel Company, and a few other less important undertakings.

The industrial development of the country had to await the five-year plan periods to break out of this long period of hibernation. The development was then remarkably rapid, as outlined in Chapter 4.

On Such Foundations

A clear revelation from the names mentioned is the preponderance of Englishmen in the management of science and of scientific organizations in pre-independence India, in spite of the accomplishments and influence of the somewhat limited number of famous Indian scientists of the time. Of the 33 presidents of the Indian Science Congress from the year of its formation (1914) to the year of independence (1947), 16 were Englishmen, many of whom were Fellows of the Royal Society. Unfortunately, the bulk of the Indians appointed in government scientific departments were employed only in subordinate positions — a fact already noted. And yet, irrespective of Britain's official policy, many of these British scientists did enormous good for Indian science and enthusiastically demonstrated their keen desire to recognize and encourage Indian scientists.

It is instructive to recapture in a capsule the essence of what was described in Chapters 1 and 2, to serve as the basic foundation for the evolution of science in post-independence India, with particular reference to the NCL:

- The Vedic and non-Vedic cultures of antiquity have left their lasting imprint on the scientific temper of India. Scientific thinking and readiness to learn, even to emulate, have been the most pervasive of our inheritance. But lost in the transmission are the brevity of prose, a penchant for the best with little concession to haste, and an arguable impatience with empiricism. Mathematics, astronomy, physics, and to a lesser extent chemistry, were the ancients' strengths that have come down to us practically undiminished. The lineage and leverage that this offers have still to be fully integrated into the "modern" science that has rightfully become our latter-day heritage.
- Great Britain's motives in bringing modern science to India have been a matter of debate. The view that this was part of their strategy to control India is perhaps

correct, given the general attitude of all colonizing powers in history of exploiting all instruments of power to retain control. On the other hand, it is equally true that many Englishmen who taught and did research in India had generally very good intentions, often unassailably noble. Striking examples of their direct or indirect involvement are the creation of the Asiatic Society, the Indian Science Congress, various scientific departments or (surveys) of the government, a few first-rate universities, and just before their departure some major research and development establishments like the Council of Scientific and Industrial Research, and other similar councils. Many learned societies were also formed during this period, including the National Institute of Sciences (the present Indian National Science Academy, the country's flagship scientific body), the Indian Chemical Society and the Indian Biological Society.

- Britain had also put in place a strong bureaucracy, administrative and scientific. So when India woke to the daylight of independence, she also woke to a working bureaucracy whose influence in shaping the future was truly inestimable. Bureaucracy is almost a "bad" word in scientific circles, and yet no civilized government can function without it. What one rebels against is a mindless, stratified bureaucracy to which rules and procedures are paramount and not expeditious action, and where precedent is king. In truth, therefore, free India inherited the built-in services of a functioning system that had to be changed, molded and trained to suit the emerging scenario. Not many nations emerging into freedom had such an advantage.
- The existence of an educational system, of a scientific infrastructure, of many educated Indians, of a reasonable means to education, and a legacy of such other infrastructures as the railways, telegraphy, telephony, and an efficient postal system made the planning and execution of new programs during the transition and post-transition periods that much easier. This relieved the new government of the need to create these basic facilities, thus leaving it free to pursue the more pressing aspirations of a resurgent country.
- As implied in Item 1 of this abstract, chemistry was not the ancient Indian scientists' forte as compared to mathematics, astronomy, and physics. However, the chemical industry was perhaps the strongest and most indigenously based among all the industries in British India (with the possible exception of the iron and steel industry). For example, the country had a reasonable base in the fertilizer, textile, pharmaceutical, dyestuff, oils and fats, fermentation, and several small volume chemicals industries. These, superimposed on an extensive base in chemistry, such as it was in quality, gave the NCL and other laboratories of its type the kind of foundation not enjoyed by any other scientific discipline in the country. Many other disciplines have since built up strong foundations of their own, but without comparable head starts.
- Most ancient cultures had strong ties to theory. Vedic science was no exception, although some scholars claim that it was practically driven and practiced not as an elevating science but as a means to accomplish ritual's dictates. This was probably true during the period of torpor to which I have already referred earlier but not during the heyday of science. The priest was no doubt an awesome religious figure but he

was no less a mathematician. There were also others who were not priests and it is they who produced the bulk of ancient Indian mathematics. Against this ancient culture of theory inherited by Indians, they also were heir to a latter-day scientific tradition bequeathed by the British: experimental science. Of all the scientific cultures in the world, no other culture has laid so much store by experimental science as the British. Two of the greatest experimental scientists the world has known, Faraday and Rutherford, were from England (Rutherford was a New Zealander settled in England). Inevitably, thanks to a long period of British rule, some of their taste for experiment had rubbed off on Indians. Although the original roots in theory are perhaps still stronger, one must remember that many of India's more recent discoveries were experimental in nature.

Internalization of Imported Science

Vedic and post-Vedic Indian sciences have left an indelible mark on the neuron firings of the Indian mind. Though submerged in recent centuries by the dazzling advances of Western science, they have created a receptivity in the Indian mind that has had a latent effect on its absorptive and creative capacities. Indian science has much to thank the British Raj, for fostering the re-flowering of this heritage from millennia past. Although centrally controlled organization of a variety of intellectual and artistic pursuits was a feature of the pre-Christian Mauryan empire, particularly under Ashoka, it took on a firmer aspect during the British rule. Quick to grasp and hold on to this rediscovered capacity, the first Indian government under Jawaharlal Nehru made the organization of scientific research for the public good a central edifice of its policy. In the 60 years following independence, much progress has been made. On the whole, we still follow, we do not lead. This deficiency is more a reflection of the lack of a stimulating atmosphere in 90% of the research institutes of India than any intrinsic deficiency in the Indian scientist.

Anyway, as far as the British era science in India is concerned, near total acceptance of Western science was the defining feature in the Hindu–Muslim–British serial continuity of science as a whole in the country. This has been the springboard for the Indian science of today.

> *This is best seen in the attitude to its three greatest imports: democracy, the English language, and modern Western science. For Indians these were not alien ideas to be handled with suspicion but celebrations, which they had to internalize and reinvent for themselves. Indeed, the confidence and openness with which India greeted and scrutinized science constitutes one of the most fascinating chapters in the encounter between science and democracy.*
>
> (Viswanathan, 1998)

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3

FROM BIG HISTORY TO HISTORY
THE RUN UP TO THE BEGINNING

The West, throughout the ages, has accepted intellectual illumination from Eastern repositories of ancient wisdom; more recently, the East has received its guerdon in the benefits of Western Science; the time is approaching when it will become an obligation on the East to return the shuttle of enlightenment.

Martin Onslow Forster, FRS
(Director, Indian Institute of Science, 1922–33)

With the material covered so far, we are done with the big history, and are just a few steps away from the physical beginnings of the NCL. There was a great beginning to the beginning of all science in India over 3,000 years ago, waxing across the night sky but waning at the end, the prelude that brought us to the dawn of the modern day. The run up to the beginning is now upon us — from big history to the history of the CSIR and then the NCL. As we approach it and look back, let us reject any comparison to Rudyard Kipling's miscalling of a city (Madras, recently renamed Chennai) as

The withered bedlame now, brooding on past fame

Quoted in Bannerman, 1915

Past fame there certainly was, but no bedlam now. Indubitably, we are the heirs to some of the first stirrings of science in remote antiquity and successors to a British-inspired Western science of the immediate past, but we have also created scientific competence — even excellence — all its own that boasts of a linear (genetic) linkage with the past but does not rest on past fame.

The NCL has been a major symbol of India's technological resurgence in the field of chemicals, which was thanks chiefly to the vision of the nation's first Prime Minister. Steeped in a long tradition of scholarship and respect for learning, India emerged in 1947, after two centuries of loss of identity and resolved to make science and technology the pillars of its progress within a democratic framework of governance. Prime Minister Nehru was deeply conscious of the role of scientific institutions in the country's overall advancement and often referred to them as temples that held the key to modernization and progress.

One of the first steps taken by the first Prime Minister was to greatly strengthen and accelerate the creation of these "temples" under the aegis of the Council of Scientific and Industrial Research (CSIR), as described later. The first few of these, conceived before he entered office, were the early seeds of what was to grow into the world's largest chain of laboratories (the number now standing at 38, after a period of growth followed by pruning and consolidation).

Science and Technology in Transition

The period of transition from British rule to independence was in many ways the spring-board for India's rise in science and technology. We have already seen in Chapter 2 how several facilities were ripe for sustained development and a few others were on the anvil, all primed for an enthusiastic run to a future of their own making.

A scientific and industrial infrastructure of sorts had been established by the British. Indeed, as will be described below, the CSIR was created a few years before independence but started functioning as a cohesive unit with a few laboratories, including the NCL, under its jurisdiction only immediately after independence. It is therefore relevant to trace the state of the chemical sciences and the chemical industry in India at the time of transition — covering a few years immediately preceding independence and the exciting few years of the first flush of freedom. This will provide a true measure of the evolution of these areas, and the NCL's role in it, following India's emergence as a free nation. Since much of this was covered in the previous chapter as part of examination of the pre-independence state of science and technology, a tabulated summary of the state-at-transition, of the more relevant features of Indian science, education, and industry is presented in Box 3.1.

Box 3.1: The state of education, research and industry at independence

General infrastructure

A working bureaucracy; good postal service, railways, telegraphy, telephony; a fair number of highly educated citizens.

Education

Just about a dozen major universities and colleges including the State Universities of Calcutta (now Kolkata), Madras (now Chennai) and Bombay (now Mumbai), and the Central Universities of Banaras and Allahabad, the Presidency Colleges at Madras and Calcutta, and the Sreerampur College in Calcutta (where chemistry was first taught); Indian Institute of Science, Bombay University Department of Chemical Technology among other major centers of education; engineering education much poorer than in the sciences; the beginnings of University Grants Commission; College of Engineering in Pune, perhaps the most reputed center of engineering education, other centers being Madras (College of Engineering at Guindy), engineering departments at Jadhavpur University, and the chemical engineering section at UDCT; three major agricultural colleges, at Pusa in New Delhi, in Coimbatore, and in Pune; no educational program in atomic energy or space science.

Research

Basic research at Indian Institute of Science in Bangalore, the University College in Calcutta, Indian Association for the Cultivation of Science in Calcutta, the Bose Research Institute in Calcutta, University Department of Chemical Technology in Bombay, and in some of the universities mentioned under Education; some research at the Nizamiah Observatory in Hyderabad, the Kodaikanal Observatory, and the observatory in UP; research in agriculture at the Agricultural Institute at Pusa, the Provincial Agricultural Colleges in

(*Continued*)

Box 3.1: (*Continued*)

Pune and Coimbatore, and the Central Forest Research Institute at Dehra Dun; research in animal diseases at the C.V.D. Institute at Muktesar in UP; medical research at Central Research Institute at Kasauli, and at Institute for Preventive Medicine in Madras; Pasteur Institutes at Parel in Bombay, Shillong in Assam, and Coonoor in the then Madras province; practically no research in engineering.

Scientific institutions

Laboratories maintained by government, such as Astrophysics, Railway, Forest, Medical, Sanitary, Veterinary and Meteorological; other institutes include the Mining Institute at Asansol, the Iron Institute at Jamshedpur, and the Alipore Test House; various surveys such as Geological, Botanical, Zoological, Archaeological, and Trigonometrical, and the Survey of India; the Birbal Sahni Institute of Palaeobotany at Lucknow and the Council of Scientific and Industrial Research in New Delhi (with no functioning laboratories yet), both just started in 1946–7 (although the CSIR was present in different forms since 1902 when it first made its appearance as Board of Scientific Advice); the Indian Museum at Calcutta also active in various fields of science; in the private sector, hardly any with the notable exception of CIPLA in Bombay and Shalimar Paints in Calcutta.

Associations, academies

National Academy of Science, Allahabad; National Institute of Sciences (the present Indian National Science Academy), New Delhi, the flagship academy of the country, first housed in the Asiatic Society Building in Calcutta; the Science Congress Association; the Chemical Society of India; the Physical Society of India; the Biological Society of India, the Royal Institute of Chemistry.

Project engineering companies

Except for some in-house project engineering on a very limited scale, project engineering culture did not exist in the country.

Major discoveries and engineering accomplishments

Raman Effect; Megnath Saha's discovery that the theory of ionization by thermal excitation was a natural extension of what was happening in the sun and other stars; S.N. Bose's discovery of the fundamental class of particles known after him, the boson (the only other being the fermion known after Enrico Fermi), also the Bose-Einstein statistics; Subramanyam Chandrashekhar's comprehensive theory of stellar structure (much of this study was done after he had moved to the USA); J.C. Bose's finding on plant life (still unproved); T.R. Seshadri and K.Venkataraman's studies in natural products chemistry.

The chemical industry

Both organic and inorganic chemical industries were operational, though plants for the latter were generally much larger. On the organic side: petroleum cracker at Digboi in Assam; distillery for potable liquor of Parry and Company in Nellikuppam, Madras; Shalimar Paints, Color and Varnish Company in Calcutta; government Cordite Factory in Aravankadu, Madras; government Armaments Factory in Poona; Alembic Chemicals in Bombay (moved subsequently to Baroda); coal-tar distillation factories in several places, including a major one in Badravati in the then Mysore State; factories for making power alcohol for industrial use and for glycerine for making soap; a prosperous vegetable oil industry, including hydrogenated edible oils known by the brand name *Vanaspati* (familiar to every housewife). Inorganic chemical industries: Sri Shakti Alkali Works at Dhrangadra; Tata Chemicals at Mithapur; Dharamsi Morarji Chemicals near Bombay; Parry and Company at Ennore in Madras; Fertilizer and Chemicals of Travancore (FACT); Associated Cement Companies (ACC); Dalmia Cement Works.

Other industries

The Tata Iron and Steel Company at Jamshedpur and the Indian Iron and Steel Company were two of the most prosperous companies of the time.

The Coming of the CSIR: A Pre-Independence Creation

A CHECKERED BEGINNING

While the CSIR was being conceived and created, India was on the verge of independence. After describing his dream of freedom, the Nobel Prize winning poet, Rabindranath Tagore, wrote *Into such a land of freedom, my father, let my country awake* (Tagore, 1912)

This line from his inspirational poem, written during the first stirrings of India's freedom movement, is equally true of the country's scientific resurgence. For, "India awoke while the world slept" (Jawaharlal Nehru in his first Independence Day oration, referring to the time difference between India and the West). I heard it along with hundreds of other students gathered in the grounds of the College of Engineering at Guindy in Madras, with the loud-speaker blaring out the speech from the top of a pole. (Unlike now, I had good hearing then, and did not need the blare!) It also awoke us to the scientific reality of the time in the country. How this scientific reality, remnants of the mixed blessings of the departing Raj, was systematically transformed into the present infrastructure is a story in itself, with the NCL as part of it. But I am jumping the cart. The seeds of the CSIR were sown as far back as in 1902 when the government created a Board of Scientific Advice. With no clear objectives, this amorphous body managed to last till 1924, when it probably died of studied neglect. Even before its demise in 1915, the Government of India addressed a letter to the Secretary of State (in England) in the following words:

> *After the war India will consider herself entitled to demand the utmost help which the Government can afford to enable her to take a place, as far as circumstances permit, as a manufacturing country.*
>
> Sir Ardeshir Dalal, 1941, *Current Science*

This was accepted by the Secretary of State and soon a body known as the Indian Industrial Commission was set up under the chairmanship of Sir Thomas Holland. This, too, did not last long, for the end of the war led to a languishing interest in the industries that were set up during that time. These industries soon almost ceased to exist, but interest revived with the threat of a new World War. This time, the Indian scientists openly expressed their concern at the lack of any organized industrial research capability in the country. These included Sir J. C. Ghosh in his presidential address to the Science Congress (1939), Colonel Chopra in his presidential address to the National Institute of Sciences in Madras (1940), and Sir M. Visveswarayya in his address to the Indian Institute of Science in Bangalore. The Indian Science Congress also passed a resolution to this effect in 1940.

No single agency was formed for a long time to replace this Commission, but several government and privately funded institutions were created, some of which were the Indian Research Fund Association, the Imperial Council of Agricultural Research, the Indian Central Cotton and Jute Committee in the public sector; and the Indian Association for the Cultivation of Science in Calcutta (referred to previously), the Indian Institute of Science in Bangalore (through a Tata bequest), the Bose Research Institute at Calcutta (through an endowment by Sir Jagadish Chandra Bose), and the Laxminarain Institute of Technology at Nagpur (through an endowment by Raja Bahadur Laxminarain) in the private sector. There was, however, a noticeable absence of any institution devoted to industrial research. This was partly due to the priority differences of the political and scientific leaders of the time. As Rajagopal, Quereshi and Baldev Singh point out:

> *The person responsible for bringing out the desired nexus between political thought and scientific research was none other than Jawaharlal Nehru, the first Prime Minister of independent India.*
>
> Rajagopal et al, 1991

Nehru was an idealist, a man of many parts, in whom the new blended with the old. Bursting with ideas for the India of his dreams, and with the country poised on the threshold of transition, one can verily agree with William Vancey (a leader of the American Confederacy) that *The man and the hour met.*

Thus did modern India make a determined beginning, with science and technology as its strongest pillars, thanks largely to S. S. Bhatnagar (Figure 3.1) Any hesitation at this hour of India's emergence as a free nation would have spelled disaster, for who can doubt that

> *On the plains of Hesitation bleach the bones of countless millions who, at the dawn of Victory, sat down to wait, and waiting — died.*
>
> Attributed to G. W. Cecil as an advertisement in the *American Magazine* of March 1923

Nehru was a firm believer in ushering in the age of science and technology in India. He had a great admiration for scientists in general and for those who changed our understanding of the world in particular. I distinctly recall his visit to the USA in 1949, when I was a student at the University of Wisconsin. Nehru made it a special point to visit Einstein at his home in Princeton. He also visited two universities in the USA: Harvard and Wisconsin. It so happened that his stay was arranged at a hotel in Madison where, as a student, I was working to make a few dollars more! I became an instant celebrity and the chief consultant to the Manager on "the Indian Prime Minister's food habits" (although the Indian Embassy had already contacted the hotel in this matter, instructing them to strictly avoid beef)! I also had the privilege of being a member of a small group of students selected for a discussion with the Prime Minister.

To get back to the CSIR story: in 1938, at the behest of Meghnath Saha, Subhash Chandra Bose, the then President of the Indian National Congress, created a National Planning Committee under the chairmanship of Jawaharlal Nehru. This was the beginning of a major role for science in the planned development of India and the direct involvement of the political leadership of the country. It was also the beginning of Nehru's sustained personal involvement with scientific and industrial research in India.

Coming now to the actual creation of the CSIR, it is interesting to first briefly trace the institutionalization of science in India. With the Second World War in 1939 overshadowing most other considerations, strict economy in expenditure was imposed by the Government of India. Inevitably, the axe first fell on scientific research (a practice that seems to have gained strength with time!). By this time, a Bureau of Scientific Research was in place and

Figure 3.1: Footprints of a new era in India: Indigenous technology development. Top: The beginnings of the NCL (the first CSIR lab) in a temporary cottage. Bottom: Bhatnagar at the NCL's opening

the government decided to abolish it. But, as the saying goes, opportunity arose and the man appeared — at the functional level, as Nehru had at the higher, political level. He was Sir Arcot Ramaswami Mudaliar, the then Commerce Member of the government, a great administrator, and a strong protagonist of science. When a note was put up to him recommending that, as a major step in retrenchment, the Bureau of Scientific Research should be abolished, his response came as no surprise to those who knew him but as a bombshell to those who did not, and was reported by the editor of *Science and Culture* in (mostly) his own (Sir Arcot's) words:

> *Yes, the old Bureau should be abolished not as a measure of economy but to make room for a Board of Scientific and Industrial Research with vaster resources and wider objectives. In wartime no economy can be too disastrous which starves industrial research and no expenditure can be too high which mobilizes the scientific and industrial talent of the country for research and production of war materials.*
>
> Ramaswami Mudaliar, 1943

And so it was that in April 1940 the government set up a Board of Scientific and Industrial Research (BSIR) in place of the old Bureau of Scientific Research. A full report (1940) on the functions of the Board appeared a month later in *Science and Culture*. According to this report:

> *The Board will coordinate the work of the existing organizations already employed in this field … and make recommendations to the government, who will prescribe from time to time the general lines on which industrial research should be undertaken and pursued.* The report then goes on to say that the *Board should be a self-contained department attached to the Department of Commerce and its Advisory Body should be purely scientific and presided over by a distinguished non-official scientist. There may be one or two industrialists in it, but the main body of industrialists should be constituted into a separate board for planning and development.*
>
> *Science and Culture*, 1940

It would appear from the Board's decision that the founding members desired a clear separation between research and its industrial links. This problem was addressed by government a year later in 1941. While the newly created Board functioned quite effectively, it was statutorily not required to forge links with the industry and was hence restricted to solving mainly problems relating to the War and doing non-industrial research. In order to establish an effective link with the industry, the government set up in 1941 an Industrial Research Utilization Committee. This was a high power committee consisting of some of the most outstanding Indians of the day: Sir Ardeshir Dalal, Sir Homi Modi, Sir Sultan Ahmad, Kasturbhai Lalbhai, Sir Syed Mahtab Ali Shah, Sir Rahimtollah Chenoy, Sir Shanti Swarup Bhatnagar, Sir Frederick James, Sir Jwala Prasad Srivastava, Sir Abdul Halim Ghaznavi, and a few others.

Considering the hold of the bureaucracy, it is not surprising that some of the greatest scientists of the day, who were genuinely interested in Indian science and technology, entertained fears that the management of the BSIR would slip into the hands of bureaucrats. This fear was most eloquently expressed by Lord Rutherford of Nelson, Nobel Laureate, in his presidential address to the Indian Science Congress in 1938 (delivered by Sir James Jeans due to the death of Rutherford). Comparing any scientific agency in India to those in England, he said:

> *It is to be hoped that if any comparable organization is to be developed in India, there will be a proper representation of scientific men from the universities and the corresponding institutions and also of the industries directly concerned. It is of the utmost importance that the detailed planning of research should be left in the hands of those who have the requisite knowledge of the problems which require attack.*
>
> Jeans, 2007

This fear was largely addressed by the government when it appointed a combination of scientists and bureaucrats to the Board. Even so, not much was accomplished because of the government's inability to appreciate the magnitude of funding needed for the fledgling scientific agency covering a whole range of sciences. The amount granted was a princely Rs. 5 lakhs, about $ 70,000 using the approximate exchange rate of that period (Dalal, 1941)! Compare this with six million (approximately $ 15 million) spent by Great Britain during normal times before the War, of which one-half was spent on industrial research, and $ 300 million spent by the USA. Apparently India had a consistently unflattering record in research spending, a situation that was largely remedied in more recent times.

If the developments cited above signaled the advent of a centralized scientific authority in India, it should be a sobering thought that we were not the first. The idea of setting up a centralized authority for science and technology first originated in England when a deputation to the government of the Joint Board of Scientific Societies led by Sir J. J. Thompson (discoverer of the electron), Nobel Laureate and President of the Royal Society, resulted in the establishment of the Department of Science and Technology in the UK with the two-fold objective of conducting research on behalf of the government and of introducing a system of cooperative research by which the major industries would be encouraged to form themselves into individual groups, each representing a particular industry, and organize and maintain a research association (see Venkataraman, 1940). Although both these goals are envisaged in India's more recent Department of Science and Technology and the CSIR, the emphasis on the latter is much less. Similar organizations called National Research Councils were established in Canada and Australia.

Also, lest the impression be created that the concept of national laboratories in India was born in the 1940s, although it established its roots during that period, it would do well to recall the little known fact that its seeds were first sown as far back as in 1923, when Sir Mokshagandam Visveswarayya articulated such a concept in his presidential address to the Indian Science Congress that year:

> *Furthermore, an All-India centralized laboratory to help industries is a desideratum. This should be of the type of the National Physical Laboratory of England on which the government spend Rs. 30 lakhs annually. Another model is the Washington Bureau of Standards on which the government of the United States spend over Rs. 18 lakhs per annum. I make this recommendation from a personal knowledge derived by a recent visit to these institutions. Japan has a National Laboratory for Scientific and Industrial Research with a fund of Rs. 75 lakhs intended to be utilized during a period of ten years. Similar institutions exist in Canada and Australia.*
>
> Visveswarayya, 1923

The formation of the Board of Scientific and Industrial Research was a watershed in the country's industrial research. No better description of this momentous event in India's scientific history is possible than through the words of its first chief (then known as the Director but re-designated in 1970 as Director-General), Sir Shanti Swarup Bhatnagar, FRS. When he was asked in 1941 by the then Viceroy of India, Lord Linlithgow (one of the tallest men in India at that time), to take up the post of Scientific Advisor and Director, Scientific and Industrial Research, Bhatnagar's immediate reaction appears to have been mixed, but he did take on the challenge. This is what he said about it in his address at the Inauguration Ceremony of the NCL (1950):

> *When in 1941 I was asked by the then Viceroy Lord Linlithgow (to take up the post of Scientific Advisor and Director, Scientific and Industrial Research), I was hesitant to leave the peaceful cloisters of learning in my University for the maddening hurry and strife of government work.*

> *The request from the Viceroy was, however, a command and the Chancellor of my University told me that no patriotic individual could refuse the call for help in the war effort, as I was expected to make good by the aid of science the shortages of supplies in India and the Middle East resulting from the War. I was still wondering as to what to do when Sir Ramaswamy Mudaliar cornered me in my den in the Punjab University and urged me to accept this office. He assured me that this temporary activity might ultimately result in big developments for scientific research in the country. His statement convinced me that I must leave the university for a larger field to help in building up India's scientific research, training her young scientists and inspiring her young men to take up research as a career not for monetary gain but for the sake of research itself. In that hour when I decided to take up office, I dreamt of a chain of National Laboratories, of large teams of scientists working for the development of India and for the creation of a scientific outlook on life among India's masses. Those who feel that India's ills can be cured by increasing productivity must realize that this can be achieved only by the application of science to its agriculture. I have struggled through the years to fulfill that dream and it seems that it may now come true.*

Bhatnagar's stipulation that he should have his own laboratories for research was accepted by the government. Thus in the early years of his stewardship of the Board, he divided his time between Delhi and Calcutta, where he had his laboratories in the government Testing House, Alipore. Then, following threats of Japanese invasion, his headquarters were fully shifted to the university buildings in Delhi.

The Board of Scientific and Industrial Research was a completely government controlled entity, which was not conducive to good research. Hence on September 26, 1942, thanks again to the foresight of Sir Ramaswami Mudaliar, the government reconstituted it as an autonomous body and renamed it Council of Scientific and Industrial Research (famously known as the CSIR throughout the country and in many parts of the world), and Bhatnagar remained its head. It was registered under the Registration of Societies Act XX1 of 1860. Excerpts from the Commerce Department's resolution moved by Ramaswami Mudaliar and passed by the Legislative Assembly on November 14, 1941, outlining the functions of the CSIR are reproduced below, and the Certificate of Registration issued by the Registrar of Joint Stock Companies on March 12, 1942, is reproduced in Figure 3.2.

From the autobiography of K. A. Hamied, founder of CIPLA, one of India's major pharamecutical companies, it appears that he also had a say in the ultimate formation of the CSIR through his letter to Sir Robert Target, Director-General of Supplies, directly under Ramaswami Mudaliar. He writes:

> *Without Sir S. S. Bhatnagar's untiring energy and flair for promoting industrial research in a big style, these laboratories would not have come into existence or at least not in the gigantic size and manner in which they have been established.*
>
> Hamied, 1972

Excerpts from the Commerce Department resolution are given below:

- *The promotion, guidance and coordination of scientific and industrial research in India including the institution and financing of specific researches.*

Figure 3.2: The CSIR's certificate of registration issued by the Registrar of Joint Stock Companies on March 12, 1942

Certificate of Registration of Societies

ACT XXI OF 1860

No. X of 1941—1942

hereby certify that The Council of Scientific and Industrial Research has this day been registered under the Societies' Registration Act, XXI of 1860.

Given under my hand at Delhi this Twelfth day of March one thousand nine hundred and Forty two.

Fee Rs. 50/- paid.

Sd -
Registrar of Joint Stock Companies,
DELHI.

SEAL

- *The establishment or development and assistance to special institutions or departments of existing institutions for scientific study of problems affecting particular industries and trade.*
- *The establishment and award of research studentships and fellowships.*
- *The utilization of the results of the researches conducted under the auspices of the Council towards the development of industries in the country and the payment of a share of royalties arising out of the development of the results of researches to those who are considered as having contributed towards the pursuit of such researches.*

- *The establishment, maintenance and management of laboratories, workshops, institutes and organizations to further scientific and industrial research and to utilize and exploit for purposes of experiment or otherwise any discovery or invention likely to be of use to Indian industries.*
- *The collection and dissemination of information in regard not only to research but to industrial matters generally.*
- *Publication of scientific papers and a journal of industrial research and development.*
- *Any other activities to promote generally the objects of the resolution.*

September 26 is now celebrated as the CSIR Foundation Day. Bhatnagar lived to see the establishment of a total of 11 laboratories under the CSIR's aegis before his sudden death on January 1, 1955, one day prior to his planned visit to the NCL for what was rumored to be a crucial meeting with the then Director, Prof. Finch (see Chapter 6). This number steadily rose and was at 42 at its peak. A number of branches and regional centers were also established for some major laboratories, such as for the Central Leather Research Institute and the Central Electrochemical Research Institute. [The NCL consistently resisted any attempt to establish centers, but did accept part of the responsibility for running the Mechanical Engineering Research and Development Organization (MERADO), a regional center of the Central Mechanical Engineering Laboratory — see Box 3.2.] In an attempt to consolidate these centers, a committee was appointed by the then Director-General, G. S. Sidhu, with Doraiswamy as Chairman, to make appropriate recommendations. A small part of these recommendations was implemented; otherwise the report went the way of many of its kind, into the storage rooms of the CSIR — largely because of changes in its leadership. More recently, however, the last Director-General, R. A. Mashelkar, reviewed the functions and workings of all the laboratories and centers and closed down some of them. He consolidated them to a total of 38: 11 in 1955 to 42 and finally, to 38 in 2002. The names and locations of all the present laboratories are shown in Figure 3.3 and Box 3.2 lists their functions along with one major accomplishment of each.

SOME MAJOR EARLY DECISIONS

Important decisions regarding rules, administration, new laboratories, lines of authority, etc. were taken at several crucial meetings of the Governing Body. The matters brought before the body and the decisions taken at the October 1942, March 1944, September 1945, and January 1946 meetings are particularly relevant to the theme of this book; some of them are described below:

- Choice of site for laboratories never ceased to stimulate discussion. Political considerations and regional biases were not the least of factors. For instance, when the choice of site for the NPL came up for discussion, the Maharashtra Chamber of Commerce advocated Bombay while Dr. B. C. Roy, a well known physician-politician of Bengal, lobbied strongly for Calcutta. Delhi, the site finally chosen, was perhaps not the best, being too close to the centers of power and politics, but has managed to do well as a site for more than one laboratory.

- It was agreed that industrialists could donate money to the CSIR with the expectation, but no guarantee, that a laboratory would be located at a place of their choice.
- By 1953, the office of the CSIR had moved into its present premises. The opening ceremony was performed by Education Minister Maulana Abul Kalam Azad in January 1953.

Figure 3.3: Names and locations of all the present laboratories of the CSIR

(*Continued*)

Figure 3.3: (*Continued*)

AMPRI	Advanced Materials and Processes Research Institute Bhopal-462 026, www.ampri.res.in
CBRI	Central Building Research Institute, Roorkee-247 667 www.cbri.org
CCMB	Centre for Cellular and Molecular Biology Hyderabad-500 007, www.ocmb.res.in
CDRI	Central Drug Research Institute, Lucknow-226 001 cdriindia.org
CECRI	Central Electrochemical Research Institute Karaikudi-623 006, www.cecri-india.com
CEERI	Central Electronics Engineering Research Institute Pilani-333 031, www.ceeri-res.in
CFTRI	Central Food Technological Research Institute Mysore-570 020, www.cftri.com
CGCRI	Central Glass and Ceramic Research Institute Kolkata-700 032, www.cgcri.res.in
CIMAP	Central Institute of Medicinal & Aromatic Plants Lucknow-226 015, www.cimap.res.in
CIMFR	Central Institute of Mining & Fuel Research Dhanbad-828 108, www.cimfrindia.nic.in
CLRI	Central Leather Research Institute, Chennai-600 020 www.clri.com
CMERI	Central Mechanical Engineering Research Institute Durgapur-713 209, www.cmeri.org
CRRI	Central Road Research Institute, New Delhi-110 020 www.crridom.org
CSIO	Central Scientific Instruments Organisation Chandigarh-160 030, www.csio.nic.in
CSMCRI	Central Salt & Marine Chemicals Research Institute Bhavnagar-364 002, www.csmcri.org
IGIB	Institute of Genomics & Integrative Biology Delhi-110 007, www.igib.res.in
IHBT	Institute of Himalayan Bioresource Technology Palampur-176 061 (HP), www.ihbt.org
IICB	Indian Institute of Chemical Biology Kolkata-700 032, www.iicb.res.in
IICT	Indian Institute of Chemical Technology Hyderabad-500 007, www.iictindia.org
IIIM	Indian Institute of Integrative Medicine Jammu-180 001, www.iiim.org
IIP	Indian Institute of Petroleum, Dehradun-248 005 www.iip.res.in
IMMT	Institute of Minerals and Materials Technology Bhubaneshwar-751 013, www.rribhu.res.in
IMTECH	Institute of Microbial Technology, Chandigarh -160 036 www.imtech.res.in
IITR	Indian Institute of Toxicology Research Lucknow-226 015, www.itrcindia.org
NAL	National Aerospace Laboratories, Bangalore-560 017 www.nal.res.in
NBRI	National Botanical Research Institute Lucknow-226 001, www.nbri-iko.org
NCL	National Chemical Laboratory, Pune-411 008 www.ncl-india.org
NEERI	National Environmental Engineering Resarch Institute Nagpur-440 020, www.neeri.nic.in
NEIST	North-East Institute of Science and Technology Jorhat-785 006, www.rrijorhat.org
NGRI	National Geophysical Research Institute Hyderabad-500 007, www.ngri.org.in
NIO	National Institute of Oceanography, Goa-403 004 www.nio.org
NIIST	National Institute for Interdisciplinary Science and Technology, Thiruvananthapuram-695 019 www.niist.csir.res.in
NISCAIR	National Institute of Science Communication And Information Resources, New Delhi-110012 www.niscair.res.in
NISTADS	National Institute of Science Technology And Development Studies, New Delhi-110012 www.nistads.res.in
NML	National Metallurgical Laboratory, Jamshedpur-831 007 www.nmlindia.org
NPL	National Physical Laboratory, New Delhi-110 012 www.nplindia.org
SERC	Structural Engineering Research Centre Chennai-600 113, www.sercm.org

Source: CSIR booklet 2009.

- A decision was taken to send scientists from the NCL, the NPL, and other laboratories for training abroad. Provision was also made for granting study-leave to scientists. These may sound unimportant, almost trite, in the context of the dramatic changes in today's rules, but they were quite groundbreaking for their time.
- A tentative budget for establishing the NCL was approved.
- A suggestion by M. N. Saha was accepted that the rules ought to indicate that the chief executive officer of the Council of Scientific and Industrial Research should not

Box 3.2: List of CSIR laboratories (year of establishment and one significant/impact making outcome)

SI No.	*Laboratory*	*Year*	*Significant outcome*
1.	Central Building Research Institute (CBRI), Roorkee	1953	Diverse types of pile foundations, especially for sandy soils and low cost housing
2.	Center for Biochemical Technology (CBT), New Delhi renamed as Institute for Genomics & Integrative Biology (IGIB) in 2003	1966	Genomic mapping of Indian population and bioinformatics
3.	Center for Cellular & Molecular Biology (CCMB), Hyderabad	1977	DNA fingerprinting
4.	Central Drug Research Institute (CDRI), Lucknow	1951	Development of new drugs and generating human resources for pharma industry
5.	Central Electrochemical Research Institute (CECRI), Karaikudi	1953	Titanium anodes for chlor-alkai industry
6.	Central Electronics Engineering Research Institute (CEERI), Pilani	1953	High power microwave devices and instrumentation for defence
7.	Central Food & Technological Research Institute (CFTRI), Mysore	1950	Infant food formulation – Amul from buffalo milk, mini *dal* (pulse) mills, neutraceuticals and human resources for industry
8.	Central Fuel Research Institute (CFRI), Dhanbad	1950	Flow sheet of coal washeries
9.	Central Glass & Ceramic Research Institute (CGCRI), Kolkata	1950	Optical glasses (now radiation shielding glass) for atomic energy
10.	Central Institute of Medicinal & Aromatic Plants (CIMAP), Lucknow	1959	Menthol hybrid varieties
11.	Central Leather Research Institute (CLRI), Chennai	1953	Greening of the leather industry & human resources development for Indian, SE Asian & African countries
12.	Central Mechanical Engineering Research Institute (CMERI), Durgapur	1958	Wholly indigenous 12 HP tractor
13.	Central Mining Research Insitute (CMRI), Dhanbad	1955	Mine roof support systems
14.	Central Road Research Institute (CRRI), New Delhi	1952	Road and traffic planning, highway engineering
15.	Central Scientific Instruments Organisation (CSIO), Chandigarh	1959	Optic, Opto and medical electronic devices
16.	Central Salt & Marine Chemicals Research Institute (CSMCRI), Bhavnagar	1954	Reverse osmosis membranes and water purification technologies
17.	Indian Institute of Chemical Biology (IICB),[@] Kolkata	1956 (1935)	Physical and genetic mapping of the cholera virus and development of oral vaccine
18.	Regional Research Laboratory, renamed Indian Institute of Chemical Technology (IICT),[@] Hyderabad	1956 (1944)	Process know how for several pesticides and generic drugs
19.	Indian Institute of Petroleum (IIP), Dehradun	1959	Extraction of benzene and toluene through solvent extraction of naphtha and several technologies for petroleum refining
20.	Institute of Microbial Technology (IMTECH), Chandigarh	1984	Process for Urokinase and Streptokinase

(*Continued*)

Box 3.2: (*Continued*)

SI No.	*Laboratory*	*Year*	*Significant outcome*
21.	Indian National Scientific & Documentation Center (INSDOC),* New Delhi	1952	National Science Library & National Union Catalog of Scientific serials in India
22.	Industrial Toxicology Research Center (ITRC), Lucknow	1965	Toxicological map of India
23.	Institute of Himalayan Bioresource Technology (IHBT), Palampur	1983	Rejuvenation of green tea cultivation in HP, essential oils and technology for Stevia
24.	National Aerospace Laboratories (NAL), Bangalore	1959	Design, development, fabrication and testing of civil air-craft & research support to national aerospace programmes
25.	CSIR Center for Mathematical Modelling and Computer Simulation (C-MMACS), Bangalore	1988	Algorithms for evaluating sea-surface temperatures and climate modelling
26.	National Botanical Research Institute (NBRI), Lucknow	1953	New cultivars of ornamental plants: gladioli, chrysanthemum and bouganvillae
27.	National Chemical Laboratory (NCL), Pune	1950	Zeolite based novel catalysts for xylenes isomerization ethylbenzne and several other petrochemical/organic processes
28.	National Environmental Engineering Research Institute (NEERI), Nagpur	1958	Common effluent treatment technologies
29.	National Geophysical Research Institute (NGRI), Hyderabad	1961	Integrated geophysical surveys for location of hydrocarbons, 2D and 3D modeling of seismic structures
30.	National Institute of Oceanography (NIO), Goa	1966	Survey and location of polymetallic nodules in the Indian Ocean
31.	National Metallurgical Laboratory (NML), Jamshedpur	1950	Characterization and processing of iron ores, flow sheet for phosphatic and copper plants
32.	National Physical Laboratory (NPL), New Delhi	1950	National Metrology Institute at par with counterparts world over
33.	Publications Information Directorate (PID),* National Institute of Science Communication (NISCOM), now National Institute of Science Communication and Information Resources (NISCAIR), New Delhi	1951	Wealth of India, now Traditional Knowledge Digitial Library (TKDL)
34.	National Institute of Science, Technology and Development Studies (NISTADS), New Delhi	1981	History, sociology and philosophy of science & technology
35.	Regional Research Laboratory (RRL), Bhopal	1981	FRP gear casing for locomotives & fly ash based wood substitutes; materials from waste
36.	Regional Research Laboratory (RRL), Bhubaneswar	1964	Processing of low assay nickel ores and mineral benefaction technology
37.	Indian Institute of Integrative Medicine (IIIM)	1957	Terpeniols, citronellol and bioenhancers
38.	North East Institute of Science and Technology (NEIST)	1961	Low capacity vertical shaft kiln for cement, argrotechnolgy & processing of citronella
39.	National Institute of Interdisciplinary Science and Technology (NIIST)	1978	Small capacity palm oil mills, technology for titanium sponge, smart materials

(*Continued*)

SI No.	*Laboratory*	*Year*	*Significant outcome*
40.	Structural Engineering Research Center (SERC), Ghaziabad**	1965	Instrumentation & monitoring integrity of bridges
41.	Structural Engineering Research Center (SERC), Madras (Chennai)	1965	Analysis and design of long and tall structures

* PID & INSDOC merged into a single entity: National Institute of Science Communication and Information Resources (NISCAIR), New Delhi, in 2002.

** Closed since 2001

@ These laboratories were set up in the year given in parentheses but acquired by CSIR in the year mentioned.

be in charge of any of the laboratories, each of which should have its own director. The CEO should keep watch over their activities according to directions given by [the] CSIR. *This statement is unique for two reasons:*

(1) It would seem to indicate that the suggestion for a director being in charge of a laboratory came for the first time at that meeting and that it was not a self-evident fact.

(2) The reference to the head of the CSIR as CEO and not director (or director-general as modified later) came as far back as 1942 and is historically significant. I have not researched this matter, but it is almost certain that it never surfaced again till a more recent Director-General (R. A. Mashelkar) promoted the use of CEO in place of Director-General. The contexts were different but the use of an industrial terminology for the head of a research organization (conglomerate, one might say) by two people separated by 60 years is a remarkable coincidence.

- A suggestion by J. C. Ghosh that the CSIR constitute an Advisory Board for each laboratory was almost the beginning of the latter-day Scientific Advisory Committees/ Executive Councils/Research Advisory Councils/Research Councils of the national laboratories. (Details of these Councils for the NCL are given in Chapter 13).
- A selection committee of the CSIR under the chairmanship of C. Rajagopalachari selected, in 1946, Syed Hussain Zaheer as the second in order of preference for a post of Assistant-Director in the NCL. Zaheer did not join the CSIR then, but went on to become the Director-General in 1962.[1]

THE NEHRU-BHATNAGAR ELEVEN AND THE NEHRU-BHATNAGAR EFFECT

Following this early period came the Nehru era when, as Prime Minister, he also became the President of the CSIR. The growth of the organization during his overall stewardship, particularly during the early years when Bhatnagar was DG, was phenomenal. His commitment to science and to scientific development as the means of improving the lot of his people was immense. Eleven laboratories were in place by the time of Bhatnagar's sudden death. As his formidable initiatives and Nehru's outright support were responsible for creating most of them, the laboratories were nicknamed "The Nehru-Bhatnagar Eleven" borrowing a popular term from cricket (Rajagopal, Quereshi, and Baldev Singh, 1991).

(I also understand, with no confirmatory details, that whenever Bhatnagar wanted a new laboratory, all he had to do was convince the Prime Minister, no difficult task considering his great personal commitment to science, and the rest was mere formality.) Extending the analogy to include a wider range of accomplishments, this time borrowing a scientific term from Raman's researches, the effect of these accomplishments on the CSIR was called the "Nehru-Bhatnagar Effect" (Rajagopal, Quereshi, and Baldev Singh, 1991). (The various changes introduced in the CSIR have been succinctly summarized by the same authors.)

When Bhatnagar attained the age of superannuation, he was requested to continue as Director of the CSIR but without the rank of Secretary to the Government which he had till then enjoyed. In a moving letter to Nehru, he wrote that only a scientist should be in overall charge of scientific research and that he could not accept the division of scientific and administrative roles, only the latter enjoying the rank of secretary. He therefore requested that he be fully relieved of all his responsibilities. At the GB meeting at which this was considered, Nehru said that he would like to think about it, but before a decision could be taken, the live-wire of Indian science was dead. So ended a colorful era, one that gave the CSIR content and uniqueness and will be most remembered by scientists all over the country.

The CSIR had several DGs following Bhatnagar's death (Box 3.3):

> M. S. Thacker (the suave gentleman, consolidator, head of the CSIR family as he always called himself), Atma Ram (a good technologist but who did not leave any permanent mark and who was largely perceived to be negative), Hussain Zaheer (the pro-worker DG with an aristocratic bearing, who introduced several changes), A. Ramachandaran (who did not stay long, but was known for his quick decisions), M. G. K. Menon (an analyst to whom perfection lent its own problems), Y. Nayudama (an enthusiastic administrator, in the mold of Zaheer), G. S. Siddhu (the ever courteous scientist to whom helping the CSIR scientists

Box 3.3: The Directors-General of the CSIR and their tenures

S.No.	*Name*	*From*	*To*
1.	S. S. Bhatnagar*	1942	1954
2.	M. S. Thacker	August 1955	July 1962
3.	S. Hussain Zaheer	September 1962	August 1966
4.	Atma Ram	August 1966	August 1971
5.	Y. Nayudama	August 1971	July 1977
6.	A. Ramachandran	July 1977	September 1978
7.	M. G. K. Menon	September 1978	April 1981
8.	G. S. Sidhu	May 1981	April 1984
9.	S. Vardarajan	June 1984	January 1986
10.	A. P. Mitra	February 1986	April 1991
11.	S. K. Joshi	April 1991	June 1995
12.	R. A. Mashelkar	July 1995	December 2006
13.	M. K. Bhan and T. Ramaswami (acting)	January 2007	November 2007
14.	S. K. Brahmachari	November 2007	Till date

* The first head of the CSIR was designated director, CSIR. The designation director-general came later.

was paramount), S. Varadarajan (the ever busy and fully committed DG who took personal interest in the most important event of his time, the Bhopal accident), A. P. Mitra (the first active pure scientist to head the CSIR who gave basic research a status), S. K. Joshi (a fine gentleman and an outstanding scientist to whom the entire CSIR was one huge laboratory), and R. A. Mashelkar (an outstanding scientist administrator who ushered in the culture of patenting as well as professionalism in CSIR), and Professor Brahmachari, the first biologist to head the CSIR with a fresh agenda for the transformation of CSIR. All of them have left their own imprints on the CSIR, but this is not the occasion to describe them. I would however like to briefly touch upon a major accomplishment of Mitra a little later in this section.

SUMMARY OF MAJOR CHANGES IN THE CSIR

Some important decisions of the Nehru era are listed below:

- In an attempt to eliminate rank and hierarchy among scientists, Zaheer abolished designations such as junior scientific officer, senior scientific officer, assistant-director, etc., and replaced them with one uniform designation, Scientist. Different levels were indicated by A (lowest), B, C, and so on, but these were for internal administrative purposes only. Unfortunately, Zaheer had not reckoned with the Indians' penchant for rank, for Scientist, A, B, C soon became as much a mark of position as the displaced designations. A position of scientist G was created to promote deserving scientists to the rank of a director and and was also called "scientist in the director's grade." When the level of director was elevated recently, one more level — H— was created.
- Zaheer also created a system of promotions after every five years or so. This did away with the need for the existence of a higher-level vacancy for any promotion to occur. Thus any number of scientists could be promoted if a suitably constituted selection committee so recommended. The system has stood the test of time, although the laboratories are becoming increasingly top-heavy.
- Several review committees were appointed from time to time to assess the performance of the CSIR and to make recommendations for improvement. The committees which go by the names of their chairmen are listed in Chapter 13.

In addition to the above, over the years, the CSIR introduced many changes to its functioning, which set it apart from the routine functioning of the government in general. To mention a few: administrative changes were made to attract and retain talent; the CSIR's role in the country's industrial development was modified to be in tune with the changing world scene; the role of bureaucracy was reduced; autonomy to individual laboratories was extended; modern job-oriented accounting practices were introduced; salaries were increased and also promotion opportunities (through personal promotion even when a higher position did not exist); and promotions and appointment to senior positions were centralized in the interest of uniformity. In addition to these, more freedom was given to directors in awarding contracts for high-quality constructions thus enabling modern sophisticated laboratories to be built; rules for collaboration and partnership with industry were relaxed; collaboration with overseas firms including multinationals was encouraged;

consultation fee limits for scientists were removed; foreign trips were made easier; and sitting fees were paid to top scientists to encourage them to accept memberships of senior management committees.

These changes in rules and procedures introduced over two to three decades loosened the bureaucratic shackles of the CSIR, thus making it almost — but not quite — competitive with the more forward looking companies of the country. Bureaucracy, as the father of a former colleague of mine, who was a senior bureaucrat in the Government of India, told me on one occasion, encourages its members to just "get on" (meaning no imaginative decisions are taken), but added in a matter-of-fact tone, with no particular justification:

They first get "on"
Then get "oner" (honor)
And finally get "onest" (honest)

Hussain Zaheer in the earlier years and Mashelkar in more recent years were perhaps the two Directors-General most responsible for these changes.

THE POWER OF A SIMPLE CONJUGATIVE

A. P. Mitra was the strongest supporter of basic research the CSIR has had. He had voluminous compendia of basic research in different fields in the organization prepared during his term. These volumes throw light on the breadth and depth of basic research at the CSIR, which are indeed very impressive, and to this day remain the strongest evidence in print of it's basic research accomplishments till the mid-1980s.

Mitra deserves a great deal of credit for restoring and strengthening basic research at the CSIR. The difference between his approach and the more recent approach of Mashelkar, each with its own merits, lies in the single word *and* Mitra would have the CSIR read as Council of Scientific *and* Industrial Research, while Mashelkar would have it as Council *of* Scientific Industrial Research. Mark the power of a simple harmless conjugative!

It is doubtful if either of these points of view has fully prevailed. As most other non-scientific things in science, it perhaps never will. As far as the NCL was concerned, it appears to me that the laboratory showed no particular preference, and the ambiguity continues merrily.

POLITICAL AND ADMINISTRATIVE SUPPORT

Indian science has had the good fortune of strong political support ever since independence — and even during the later decades of the British rule. Political stalwarts like Jawaharlal Nehru, C. Rajagopalachari, Shyama Prasad Mukherjee, Maulana Abul Kalam Azad, Humayun Kabir, Nurul Hasan, B. G. Kher, and many others recognized the importance of science in the development of the country. It also had the support of many great administrators and industrialists, such as Sir Ramaswami Mudaliar, Sir Ardeshir Dalal, Sir Akbar Hydari, J. R. D. Tata, P. A. Narielwala, Darbari Seth, Arvind Mafatlal, and many more.

The attachment to science of all these political and administrative leaders, who helped shape the country's scientific future, comes across very clearly in their speeches and writings. I quote a few:

- Jawaharlal Nehru, in a message to the Royal Institute of Science on the occasion of its Silver Jubilee:

  Of all the big problems that face India today, nothing is more important than the development of scientific research, both pure and applied, and the scientific method…We have to fill this gap rapidly and on an extensive scale, and at the same time efficiently.

  Singh, 1986

  His commitment to science was not just that of his government but deeply personal. This is what he said at the first meeting of the CSIR Governing Body after independence presided over by him in 1947 (the Prime Minister of India had just been named statutory president of the Governing Body):

  I have placed scientific research under my personal charge. However, I have no desire to interfere in scientific research and wish to be closely associated with it and help in its promotion.

  National Chemical Laboratory of India, 1947

- Chakravarti Rajagopalachari (1947) (the last and only Indian Governor-General to hold that title, for the period between independence and establishment of India as a sovereign republic) (Note: This was the last meeting of the pre-independence CSIR. The next meeting was presided over by Jawaharlal Nehru, India's first Prime Minister, and a new chapter began in Indian science and technology):

  The present Government of India is extremely partial to scientific research. I hope the several national laboratories which are now in the course of establishment will soon grow up and make use of this and put India prominently in the map of science in the world beyond all doubt or cavil.

  National Chemical Laboratory Of India, 1947

  He then went on to advise the scientists, probably only half in jest, on how to cope with invincible government rules:

  I hope you scientists will look upon us as one of those many natural forces you have to cope with. You have to deal with friction, you have to deal with heat, you have to deal with all sorts of things in this physical world and you may treat Government as one of these difficulties you have to overcome…You will have to make friends of all your difficulties including your Member-in-Charge [equivalent to the minister of these days] *and the Finance Department also.*

  National Chemical Laboratory of India, 1947

  If there was a twinkle in his eyes, it probably was not missed!

PLACING THE CSIR AND NCL IN CONTEXT

With its nearly 40 laboratories under its jurisdiction, the CSIR represents a vast chain of laboratories covering practically all important fields of science, but not quite all. Several large areas such as space, atomic energy, medicine, and agriculture are not represented in the chain. Besides the CSIR, several other laboratory systems were built up by the Nehru (and subsequent) government(s). Thus the CSIR can be regarded as just one among many chains or collections of science-based agencies or institutions. I say science-based because some of them are not laboratories but repositories of scientific knowledge in specific areas, collecting and disseminating information. The CSIR has the largest number of laboratories within its jurisdiction but atomic energy and space are much better funded, particularly the former, as indicated below:

Annual budgets (2005–06) in Rs. (crores or 10^7) of various departments/agencies/councils:

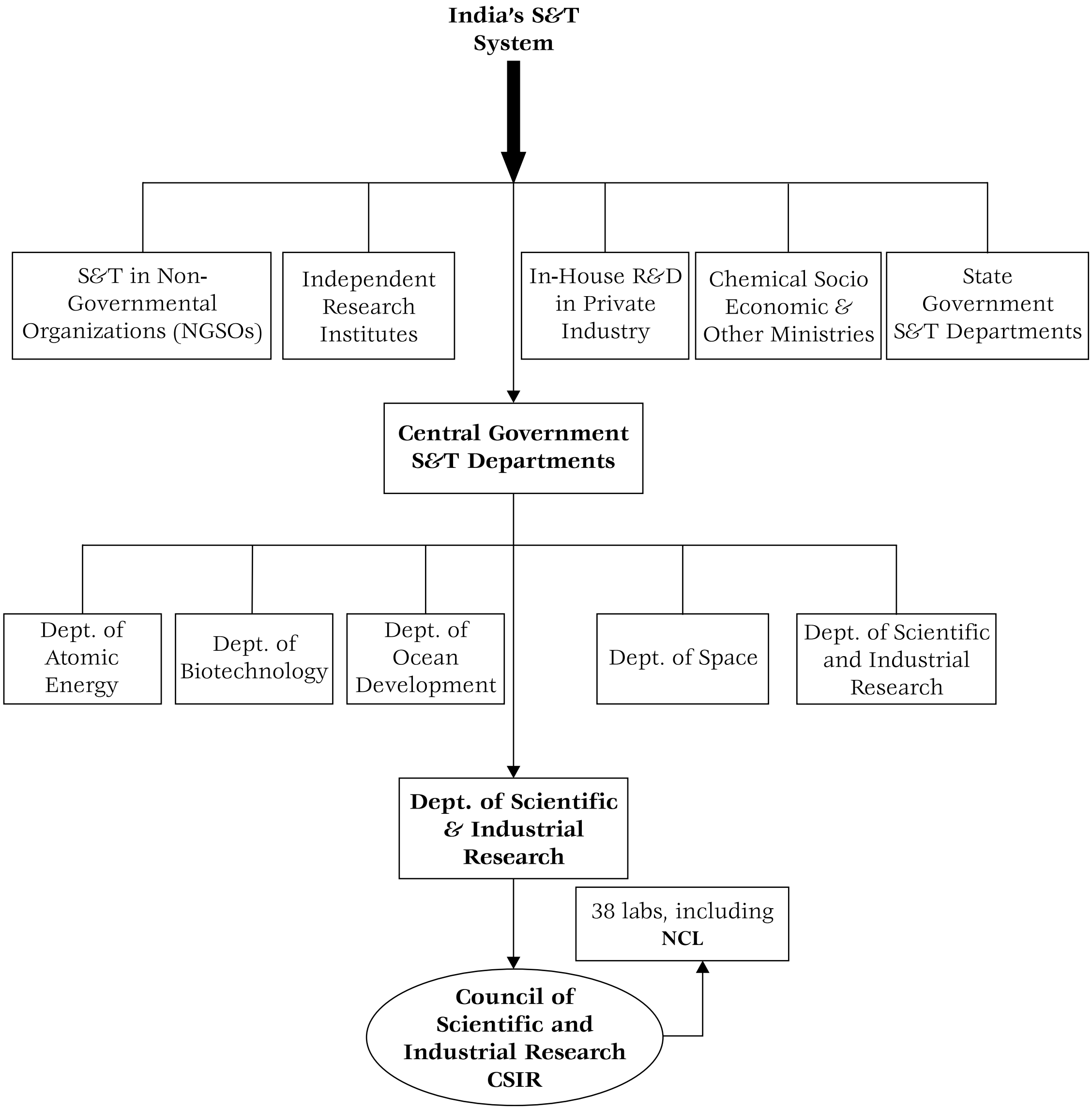
Council of Scientific and Industrial Research: 1503
Department of Atomic Energy: 6689
Department of Space: 3148
Department of Science and Technology: 1668
Indian Council of Agriculture Research: 1897
Indian Council of Medical Research: 231

Figure 3.4 attempts to present the various science-based institutions of the government in terms of the overall S & T system in India, and Figure 3.5 presents a selection of important ministries, departments, agencies, councils, and laboratories. The number, designation, and ministry-level placement of some of these institutions depend on the disposition of the government in place, but the changes are usually not of a drastic nature. Figures 3.4 and 3.5 are based on the information available for the year 2005, in particular the department of Science and Technology website (see References).

The CSIR has a character of its own that has attracted criticism as well as admiration. It is home to both basic and applied research and tends to foster a culture that is a unique blend of the academic and industrial cultures. The two cultures being disparate, it can well be imagined that the CSIR was constantly under criticism from one side or the other. But it has never wavered from its determination to never dilute this double role. Its performance is under constant review and changes in its functioning are being regularly introduced. In spite of its fixity of purpose, there is no such invariance in its style of functioning, which has been dictated as much by the vision of its chiefs as by the prevailing political dispensation. It is therefore instructive to place this unique scientific agency in context in the country's scientific and industrial development.

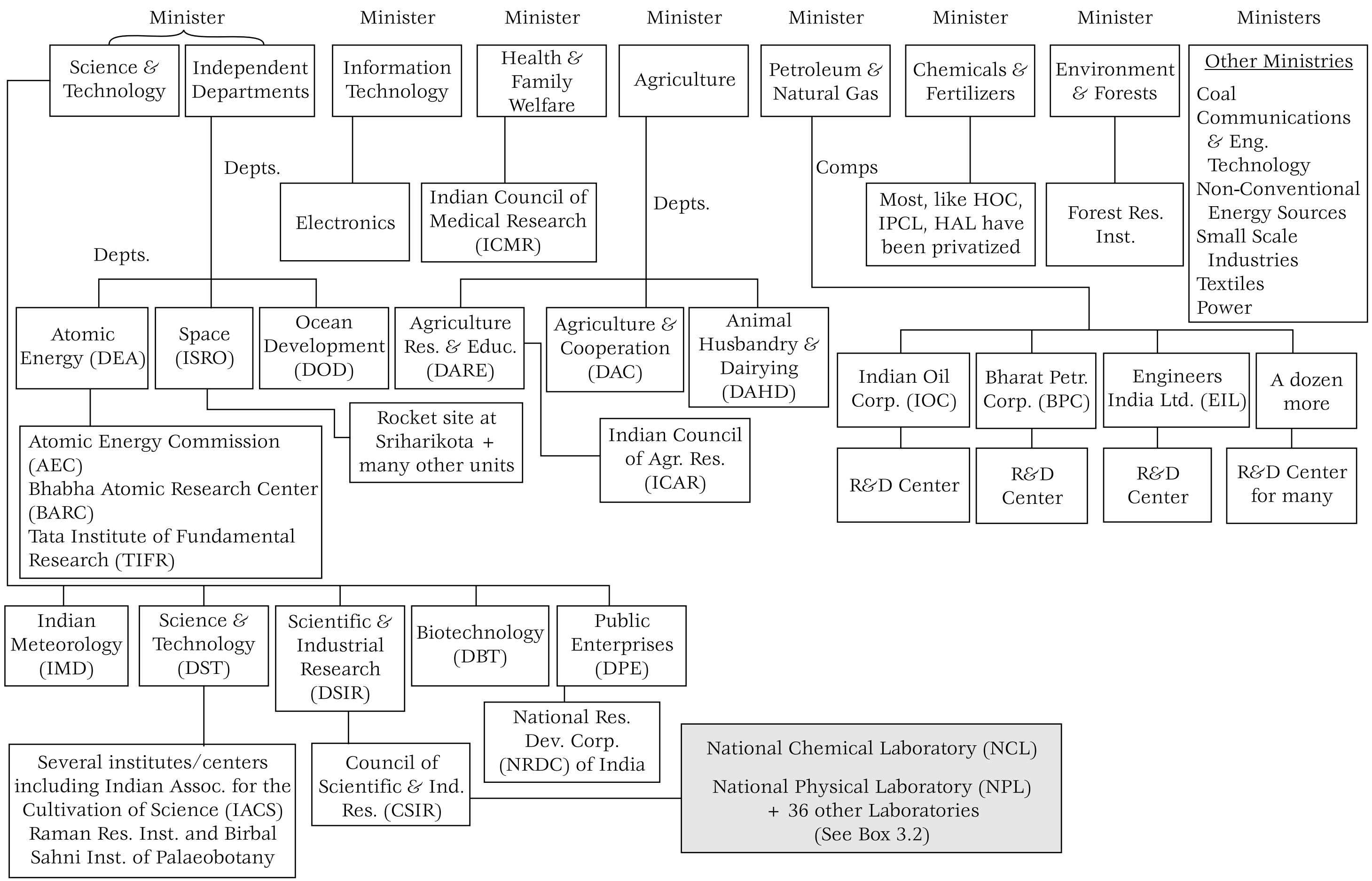
- G. Thyagarajan, the lone CSIR scientist to have had the privilege of heading three of its laboratories at different times — the RRL (Jorhat), IICT (Hyderabad), and CLRI (Chennai) — drew attention to the CSIR's role in national life by using in his Foundation Day Lecture at the NCL (2005), the famous promotional lines of the erstwhile Burmah-Shell Company: *CSIR in India's life and part of it* (*Business Standard* 2007:14).[2] How true and how beautifully adapted! This is a distinction no other scientific agency in India enjoys.
- While placing the CSIR in context, a particularly important fact should be kept in mind. This fact is so central that any comparison of the CSIR with organizations

Figure 3.4: India's Science and Technology (S & T) system



like atomic energy and space becomes almost meaningless. The CSIR is required to develop and transfer technology to both private and public sectors in competition with other technology generating agencies, including those from abroad. Atomic energy, space and agriculture are under no such obligation. They manufacture what they develop, they test and commission and put into use what they develop. If the experiment fails, the government bears the brunt of the loss. Obvious and necessary as these features are of the CSIR on the one hand and atomic energy and space on the other, the spin-offs of this situation are usually not fully realized. Some of them are:

Figure 3.5: The various ministries and their science/industry connections



- Cost is not a consideration for the AEC, ISRO, and Defense, and other national considerations, not excluding national pride, are paramount issues. Occasionally questions are asked in parliament concerning expenses and results but there is seldom a lengthy debate and even the media tend to be reasonably quiet on this issue. On the other hand, where the CSIR is concerned, the media have largely been critical, except in more recent years when a forceful PR drive and successful information dissemination have blunted the criticism. Further, the CSIR's initiatives (largely Mashelkar's) have resulted in patent issues concerning *basmati* rice and turmeric, unfairly claimed by certain parties in USA, being resolved in India's favor. This has led to a greater appreciation of the CSIR's power that had remained somewhat dormant in the earlier years. Notwithstanding all this, comparisons persist, rarely to the organization's advantage.
- The accomplishments of the AEC and ISRO tend to show lightening peaks that are spectacular and cater to the national pride. The CSIR's accomplishments are spread out more evenly — for instance, the lowering of the cost of production of a major item of commerce, the discovery of a new product or the production of a machine/tool indigenously does not produce even a minor ripple. The public and the media are unmindful of all the failed attempts to send up a satellite or implode a nuclear device as long as even one succeeds, but is not so forgiving with failed CSIR technologies.
- The scientific spectrum of the CSIR is very wide and encompasses subjects varying from molecular biology and nanotechnology to aeronautics and mining (see Box 3.2), unlike the AEC and ISRO, where the areas are more limited. This makes it easier for these organizations to earmark more funds for fewer laboratories/projects.
- The CSIR is under increasing pressure to earn its own keep. The move to a free market economy has affected the organization much more than it has the ISRO or AEC, which continue to be funded by the government at almost the same level as before the globalization era. This shift to globalization brought in its wake for the CSIR its own features that make it difficult to concentrate on indigenous technology development of a high order, as was done in the case of Encilites at the NCL in the pre-globalization era.
- Any accomplishment of the CSIR is usually downplayed by the assertion that it is "old hat" and that other countries did it long ago. Similar assertions are notably absent while lauding the accomplishments of the AEC or ISRO although they are also "old hat" — older, because of the speedier developments in these areas.

And Now to the NCL (The Small History Begins)!

On this plateau will soon begin the construction of one of the finest laboratories which our architects have planned...The laboratory with its buildings and residential quarters and the surrounding rural sources of supply will make a new suburb of this historic town.

C. Rajagopalachari
The last Governor-General of India
at the NCL's Foundation Stone Laying Ceremony
National Chemical Laboratory, 1947

CHEMISTRY LAGGED BEHIND PHYSICS IN INDIA

Bhatnagar, in his desire to create a series of laboratories spread throughout the country, decided to establish 11 laboratories in the first instance. This list included the National Physical Laboratory at New Delhi and the National Chemical Laboratory at Pune. The first practical seeds of these two bedrock laboratories of the CSIR were sowed at the first meeting of the Board of Scientific and Industrial Research, in April 1940 under the chairmanship of Ramaswami Mudaliar. From the NCL's point of view, the following minutes of the meeting are perhaps the most relevant, for they marked its embryonic beginning:

> [It is necessary to establish] *a National Physical Laboratory to standardize all instruments and meters used in commerce and industry, as well as to organize researches which require far costlier equipment than a normal university laboratory is expected to possess. In addition to the above, there are needs for a National Chemical Laboratory possessing both analytical and development sides.*
>
> National Chemical Laboratory, 1947

If one sensed in this a trace of partiality towards the National Physical Laboratory (NPL), one is probably right, since physics had reached a high point in India, thanks to the researches of C. V. Raman, K. S. Krishnan (who later became the first Director of the NPL), S. Bhagavantam, D. S. Kotahri, and many others in the field of molecular physics. There were no equivalent names or achievements in chemistry. More specifically, a review by Oza of Indian publications in chemistry during that period and the years immediately following independence, throws a decidedly unflattering light on the quality of chemical research in India. P. Ray, a well known inorganic chemist of that time, had this to say:

> *The standard of Indian publications, both qualitatively and quantitatively, lies far behind even that of the tiny countries like Switzerland and Holland.*[3]
>
> National Chemical Laboratory, 1947 (Quoted in Oza, 1958)

Indeed, it is a measure of India's standing in chemistry as compared to physics at that time that the first two directors of the NCL had to be selected from outside the country, while NPL did not have to look beyond the country's borders for leadership.

Sometimes, administrators with a genuine interest in science are also apt to hold views that can at best be described as strange, and based largely on expediency. While one should be extremely thankful for their generous support and help, one should equally be thankful that some of their ideas did not fly, indeed were nipped in the bud. One such idea was that of Sir Ardeshir Dalal:

> *While we must necessarily make a very modest beginning, the development of the Alipore Test House* [in Bengal] *into a National Physical and National Chemical Laboratory seems to be obviously and urgently required.*
>
> Dalal, 1941

Had this advice been implemented, the growth of the two laboratories would almost certainly have been stunted.

BIRTH, LOCATION, AND SITE

The NPL was to be the first but as it turned out, the NCL was actually the first, followed a few months later by the former. Proposals for the creation of the National Chemical Laboratory were put forward by Bhatnagar in September 1941 and were accepted by Ramaswami Mudaliar, the then Commerce Member (cabinet members during the British rule were called members, exactly what they were, and not ministers, which indicated an elected status) to the Government of India and President of the Board of Scientific and Industrial Research. A Planning Committee for the laboratory was then set up in 1943 by the Governing Body under the chairmanship of Sir Ardeshir Dalal (Chairman of the Tata Iron and Steel Works, the first mega company of those days in India). Then, in 1944, when Sir Ardeshir joined the government as Member for Planning and Development, John Mathai (who later became Principal Secretary to Prime Minister Indira Gandhi) was chosen to take his place as Chairman of the Planning Committee. In 1945, the Committee drew up a tentative scheme for establishing the laboratory and circulated it to a large number of scientific organizations and individuals in India and abroad for comments and suggestions. Simultaneously, Bashir Ahmed was appointed Assistant Director (Planning) and Secretary to the Planning Committee, and was succeeded by B. D. Laroia in 1947. A detailed plan for the establishment of the NCL was then drawn up after a careful consideration of the many suggestions received, the lines along which similar laboratories in other countries were established, and the special needs of India. Then, in 1943, the NCL was formally created by a resolution of the Governing Body of the CSIR (1945), (see reference 4th CSIR GB meeting, July 14, 1943).

Box 3.4: Resolution of the Governing Body of CSIR creating the National Chemical Laboratory

4th Meeting of the Governing Body held on 14th July, 1943
POLICY/IMPORTANT DECISION

1. Proposed representation of the Forest Research Institute on Board of Scientific and Industrial Research.
2. Plans and estimates for National Chemical Laboratory.
3. Patent right in respect of Researchers partly financed by Council of Scientific and Industrial Research.

9th Meeting held on 21st September 1946
POLICY/IMPORTANT DECISION

1. Management of bye-laws and rules and regulations of the Council of Scientific and Industrial Research.
2. Consideration of the "proposed plan of the National Chemical Laboratory."

National Chemical Laboratory

The D.C.I.R. informed the members that the architects had been appointed for designing and planning the National Chemical Laboratory and the final terms were being settled. The acquisition of land was being notified in the Gazette of the Bombay Government after which the land would be placed at the disposal of the Council.

The question then arose regarding the location of the NCL. How the planners dealt with this and other problems is described in the reports titled National Chemical Laboratory of India, 1947, 1950, 1952. It must be clear from Chapter 2 that the center of gravity of research and industry was in Eastern India, mostly in and around Calcutta, but there were already signs that the scene was shifting to Western (and Southern) India, particularly to the provinces of Bombay (now Maharashtra) and Gujarat. But what perhaps clinched the issue was the tremendous interest shown by the Tata Group, especially a munificent donation by the Dorabji Tata Trust of a sum of Rs. 8.3 lakhs to the CSIR, specifically for establishing a chemical laboratory in or in the vicinity of Bombay. This led to the suggestion at a meeting of the BSIR that the name of Tata should be associated with this laboratory, but that did not happen. The Government of India allocated a sum of Rs. 2,500,000 for building and other capital expenditures. Although the actual expenditure far exceeded the total amount gifted and granted, there were problems of a more immediate nature that had to be surmounted before the actual construction could begin.

The first was with respect to the site, and was in some ways the most bizarre and in many ways the most difficult to overcome. Although Pune appears to have been the preferred location, Bombay was by no means ruled out (particularly if suitable land could not be found in Pune). In those days, what is now the University of Pune was the summer headquarters of the Governor of Bombay. The CSIR's first choice was a site that lay across the governor's mansion. The culinary staff of the Governor, Sir John Colville, aided by some of his very senior officials, raised a serious objection: the stink and obnoxious fumes from the chemical laboratory, they complained, could not be allowed to contaminate the salubrious surroundings of His Excellency's mansion.[4] This was particularly objectionable since, they argued, the laboratory would be within a mile of the governors's mansion! Based on this objection, the Government of Bombay decided not to allow the laboratory to be built on that site.

The ball was back in Bhatnagar's court. He had no option but to accept the decision, and selected another site of 475 acres on the road connecting the university to the village of Pashan. The great advantage of this location was an adequate water supply in an otherwise arid area. This land belonged to the military establishment in Pune and no great difficulty was foreseen in acquiring it. As it turned out, however, the presiding military officers were reluctant to part with it. According to Bashir Ahmed,

> *The military who were in possession of this land showed little inclination to vacate it. When the suggestion was made, the military authorities smiled ironically at the presumption that an important military camp should be moved to give place to a mere laboratory.*
>
> National Chemical Laboratory Booklet, 1947

But Bhatnagar was not one to be deterred and approached the Defense Minister, Sardar Baldev Singh, with the plea that

> *the loss of a site of 450 acres or so to the military was like a drop in the ocean while the national gain to industry and research would be enormous.*
>
> See writeups on the NCL, listed under references

Sardar Baldev Singh, known for his friendly manner and fair-mindedness, over-ruled all objections and transferred the land to the CSIR.

Even for the new site Bhatnagar had to provide enough evidence to show that the "smell" from the NCL would not pollute the governor's mansion. He therefore sought expert advice on the "odor objection" from a number of leading scientists, including Sir Edward Appleton of the Department of Scientific and Industrial Research, UK and Dr. R. P. Linstead, Director of the Chemical Research Laboratory, Teddington, UK. Fortified with their opinions, he approached B. G. Kher, the Premier of Bombay (the Chief Minister was called Premier in those days) and persuaded him to visit the site along with Bombay's Minister for Home and Revenue. As a result, Kher agreed to the decision of locating the NCL on the Pashan Road (later re-named Dr. Homi Bhabha Road) but with the caveat that the actual location of the building shall be no closer than one mile from the Government House (the one-mile limit was stubbornly stuck to by *all the Governor's men*!). The Governing Body of the CSIR tentatively approved this new location in 1943. But further discussion seemed to have ensued and final approval given in 1945.

It is interesting to note that during his protracted negotiations for land, an annoyed but irrepressible Bhatnagar appears to have made the following comment:

> *There would be no more stinks from the well-designed National Chemical Laboratory than from the kitchens and sewage system of His Excellency's staff.*
>
> National Chemical Laboratory Booklet, 1950

(It is my own feeling that this statement had a favorable impact on the Premier!) In his negotiations for land, Bhatnagar was greatly assisted by Dr. John Mathai, the Chairman of the Planning Committee of the NCL, who later became Prime Minister Indira Gandhi's Personal Secretary.

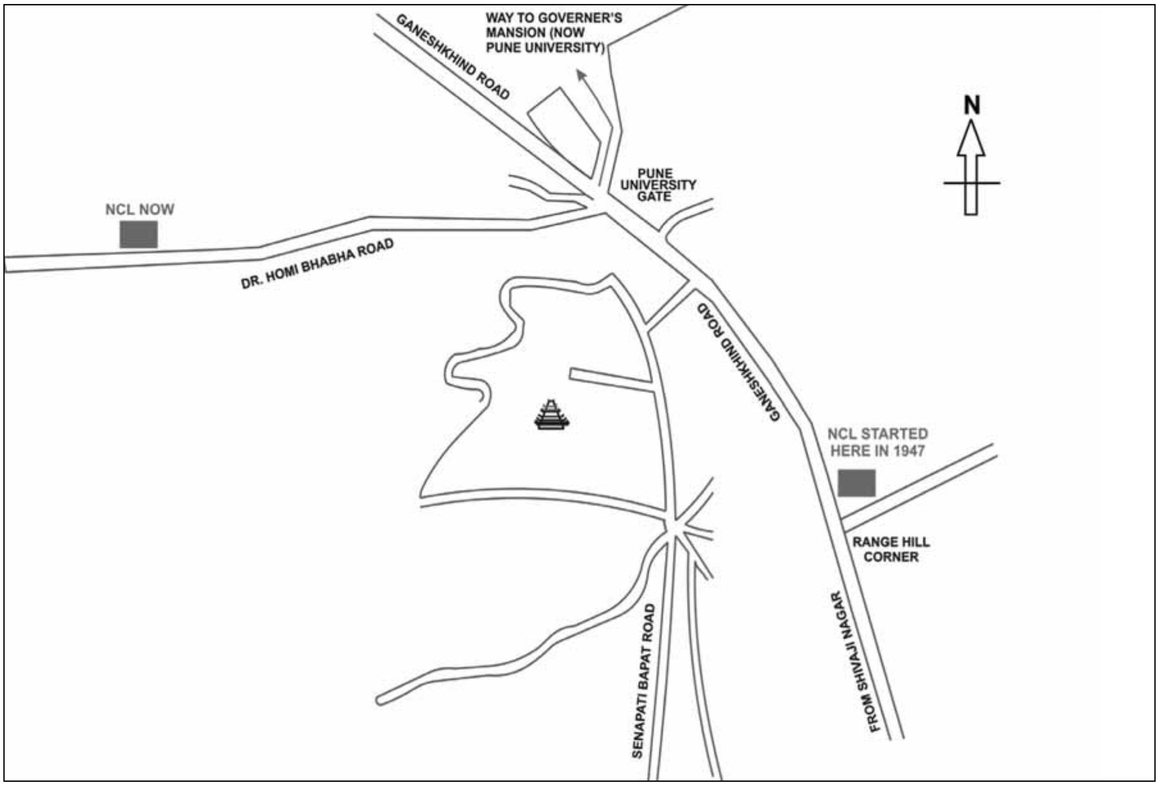
As a result of all these, there was an inevitable delay in the founding of the laboratory. In an attempt to explain this delay Bashir Ahmed had this to say:

> *The Mellon Institute of Industrial Research at Pittsburg completed about two decades ago, took ten years to plan and six years to build.*
>
> During the Foundation Laying Ceremony, 1947, National Chemical Laboratory, 1947

Many other annoying hurdles (presumably more than one would normally expect) had to be overcome and as a result, the NCL's incubation period was, in the words of Bhatnagar, unusually long. Foundation stones had already been laid for other laboratories conceived later or around the same time, such as the Central Glass and Ceramics Research Laboratory in Calcutta in December 1945, the Central Fuel Research Laboratory in Dhanbad (in West Bengal), the National Metallurgical Laboratory in Jamshedpur (also in W. Bengal) in November 1946, and the National Physical Laboratory in New Delhi in January 1947. But soon the pace at Pune picked up and the NCL was launched ahead of any other laboratory in the CSIR.

Finally, Bhatnagar and his staff in Delhi were ready to begin. As a first step they rented a spacious building, numbers 1, 3, Ganeshkhind Road (see Figure 3.6), about four miles from the site of the NCL (and over a mile away in the opposite direction from the governor's mansion!), and established it as their *modus operandi* for the construction of the new building. The well-known firm of Master, Sathe and Bhuta was selected as architects, and their representative, Bhuta, was asked to visit several laboratories in USA before submitting a design to Bhatnagar.

Figure 3.6: The NCL's locations, then (when it first began) and now (when the present building was constructed)



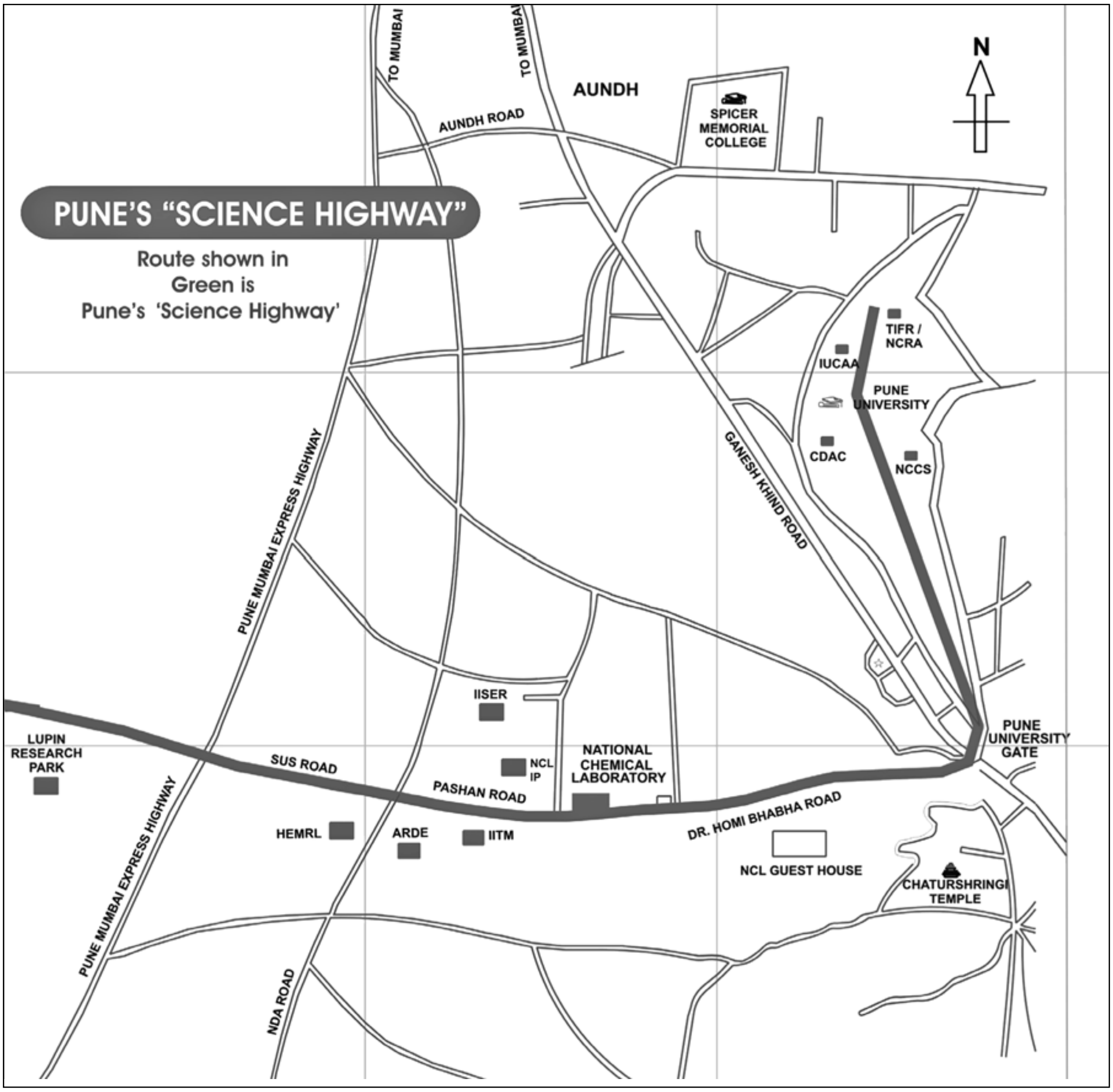
Source: Prepared by NCL.

This bungalow where the NCL was temporarily located belonged to one Brigadier Mohite, a retired Indian army officer. (Incidentally, a couple of years after joining the NCL on my return from Wisconsin, I lived in an apartment close to the brigadier's house. We used to occasionally meet during our walks in that area, when I heard some interesting tales from him about the early functioning of the NCL from his house.)

The NCL's Surroundings in Pune

After a few eventful years of temporary housing in Delhi and then in Pune, the NCL moved to its permanent home close to the village of Pashan in the then outskirts of Pune. The road leading to it was the little known Pashan Road, which around 1975 was renamed Dr. Homi Bhabha Road, in memory of the founder of the Indian atomic energy program. The renaming was also a reminder that it was Pune's "Science Highway" (see Figure 3.7), as I would call it, dominated by the NCL and including also such other important centers as the Armaments Research and Development Establishment (ARDE), and the Explosives Research and Development Laboratory (ERDL), renamed High Energy Materials Research Laboratory (HEMRL).

Figure 3.7: Map of Pune's 'Science Highway'



Source*:* Prepared by NCL.

Note: Many multinationals and other private sector companies have established R&D centers in Pune. These are not shown.

It is worthy of note that the road begins at the entrance to the University of Pune, which also houses such centers as the Advanced Center of Astrophysics. Winding its way past the NCL, NCL Innovation Park (IP) and Indian Institute of Science Education and Research (IISER), Armament Research and Development Establishment (ARDE), and HEMRL, the road ends at the entrance to another famous educational institute, a military training center, the National Defense Academy (NDA). This is one of the foremost institutes of its kind where admission is through a stiff national competitive exam like those for the Indian Institutes of Technology (IITs) and of Management (IIMs). All these institutions are fully or partly state-owned. But somewhere along the road, a branch leads to one of the finest private sector laboratories in the country (the Lupin Laboratories Research Center) with state-of-the art building and facilities and high caliber scientists, as though to accentuate the fact that the private sector was becoming an increasingly important factor in India's ascent to scientific and technological prominence.

In addition to the research institutions mentioned above, the city of Pune was, and continues to be, home to an increasing number of institutes of learning and research. A map of Pune showing all the major academic institutions appears in Figure 3.8, while a map showing all its research and development institutions appears in Figure 3.9. Many were in existence long before the NCL was launched and others came later.

Innovative Pune

What the various institutes, academic centers, and industries of Pune have accomplished is a story in itself and not germane to the preset book. But it is instructive to recall that the NCL has been a part of Pune's collective contribution to a variety of areas. To bring home this point, I can do no better than to reproduce the following lines from a recent article by Mashelkar, a former Director of the NCL:

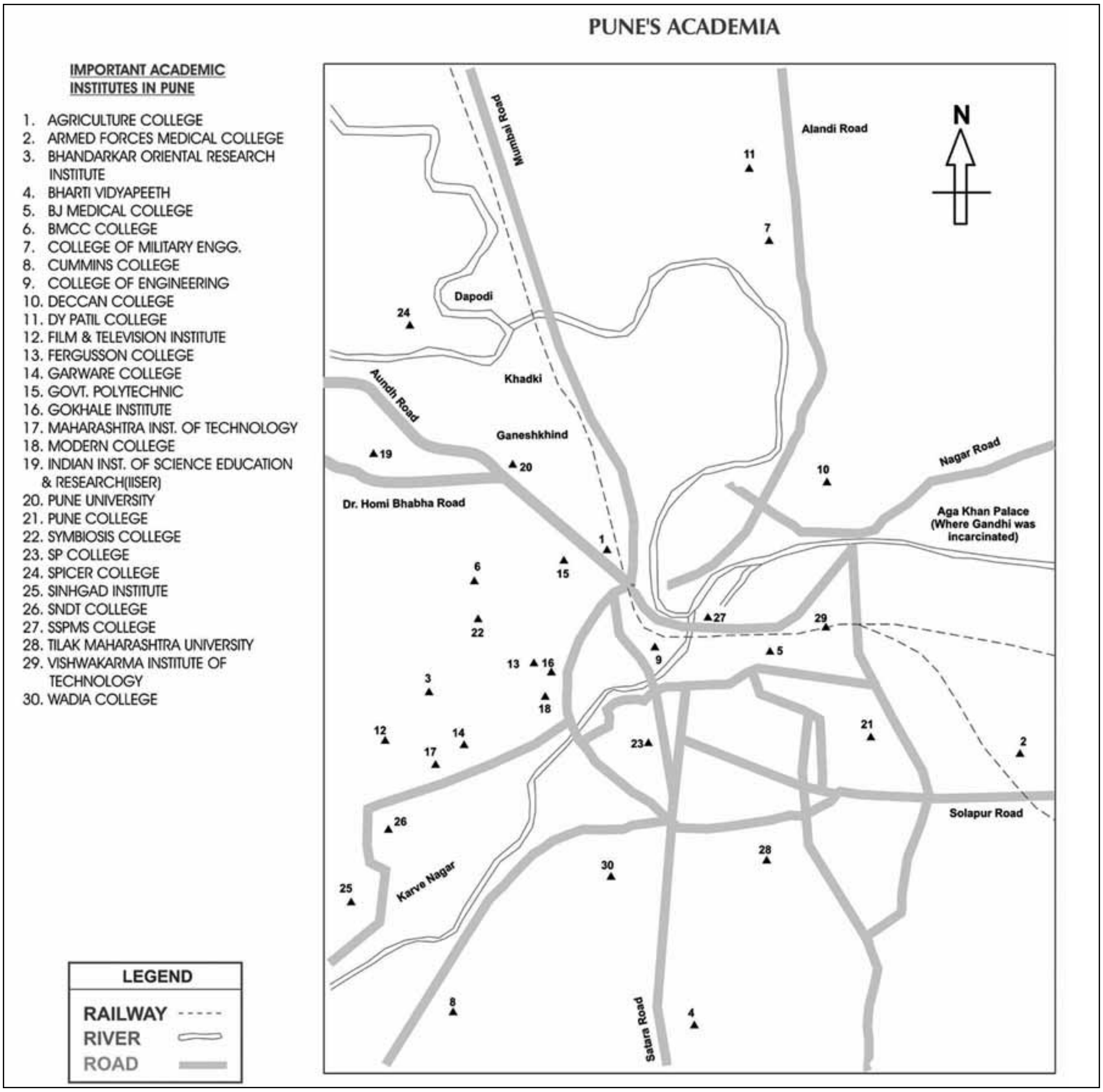
> *As regards "technology,'"we are second to none. The city boasts of producing technologies, which are transformational. India's first super computer PARAM, and world's fourth fastest super computer Eka were born in Pune. For the lower middle of the pyramid, Tata's one lakh car, people's car, was born here. Computer Based Functional Literacy (CBFL), which has the power to make 200 million Indian illiterates literate within five years was born here, in the same way as the first TB drug after 1963, a boon for the poor.*
>
> Mashelkar, 2008

The Foundation Stone is Laid

With all the basic preliminaries completed, the foundation stone of the laboratory was laid by B. G. Kher, the Premier of the then province of Bombay, on April 6, 1947, and construction of the building began in February 1948 (Figure 3.10).

Realizing that the success of an ambitious venture like the creation of a major laboratory depended on the world standing of its director and his ability to inspire and bring scientists from different disciplines together, the CSIR widely advertised the post in the USA, USSR, UK, and Europe. Apparently, few outstanding scientists from abroad showed much enthusiasm in undertaking this kind of an institution-building assignment because of its possible detrimental effect on their own research. But the CSIR did locate an outstanding Indian chemist, Syed Siddiqui, and his appointment was approved at the first meeting of the newly constituted Governing Body of the CSIR held in August 1947, under the chairmanship of the President of the Council, Prime Minister Jawaharlal Nehru. Siddiqui, however, decided to take up a position in Pakistan equivalent to that of the Director, Scientific and Industrial Research, in India. Fortunately, the disappointment did

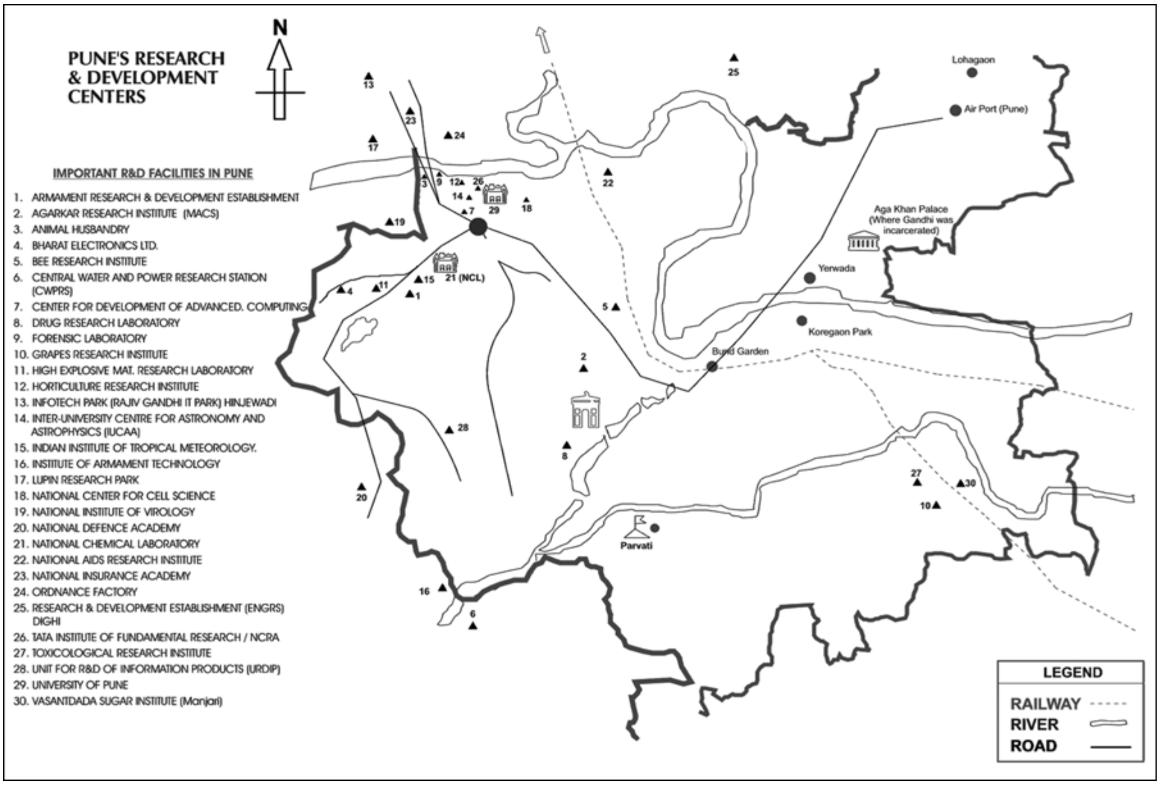
Figure 3.8: Map of Pune showing its various academic institutions



Source*:* Prepared by NCL.

not last very long. Bhatnagar was able to convince Professor James W. McBain, Emeritus Professor of Chemistry, Stanford University, to join the laboratory. The Governing Body approved this selection at its July 1948 meeting. Prime Minister Nehru then offered the position to Professor McBain. The professor accepted the offer and joined the NCL in October 1950, even as the laboratory was being constructed. Opinion is unanimous that the NCL could not have found a more fitting and enthusiastic scientist as its first Director. In my view, he laid the foundation for what was to become one of the country's most

Figure 3.9: Map of Pune showing its various research and development institutions



Source: Prepared by NCL.

prestigious laboratories and continues to be remembered with affection (although I did not have the pleasure of knowing him personally, having joined the laboratory only after he had handed over the reins of office to George Finch).

A few other distinguished scientists from abroad were also appointed directors of CSIR laboratories. One cannot but admire the perspicacity of Jawaharlal Nehru while making these foreign appointments. When the Genetics and Biometry Research Unit was established in Calcutta and the world famous British scientist, Professor J. B. S. Haldane, agreed to head the institution, Nehru is reported to have cautioned the CSIR while approving the appointment that there could be problems in subjecting some one like Haldane to bureaucratic rules and regulations (although it is my own experience that these in the USA and other countries can be no less frustrating!). Indeed there were far too many, and Haldane did not stay long (but apparently accepted another position in India). It is to the great credit of McBain that he accepted these shortcomings, regarded them as challenges, and worked with them in a spirit of cooperation and commitment, and in the process left a lasting imprint on the NCL.

The laboratory is launched

The opening ceremony was truly a memorable occasion, performed by Prime Minister Jawaharlal Nehru on January 3, 1950, in the presence of a galaxy of renowned scientists

Figure 3.10: The foundation stone is laid by B. G. Kher, Premier of the then province of Bombay

from many parts of the world (Figures 3.11 and 3.12). They included Nobel Laureates and other luminaries:

- Sir Robert Robinson, Nobel Laureate, President of the Royal Society, London
- Dr. Arthur H. Compton, Nobel Laureate, Chancellor, Washington University, St. Louis, USA
- Dr. Irene Joliot-Curie, Nobel Laureate, Director of the Institute de Radium Laboratorie, Paris, France
- Dr. P. Augers, Nobel Laureate, Director of Science, UNESCO, Paris, France
- Professor O. E. H. Rybeck, Nobel Laureate, Director of Research, Chalmers Institute of Technology, Gothenburg, Sweden
- Sir C. V. Raman, Nobel Laureate and Director, Raman Institute, Bangalore, India
- Professor J. D. Bernal[5], FRS, Professor, Birkbeck College, London, England
- Dr. E. U. Condon, Director, National Bureau of Standards, Washington, USA
- Professor Herman Mark, Polymer Research Institute, Brooklyn, USA

Figure 3.11: The new laboratory building is thrown open by Prime Minister Jawaharlal Nehru. Standing next to him is the CSIR chief S. S. Bhatnagar

Great expectations were voiced by many speakers on the occasion. A few samples of these will serve to bring home the importance of this event:

Sir Robert Robinson: *This enterprise is an expression of the vitality of India and it will be one of the factors that will lead to an acceleration of scientific and industrial development in this half-continent of such immeasurable potentialities. It was fortunate indeed that at this critical time in history, when every iron is hot upon the anvil, India found in Sir Shanti Swarup Bhatnagar an eminent scientist of clear vision, sound judgment in affairs and boundless energy in action. His high office has enabled him to realize wisely ambitious plans and today we see the concrete results, a dream come true, and one, I suspect, that lies especially close to his heart.*

Dr. Irene Joliot-Curie: *We greatly appreciate the efforts that have been made in India in recent years for the progress of scientific knowledge and for its applications for the advancement of Indian industries. We take this opportunity to express our feelings of gratification on the splendid work initiated and organized by one man, Sir Shanti Swarup Bhatnagar. We consider that at no time in the history of the scientific evolution of any country, one single person has done such an enormous service to science and has achieved such a great success in such a short time period as Shanti Bhatnagar. He is full of fruitful ideas and is bestowed with vigor and energy to execute them.*

Figure 3.12: At the NCL's inauguration function. Top: Fourth from the left is C. V. Raman, Nobel Laureate (with turban). Bottom (from left): Irene Joliot Curie, Arthur Compton, and Robert Robinson, all Nobel Laureates

Dr. Arthur H. Compton*: It is an unusual pleasure to take part today in the dedication of the National Chemical Laboratory of India. The completion of your fine building marks an important step in the progress of a great people as they take their place in the scientific work of the world. My pleasure is the greater because I see in this structure the realization of vision that I have seen in the eyes of men who have been my friends over many years, Dr. Sir Shanti Swarup Bhatnagar, Professor Carter Speers and a notable group of India's wise and loyal scientific men*. [Unlike mathematics, astronomy and physics], *chemistry is more modest. I am reminded of Aristotle's comment that of all men Pythogoras understood the world best, because he was a lover of knowledge, who did things skillfully with his own hands. I know of no better description of the chemist.*

Sir C. V. Raman: *Unlike Sir Robert Robinson and others who have spoken before me, I am not a chemist. I may add, however, that although I am the world's worst chemist, chemists attach more importance to my contributions to science than physicists do. I would like to stress the practical value of the researches to be carried out at the National Chemical Laboratory, although I do not believe that utility is the main incentive to scientific work. I believe that good laboratories alone are not sufficient to produce scientific work but it is ability of the individuals who work in the laboratories that counts. The greatest discovery in modern science — radioactivity — was made by Madame Curie and Professor Curie in tin sheds. I am sure that individuals of exceptional ability will work in the NCL and work for the advancement of science.* (National Chemical Laboratory 1947) [This was a veiled criticism. But Raman seems to have been more open in his criticism in a private conversation when he is said to have remarked: *Bricks, marble, and mortar* *do not make a laboratory*. He felt that there was more pomp to the NCL's opening than human quality. To those who heard this, it must have been a great damper, coming as it did from India's greatest scientist. Had Raman been alive today, he would have had ample reason to revise his opinion.]

Nature had the following comments to make:

> *The building of western design and magnificient proportions, makes an impressive picture set in a natural ampitheatre of hills about four miles from Poona. It is well equipped for scientific research in chemistry in both pure and applied fields. It will provide the possibility of effective cooperation which is essential to sound economy*.
>
> *Nature*, 1950

The teething problems were many and a brief account of these will highlight the difficulties experienced in creating a modern enterprise in a country just waking to independence. An account of the laboratory's evolutionary trail, before it became fully functional, will mark the end of the beginning of this narration and of the arrival of the NCL.

THE VISION STATEMENT AND A PRACTICAL AGENDA

The opening address at the foundation stone laying ceremony was given by Bhatnagar, who traced the history of the NCL from conception to foundation and also elaborated at some length on its vision, scope, functions, and responsibilities.

Vision statements for institutions are often expressions of goals clothed in lofty words, long on hope and short on projected reality. And that is as it should be. When a vision is reduced to words, the attempt is always to create an uplifting sense of the possible, not necessarily of the probable. It is in this pleasant confusion of words that one sees the truth, a dream made unachievable by its own loftiness. A goal or a mission is achievable, but a dream should not be — for its very fulfillment is its redundance. It should be constantly regenerating, like the horizon that is always advancing. But where will a nation, an institution, an individual be without a dream? And so, a vision is always needed — to inspire, to constantly rejuvenate. On the other hand, a fixed vision is not necessarily a virtue. A periodic, if infrequent, review is always desirable. It is in this context that NCL's vision and its embodiment in a renewable agenda will be reviewed and analyzed.

Jawaharlal Nehru gave the NCL a dream, a vision pure and simple, unspoiled by the practicalities of realization and the possible aberrations of future leaders, a dream that cannot be diminished and that, to this day, permeates the entire laboratory:

> *The purpose of this laboratory is to expand knowledge and to apply chemical science for the good of the people.*
>
> According to Evelyn McBain, 1954, the wife of the first Director James McBain, these words were first suggested by her husband to the Prime Minister.

There were dreamers with very similar dreams in earlier times too. For instance, Nehru's vision had its 19th century equivalent in Andrew Carnegie's vision for the Carnegie Institution of Washington, USA:

> *To encourage in the broadest and most liberal manner investigations, research and discovery, and application of knowledge to the improvement of mankind.*
>
> Quoted in Sandage, 2005

The rest of the book will let the readers decide for themselves whether Alexander Woolcott's (1887–1943) description of a play is valid for the NCL: *The scenery in the play was beautiful but the actors got in front of it.*

The scope of the NCL, as stated in the vision, is very vast and has no boundaries except the boundaries of chemical science itself in its most inclusive definition, covering conventional, new and emerging areas, and all aspects of chemical engineering. No other laboratory in India, with the exception of the National Physical Laboratory, enjoys such a wide scope. These are therefore rightly called the bedrock laboratories of the CSIR. The NCL and NPL, created in that order, have savored the vast ambit of their domains and have constantly introduced new and emerging areas. Thus the NCL, which started out with seven conventional disciplines, went on to initiate programs in many new areas, such as genetic engineering, nanotechnology, some exciting new areas in theoretical chemistry, polymer science and engineering, materials science and engineering, computational fluid dynamics, computer aided design, stochastic modeling, data-driven modeling including artificial intelligence (AI), each of which can boast of remarkable achievements.

Bhatnagar, a practical scientist, reduced Nehru's vision to a practical agenda of action. To rephrase this would be to unwittingly color it with personal interpretation and understanding. Hence his portfolio of scope and objectives, which may more correctly be called his charge to the NCL, taken from his address at the foundation stone laying ceremony of the laboratory, is reproduced in Box 3.5.

The scope, intent, and directions of the original agenda remain, but the methods have changed, linkages have shifted, and priorities are dictated by the needs of the changing times. Many of the original areas suggested have also remained, with the difference that some of them have been transferred to other laboratories of the CSIR better equipped to tackle those problems, or not taken up at all, such as fixation of atmospheric nitrogen, utilization of coal-tar, oils and fats, and development of artificial textiles and fabrics. It is interesting to note that in 1960, the NCL was invited by the Steel Authority of India Limited (SAIL) to develop processes for coal-tar utilisation and I was deputed to visit the plants at Rourkela, Bhilai, and Durgapur to make suggestions. My recommendation to the then Director, Venkataraman, was to not enter this field, and I am glad the NCL did not.

With the continuing emergence of new and exciting areas (and increasing specialization and sophistication both in theory and experiment), the nature of the projects, priorities, organizational schemes, as well as the nature of the infrastructure and work force at the NCL have also correspondingly changed. This is part of the evolutionary process, as will be detailed in subsequent chapters.

It will be noticed that the charge is quite inclusive and leaves considerable room for expansion, exclusion, adjustment, as well as intra- and inter-laboratory collaboration. It is this flexibility built into the charter that has been most effectively used in the last 60 years to keep pace with the rapidly changing scientific scene in the world. Lesser flexibility might have restrained the realization of the broader vision and diminished the laboratory as a whole in today's context.

Box 3.5: Bhatnagar's charge to the NCL

The developmental work in the National Chemical Laboratory will take the form of improving old processes in the light of new scientific knowledge or of discovering new processes. The development of new processes will be carried out to the pilot plant stage in the laboratory. When a successful process has been passed on to industry, the National Chemical Laboratory will remain in touch, and any difficulties or problems that may arise in the large scale manufacture of the product will be brought back to the laboratory for solution. In addition to the processes developed in the National Chemical Laboratory, other problems of industry which fall within the scope of investigations of the National Chemical Laboratory may be taken up. The men at the National Chemical Laboratory even on their own initiative may undertake to investigate technical processes of Indian industry and make improvements in them.

In this manner the link between the National Chemical Laboratory and the industry will be living and vital, and so will be its link with universities and other scientific institutes in the country where fundamental scientific research work is being pursued. These institutions may be invited to pass on their discoveries and inventions to the National Chemical Laboratory for developing the means to their successful industrial application.

Some of the most important scientific discoveries during the last half century, which have been of the greatest benefit to mankind, have nearly always resulted from large organisations both of workers and of materials, and have involved expenditure, which falls outside the capacity of the average scientific laboratory. In the same manner technical processes developed in the Western countries which have revolutionised industrial development and modern civilization itself, have required huge expenditure of funds and materials. The utilisation of coal tar, fixation of atmospheric nitrogen, the development of plastics and artificial rubber, of artificial textiles and fabrics, the hydrogenation of coal, and the development of the entire petroleum industry are a few important examples out of a large list. The National Chemical Laboratory hopes to be in a position to undertake such difficult, important and expensive research.

It must be mentioned here that the major problems of industry or speaking of the wider aspect, those of human welfare, are never such as fall within a narrow groove represented by a particular branch of chemistry. More often than not, for the successful solution of a problem, the cooperation of experts from different fields of science is necessary. The National Chemical Laboratory will, therefore, embrace not only chemistry, but also physics, mineralogy, engineering and biology in so far as they relate to chemical problems and the chemical utilisation of national resources. Without the provision of such a wide scope the laboratory may become sterile. The institutes of industrial research in other countries fully recognize this need. The Mellon Institute, which is perhaps one of the best industrial research institutes in the world dealing with chemistry, has highly developed sections representing biology. The famous Massachusetts Institute of Technology has a department of Biological Engineering which comprises such subjects as biophysics, food technology, sanitation, nutrition and industrial biology. The National Chemical Laboratory, recognising the same principle, will have sections of Chemical Engineering and Biological Chemistry and Evaluation.

It may also be stated that in modern applied research concerted team work is becoming more and more essential. The day of the individual research worker is nearly passing away. The solutions of problems which arise today require the specialized knowledge of a number of experts. It is, therefore, essential that the National Chemical Laboratory while embracing a large number of subjects and experts in different fields should be able to work as a team.

Last of all, the functions of the National Chemical Laboratory will include the training of research workers in specialised fields of chemistry and technology with particular reference to those for which no provision has been made in the existing scientific laboratories of the country.

From Bhatnagar's address at the inauguration of NCL

The Planning Committee of the National Chemical Laboratory recognized the fact that chemistry covers an incredibly vast area; hence no single laboratory can aspire to touch all fields comprising it, though there was no restriction on adding, subtracting, or changing areas. It proposed that seven main divisions be created, and an 8th for administration. Given below are the names of the divisions along with the names of the first assistant directors in charge (gathered from the booklets on NCL, 1947, 1950, 1952).

Inorganic and Analytical Chemistry (J. Gupta)
Physical Chemistry including Electrochemistry (S. S. Marsden)
Organic Chemistry (R. C. Shah)
Chemistry of High Polymers (S. L. Kapur)
Biochemistry and Biological Evaluation (M. Damodharan)
Chemical Engineering (J. H. Truttwin)
Survey and Intelligence (K. G. Mathur)
Administration, and Standardization of Chemicals (B. D. Laroia)

Approval was obtained for a total of 320 positions: One director, seven assistant directors, 18 senior research officers, 25 junior research officers, 64 research assistants, 42 administrative and ministerial staff, 35 technical staff, 86 laboratory assistants and attendants, and 42 peons, sweepers, and other staff. No exact figures are available on the numbers with which the laboratory actually started. As will be seen later, the divisional structure was slightly changed by Professor McBain when he took charge of the laboratory as its first Director. It underwent several more changes since, and these are discussed in Chapter 13.

A particularly significant feature of the NCL's scope is that it envisages, and provides for, the growth of certain divisions into independent laboratories within the CSIR. For example, it was recognized at the outset that electrochemistry, which was part of the Physical Chemistry Division at inception, had the potential to grow into a separate laboratory. And so it did, almost simultaneously with the NCL. The work on electrochemistry at the NCL was stopped as the Central Electrochemical Research Institute (CERI) at Karaikudi (in Tamil Nadu) was launched and grew into a thriving example of forward thinking. Another example, of a slightly different nature, is the Central Salt Research Institute at Bhavnagar (in Gujarat), renamed subsequently as Central Salt and Marine Chemicals Research Institute. Recognizing that this was (when started) essentially an inorganic chemicals laboratory, it was placed under the charge of the director of the NCL. The head of the Inorganic or Physical Chemistry Division was deputed by the NCL to represent the director for a period of several months in a year. This practice continued till the late 1950s, when the institute was completely detached from the NCL and a separate director was named.

Nearly 60 years since its inception, the NCL has grown from an ambitious fledgling to one of the country's talent-packed and best equipped centers of chemistry and chemical engineering, from its distinctly academic leanings and somewhat naïve forays into industrial research to an advanced center of research in pure and applied chemistry and chemical engineering. All institutions are children of their times. Some are precocious.

For better or for worse, the NCL was one. Whether it has carried the burden of high expectations well and has lived up to them is for the readers to judge.

As will be pointed out later, Venkataraman wanted the NCL to be the Cambridge of India. Unknowingly, McBain seems to have initiated this kind of thinking by referring to Cambridge's rival, Oxford. While introducing, at the NCL's opening ceremony, the Governor of Bombay, His Excellency Sir Maharaj Singh, who studied at Oxford, he spoke the following words — music to Oxford but nothing of the kind to Cambridge: *Balliol rules the world.*[6]

STARTING-UP PROBLEMS

An authentic account of the problems faced by the NCL as it struggled to find its feet is given by Elaine McBain in an article in *Chemical and Engineering News* (1954). It is a fascinating account, full of detail including her comments on functions that are normal in India but were new and exciting to her. One thing that clearly emerges from her account is that the NCL got off to a flying start with the seeds of democratic administration and conduct lastingly implanted in the scientists' minds. The firm establishment of democratic rule in India by Pandit Nehru was strengthened by the practice of democracy in all institutions in India, but the NCL was among the first to usher it into a major laboratory.

McBain managed the scientific program of the laboratory by being involved in every project. A discussion of his style of management will be deferred to a later chapter where the management styles of all its directors are reviewed. This chapter is concerned with the multi-dimensional aspects of the laboratory's growth before it was fully functional. Conditions in the years immediately following independence were unsettled as a new bureaucracy was replacing the old with consequent uncertainties and delays. Although the basic structure of the old bureaucracy remained intact, many changes were also introduced, consistent with the norms of an independent country. This had its impact on the functioning of all institutions, particularly those that were just beginning. The NCL was no exception, but with a difference. Its first director was a Western scientist eager to implement the scientific culture of the developed world in a developing country. Aided by his wife, he immersed himself fully in this effort at a time when there were pressures pulling in different directions in the country. They did this with great vigor and zeal, almost as a personal mission. The feeling of belonging that they created coupled with their winning manner endeared them to the entire NCL staff. In her article, Elaine McBain brings to the fore many issues of the time, apparently small but with a lasting impact on the NCL's culture. She brings old customs to life by talking about how building in India was not a mechanized but a hand-made affair, how *many women brought their tiny babies to work with them and took time off for feeding. Older children played in sand piles or in swings hung from scaffoldings, how Indian workers can always be relied upon in an emergency* (McBain, 1954).

Thanks to the combined efforts of many, the building was finally reasonably functional in 1952. One cannot do better to describe the laboratory than reproduce its first graphic description by Mrs. McBain:

> *The laboratory, finally finished, was a beautiful building 640 feet long with some 200 rooms. The floors and stairs of the entrance hall are gray marble from Italy, and the pillars which reach to the second floor are soft "vista" blue. Across the spacious hallway is a patio with fish pond and palms, and at the farther end a library runs the full length of the central block. On one side of the patio is the auditorium for 550, and at the opposite end are museums and visitor's room.*
>
> Chemical Engineering News, 1954: 604–09

Although the NCL was now a functioning laboratory, the building and infrastructure were by no means complete. The NCL administration headed by Laoria had to contend with many difficulties, not the least of which was the need for a continuous supply of utilities. Frequent interruptions of city supplies could not be allowed to reduce safety and ruin experiments. So the NCL installed its own electric substation, gas plant, water pumping station, etc. In other words, the laboratory had to be self-sufficient in almost all aspects of its functioning, from the pursuit of science to the day-to-day life and entertainment of its staff. But for the fact that much of the personnel at the junior levels were drawn from the local population with homes in the city, the pressure on the NCL's resources would have been much greater. According to Mrs. McBain, several new practices were introduced in the NCL. They are all common practice in India today but apparently not so when the laboratory was opened. An "innovation" the McBains were particularly proud of was the installation of women as receptionists which, she says, was unheard of in those days in India and that other laboratories soon followed suit. A few other aspects of those early days, as recalled by her, are referred to in Chapter 17.

Bus service from the city to the NCL campus was intermittent and inadequate. The McBains' response to this problem was to establish a housing colony (with the CSIR's help), an NCL club for entertainment, and a cooperative society for supplying the normal needs of the NCL community. The first installment of houses consisted of 75 quarters of different categories allotted according to certain procedures involving considerations of seniority, rank in the laboratory, and requirements of duty. The director himself occupied a 7000 sq. ft. flat on the 3rd floor of the laboratory. This practice was continued till 1978 when I was appointed Director and my wife positively refused to live on top of the laboratory, which required visitors to cross two levels of security before they could meet her. I therefore decided to convert this into a spacious, well-furnished conference complex, and had one of the bungalows renovated according to the CSIR's main specifications for the director's residence. Recently, after almost 20 years, Director Sivaram has renovated the entire complex, and successive directors have greatly improved the director's residence.

The need for self-sufficiency, even in the daily lives of colony residents, was in many ways quite urgent, what with the stores and other facilities of a town being far removed from the outskirts and the bus service infrequent. Dr. and Mrs. McBain tried to ameliorate the staff's hardship by starting a Consumers' Cooperative Society (Coop) in a small room in the NCL hostel that had just been constructed. It was so well patronized that soon it had to be moved to a corner suite of rooms in the same hostel. The Coop was run by volunteers from the NCL with a very small compliment of paid staff. As it continued to flourish, even more space was needed. Government regulations did not allow money to be spent on a clubhouse where the Coop could be moved. Hence McBain personally financed the clubhouse and, on his 70th birthday, amidst great rejoicing, an enlarged Coop was inaugurated in a colony center which included a library and a games room as well. A large portrait of McBain adorned one of the walls of the store for as long as it lasted.

The Coop (with the director as ex-officio president and an elected body of officers including the vice-president, secretary and treasurer) served the NCL community for close to 50 years. The post office moved to a separate building in 1960 and the library and the games room moved to a new recreation center constructed in the same year. Also, Pune's expansion took the city limits far beyond the NCL, with shopping centers in easy reach and transportation far more regular. All these developments took their toll on the Coop, and in time, it just faded away. But its necessity and usefulness to the NCL community at a time when it was needed most can never be overstated — and is now part of the NCL's history.

In view of the distance from the city and the high cost of housing there, many scientists desired to move to the colony even before enough number of living quarters were constructed. It is well known that the CSIR has never been able to meet the full residential housing requirements of any of its laboratories, hence McBain had to use dilapidated old army barracks for accommodation. The following extract (reproduced in original) from a letter written by one of the scientists to McBain and quoted by his wife (1954) reveals the conditions under which they had to live in these barracks:

> *The barrack in which I am staying at present is open to unprovoked attacks from the forces of Nature….The winter has set in…and we have no electricity. The sooner we get into an electrified place, the sooner we come into modern society and live like civilized men.*
>
> Chemical Engineering News, 1954: 604–09

This letter has the appearance of being one from a thoroughly disgruntled individual. No section of the NCL's neighborhood was ever so bad! In any case, the NCL soon established a good residential colony consisting of quarters for all grades of employees, with electricity and other facilities available to the lowest. Further, in view of the tremendous change in the political structure of India in the last decade, the housing situation greatly eased and today many scientists are able to buy their own homes.

The NCL was now becoming an increasingly important presence in Pune. This was clearly demonstrated when the Government of India instituted an annual tree planting week and the city chose the laboratory grounds for its first effort. It was a ceremonial affair with the governor planting the first of the 5,000 trees. Unfortunately, the monsoon was late that year and only a fraction of the trees survived. But the occasion did mark the beginning of a green estate in Pune that was soon to boast of the best gardens of those days in the city. We shall see later in Chapter 15 how the NCL has continued to maintain its reputation in gardening, particularly in growing roses.

Another instance of the rising interest and curiosity about the NCL and its garden was their recognition by local schools and colleges, indeed by the city population as a whole, as a 'place of pilgrimage' (McBain, 1954). Around 1953 (when the McBains left), there were about 300 visitors a week. The number grew in subsequent years to an extent that it became necessary to designate an official guide for the purpose. The scientist chosen was a tall, bearded scientist and a former student of Bhatnagar who was already on the NCL staff. He had his own way with people and constantly amused his colleagues with his words and actions. He also proved to be hilariously effective in explaining simple scientific principles to lay tourists. For example, this is how he explained the working of a distillation column:

> *Assume that two people, one fat and the other lean, are running up a flight of stairs. Who do you think will reach the top first? Yes, you're right, the lean man! That is the principle of the distillation column that takes the lean (low boiling) liquid to the top leaving the fat (high boiling) liquid at the bottom*!

Breaking up the CSIR: The Move That Failed

No account of the CSIR — and the NCL — will be complete without a reference to the most unsettling and potentially disastrous threat they faced in 1977. The Congress had briefly lost power and the Nationalist Party had formed the government with Morarji Desai as Prime Minister. Desai was convinced that the CSIR did not serve any useful purpose and was draining the national economy. A loose conglomerate of laboratories belonging to widely differing disciplines would, he felt, be ultimately unable to serve any single discipline effectively. The only way to derive some benefit from these laboratories would be to dismember the CSIR and transfer many of its laboratories to the appropriate ministries, thus undoing decades of effort of Nehru, Bhatnagar, Mudaliar and others to establish a world-class group of laboratories working under a single autonomous body, the CSIR. The NCL would be transferred to the Ministry of Petroleum and Chemicals, Fuel Research Institute to the Ministry of Energy, and so forth. Thus all autonomy would be lost and every laboratory would function as part of its ministry's lethargic, rule-bound, unimaginative bureaucracy. Directors would be waiting endlessly in the corridors of secretariats in New Delhi, only to be granted a few brief moments with the deputy secretary — forget the secretary, the highest bureaucrat, who would always be too busy, really or not so really, to meet the lowly scientist! Laboratories that could not be fitted into any ministry fared better; they would be closed down! When this talk was at its height, I was a visiting professor at McMaster University in Hamilton, Canada. The news was conveyed to me by the Dean, Les Shemilt. In fact, this was a frequent topic of conversation among many Canadian friends of India. Fortunately, the move did not succeed, and the CSIR lived to see another day — indeed, another century.

The Underpinnings that Gave The NCL a Flying Start

The bolt had been shot. The beginning had come, stayed its meandering course, and gone; and in its place stood a brand new laboratory, marble-floored in all but its working spaces, and with the air and reality of a modern research center. The question today after 60 years is: As an institution, has the NCL kept faith with the aspirations of its founders and met its obligations to science, society, and industry?

A larger question that must precede this is whether the evolution of any entity in the universe (including the universe itself), has been the result of chance intrusions of events. One thing is certain: like all other things of the past few centuries, purposeful intrusions of human culture have, in no small measure, modified the processes of natural evolution. Coming now to the first question, the establishment of the CSIR as a cohesive overlay of Western science on the body scientific of India from Vedic times was a watershed in the evolutionary process. The establishment of the first of the chain of its laboratories, the National Chemical Laboratory, was an event of no less impact in one of the most important disciplines of science: chemistry.

In this, the first part of the book [more particularly, in Chapter (3)], I have tried to show how the Indians of this age and time share an abstract fever called thought with their forebears of millennia past. Whether their natural propensity for original thought has come through to their distant Western-educated progeny after centuries of cultural enhancement followed by cultural inertia is a matter of debate. In my view it has, and will only deepen with time. To those who would question the description of the brief period of half a century covered in this chapter as an indicator of an evolutionary pattern, I would only say that the unmistakable transformation of the linear to the exponential scale of evolution during this period would justify such a description, partly if not wholly.[7]

The ultimate strength of an institution lies in its ability to be largely unaffected by the favors or disfavors of the powers that be. Whether the roots described in this part have held on to this innate strength as centuries disappeared into irreversible history should, I hope, be clear without overt assertions in favor of any particular political persuasion out of the many that have ruled the country since independence. In the ultimate analysis, nature and chance will continue to sway, with controlled intrusions of intelligent life. Verily can it be said that no history is a true history if it addresses only a single tree and not the forest. It is the privilege of the scientist to address the single tree, or a bunch of trees, of his science. The historian, even a self-proclaimed or alleged one like myself, will be a traitor to his task if he ignored the forest that nurtured the tree, and stuck to the past ignoring the present and the future. Any such effort would do well as a report (like an annual report or an investigative report), but would be self-limiting as a book. It is in this general context of length and breadth, of sequential and parallel events, that I have attempted to find a niche for the NCL.

Time present and time past
Are both perhaps present in our future
And time future contained in time past…

T. S. Eliot (*Four Quarterly 1: Baunt Norton*)

❄

Part II
Grasping the Future

Enmity be between you! Too soon it is for alliance. Search along separate paths, for that is how truth comes to light.

Friedrich von Schiller
(Von Schiller, 1852)

INTRODUCTION

Heralded as a major step in chemical research and the first in industrial chemical research in India, the NCL began its voyage determined to live up to the high expectations voiced at its inauguration by many prominent scientific leaders of the world. Progressively imbibing emerging methods and strategies and opening new doors to Indian science and technology, owning up and learning from failures, it has come a long way as the nation's premiere chemical laboratory. Somewhere along the way, not far from the beginning, the *NCL* had arrived.

Part I was concerned with a vertical set of events extrapolated backward in time and covering science and technology in India from about 3,000 years ago to the present. The present part focuses on a parallel set of events restricted to the period within which the NCL evolved. This is the major part of the big history of the NCL as conceived in this book, and may be summarized as follows:

- The events of concern to the NCL that grew parallel to it are education, research, and the chemical industry. Chapter 4 takes a quick walk through these contemporary evolutions that had an interactive relationship with the NCL in its own evolution during this period.
- Chapter 5 is essentially the heart of the book. It traces the growth of the NCL from its hopeful beginnings to the fulfillment of these hopes — and to the state-of-the-art laboratory that it is today. This includes the laboratory's continuing accent on talent, its progressive sophistication, commitment to the spirit and minutiae of excellence, and increasing use of the modern tools of management. The details of the various projects and areas of work will come later — in Part III.
- Chapter 6 goes back to the beginning of the NCL again and focuses on the personal management styles of its directors, how they have all left their mark and shaped the course of the laboratory. It attempts to relate many of the commonsensical decisions taken in the earlier years and the conventional wisdom of the early directors to the modern tools of management described in Chapter 5. Finally, it describes how these tools have come to stay, not by a process of creative destruction but by one of creative assimilation.

4

GROWING HEALTHY

THE EDUCATIONAL, RESEARCH, AND INDUSTRIAL ENVIRONMENT IN WHICH THE NCL EVOLVED

The men who lived with him became
Poets, for the air was fame

Ralph Waldo Emerson (1918)

The corollary of these words, a stanza from Emerson's poetic tribute to William Shakespeare, is truer than the words themselves. For, who can deny that growth occurs best when it occurs in an environment that gives as much as it takes?

For any meaningful exposition of the NCL's history, it is important to appreciate, besides its ancestry, the climate in which it grew. India had the advantage of a decent educational, research, and industrial infrastructure left by the departing British. This evolved following independence, even as the NCL did. The three chapters of Part I summarized the remote and immediate ancestry of the NCL and gave it a niche in time from the Vedic period. The purpose of the present chapter is to trace the evolution of its contemporary links as a prelude to its own history, for clearly the NCL's growth was greatly influenced by the contemporary strength and evolution of the vast infrastructure within which it arrived and evolved by mutual interaction.

Evolution of Education[1]

Education at the university level has been an abiding strength of the Indian education system as a whole ever since ancient times. The universities at Nalanda, Taxila, and Vikramasila were renowned centers of learning and attracted students not only from all over the country but also from other countries in Asia such as China, Korea, Tibet, Nepal, Ceylon (now Sri Lanka), and Burma (now Myanmar). The number of universities, four at the end of British days, rose dramatically since independence. Today, India manages one of the largest higher education systems in the world. This has manifested itself not only by an increase in the number of state universities but also by the creation of institutes of technology (IITs) and central universities at the national level, and recognizing a selected number of institutes as institutes of importance at the national level. The number of IITs, five till recently, rose to seven in the early few years of this century. In addition, several regional institutes of technology and colleges of engineering were created.

UNIVERSITY EDUCATION

> *We have now a wider conception of the duties and responsibilities of universities. They have to provide leadership in politics, administration, professions, industry and commerce. They have to meet the increasing demand for every type of higher education, literary and scientific, technical and professional. They must enable the country to attain, in as short a time as possible, freedom from want, disease and ignorance, by the application and development of scientific and technical knowledge. India is rich in natural resources and her people have intelligence and energy, and are throbbing with renewed life and vigor. It is for the universities to create knowledge and train minds who would bring together the two, material resources and human energies. If our living standards are to be raised, a radical change of spirit is essential.*
>
> Venkataiah, 1999:93

With these words did S. Radhakrishnan, one of the greatest modern philosophers of India and the second President of the country, commend the role of education to the people of India (see UGC website under References). India's Western educational system had come a long way from 1835 when Lord Macaulay gave the following justification for inculcating the British system in India:

> *To rear a class of people who maybe interpreters between us and the millions we govern; a class of persons, Indian in blood and colour, but English in taste, in opinions, in morals and in intellect.*
>
> Taraporevala, 2000

Then came independence and a greater involvement of government in education and research. Within a year, a University Education Commission was set up (1948) under the chairmanship of S. Radhakrishnan to report on Indian university education and suggest improvements and extensions that might be desirable to suit the present and future aspirations of the country. This committee recommended that a University Grants Commission (UGC) be set up along the lines of the UGC in the United Kingdom. The recommendation was quickly (almost too quickly) acted upon and India's UGC was inaugurated by Maulana Abul Kalam Azad, the then Minister of Education, Natural Resources and Scientific Research, on December 28, 1953. But the inauguration was three years too early, for the UGC was formally established by an Act of Parliament only in November 1956. To be more effective, the UGC, located in Delhi, quickly decentralized its operations by establishing regional centers at Hyderabad, Pune, Kolkata, Bhopal, Guwahati, and Bangalore. Its clearly articulated mandate includes promoting and coordinating university education; framing regulations on minimum standards of education; distributing grants to universities and colleges; and serving as a vital link between the union and state governments and institutions of higher learning.

Since independence, the number of universities has grown at a staggering pace. The number at the turn of the century stood at 207 (202 state plus 20 central) as against just three state universities in 1857. About 60% of the state universities, including most of the major ones, are funded by the UGC. Many state universities are named after national or local heroes, such as Potti Sriramulu (the man who died from fasting to divide the country along linguistic lines), Dr. B. R. Ambedkar, Maulana Mazharul Haque, Acharya G. N. Ranga, Veer Kunwar Singh, Justice Hidayatullah, Vinoba Bhave (who figured on the cover of *Time* magazine, with the words *I have come to loot you with love*, Pandit Ravishankar Shukla, Chaudhary Sarwan Kumar, not to mention Jawaharlal Nehru, Indira Gandhi, and Rajiv Gandhi. In addition to the state universities, there are 20 other universities that were started by the central government. As stated previously, Allahabad University was started well over a century ago (1887). Among the others, started more recently, Banaras Hindu University (1916), Aligarh Muslim University (1920), University of Delhi (1922), Jawaharlal Nehru University at Delhi (1970), Central University at Hyderabad (1974), and Central University at Pondicherry (1985) are particularly noteworthy.[2] These are quite outstanding universities (although I have no knowledge of the quality of many of the other central universities, I can attest to the truth of this statement from personal experience with one of them, the Central University at Pondicherry).

It is well known that every country considers a few of its universities as the most outstanding and deserving of government encouragement. No better example of this can be cited than what happened in England in the early 1980s when the UGC of that country was asked to prune the expenditure on universities. It decided to increase its support for the universities at Cambridge, Oxford, and London at the expense of many less known ones, which were forced to close down some of their departments. The Government of India did not do any all-round pruning but declared a selected number of its universities and teaching/research institutes as institutes of national importance (Box 4.1).

This made them practically invulnerable to any such pruning. All the seven IITs were included in this list.

UGC-CSIR examinations: Frequent mention will be made in subsequent chapters about Junior and Senior Research Fellowships, JRFs and SRFs, respectively. Hence a brief description of these appears relevant. They were created for the dual purpose of meeting the research student needs of universities, the CSIR and other research establishments, and the stipendiary needs of students desiring to pursue careers in research. Under this scheme, the CSIR holds national level joint UGC-CSIR Examinations (NET) twice a year

Box 4.1: Institutes of national importance

1. All India Institute of Medical Sciences, New Delhi
2. Dakshina Bharti Hindi Prachar Sabha, Chennai,Tamil Nadu
3. Indian Institute of Technology Assam Guwahati, Assam
4. Indian Institute of Technology Delhi, New Delhi
5. Indian Institute of Technology Kanpur, Kanpur,Uttar Pradesh
6. Indian Institute of Technology Kharagpur, Kharagpur, West Bengal
7. Indian Institute of Technology Madras, Chennai, Tamil Nadu
8. Indian Institute of Technology Mumbai, Mumbai Maharashtra
9. Indian Institute of Technology Roorkee, Roorkee, Uttaranchal
10. Indian Institute of Technologies at Hyderabad, Patna, Gandhinagar, Jaipur
11. Indian Institute of Science Education and Research at Pune, Kolkata, Bhopal, Mohali and Thiruvananthapuram
12. Banaras Hindu University, Varanasi, Uttar Pradesh
13. National Institute of Science Education and Research, Bhubaneswar, Orissa
14. National Institute of Pharmaceutical Education and Research, SAS Nagar, Mohali, Punjab, Hyderabad, Andhra Pradesh, Hajipur, Bihar, and Kolkatta (West Bengal)
15. Postgraduate Institute of Medical Education and Research, Chandigarh, Punjab
16. Sree Chitra Tirunal Institute for Medical Sciences and Technology, Thiruvananthapuram, Kerala

to select the best students. The same examinations are also used as the basis for selecting lecturers in science and arts subjects.

Different states accredited by the UGC conduct State Level Eligibility Tests (SET) for the same purpose. NET and SET have both practically the same syllabi.

Before the formulation of NET, the CSIR had worked out a system of awarding fellowships without examinations. It normalized the grades and classes awarded by different universities so that there was a common basis for comparison. This along with a few other considerations worked quite well, but NET and SET are definitely superior and are almost entirely free of bias.

INDIAN INSTITUTES OF TECHNOLOGY

In general, Indian students enjoy a good reputation in American and European universities. Usually they do very well, some exceptionally well. In fact, many of the top American universities contact the toppers to offer them lucrative fellowships to join them. When one looks at these happenings closely, one finds that all these students are from one IIT or another. The term IIT is now known in practically all universities in the world and has become synonymous with education of the highest order. How did all this happen? Once again, one sees the vision and hand of Jawaharlal Nehru. He desired to create an educational system that would take in the best and give out the best. Thus was born the first IIT at Kharagpur in Bengal in 1950, just three years after independence. The location was unintentionally appropriate because, as will be recalled, Calcutta was the breeding ground for many intellectuals and scholars in past years. There were also other, political, reasons for choosing the location. The institute was set up by an international consortium of universities under UNESCO. Then followed a series of four IITs and the number did not change till recently when two more were added. Since 2009, several new IITs have become functional.

The list of IITs together with their dates of establishment and the names of states of location is given in Box 4.2. Admission to the IITs is through a common examination administered by government followed by personal interview. The examination is tough by any standard and the selected students are allotted the IIT and subject by a computerized matching of rank and preference.

Box 4.2: Indian Institutes of Technology (IITs)

Sr. No.	*Year Established*	*Name of Institute*	*Location*
1.	1950	Indian Institute of Technology Kharagpur	West Bengal
2.	1958	Indian Institute of Technology Bombay	Maharashtra
3.	1959	Indian Institute of Technology Madras	Tamil Nadu
4.	1960	Indian Institute of Technology P. O. I. I. T. Kanpur	Uttar Pradesh
5.	1961	Indian Institute of Technology Delhi	Delhi
6.	1994	Indian Institutes of Technology Guwahati	Assam
7.	2001	Indian Institute of Technology Roorkee	Uttarakhand
8.	2009	Indian Institute of Technology Hyderabad	Andhra Pradesh
9.	2009	Indian Institute of Technology Gandhinagar	Gujarat
10.	2009	Indian Institute of Technology Patna	Bihar
11.	2009	Indian Institute of Technology Jaipur	Rajasthan

All this was initiated through the goals and objectives derived from the Sarkar Committee Report (1946) which recommended the creation of four higher technical institutions of international standard, one each in the north, south, east and west, modeled possibly along the lines of the Massachusetts Institute of Technology. In May 1950, as mentioned earlier, the first in the series was established in Kharagpur. The site chosen was the Hijli Detention Camp, where the British had incarcerated political prisoners; the institution was named the Indian Institute of Technology even before it was formally inaugurated on August 18, 1951 and embodied in the IIT Act of Parliament. The report, the IIT Act and the statutes of the IITs taken together, indicate the lines along which the IITs developed. Among the main goals are that the IITs were expected

> *to be higher technical institutions in research in some branches of engineering on the lines of the Massachusetts Institute of Technology, better known as MIT; and to provide for instruction and research in some branches of engineering and technology, science and arts for the advancement of learning and dissemination of knowledge in specific branches.*[3]

The goals and objectives were very elaborately drawn up, but it is particularly noteworthy that the IITs were also expected to provide a sense of taste and style. Considering that students are admitted entirely on the basis of merit, irrespective of their origin, this was a bold and visionary goal, for it was a recognition of the fact that many students might not have been exposed to common social graces. I am not sure that such a goal is incorporated in the statutes of any other university or institute in the country.

Evolution of Research

The evolution of research in the British period was restricted to a few broad areas as known at that time. Since then, each one of those areas has undergone a remarkable transformation, the most important element of which is that a host of sub-areas have emerged as full areas in their own right. As a result, the total number of all the areas today is very large indeed — and still counting. It would therefore be futile to even attempt to summarize the developments in each of these. But it is interesting to note how new areas are traditionally created. According to Freeman Dyson:

> *When a field of science is overturned by a new concept or a new tool, a new sub-discipline of science is formed with a new species of scientist, specialized in the new idea or in the new tool.*
>
> Dyson, 1998

I am not sure if this fundamental basis for the creation of a new discipline, defined for the loftier concepts or tools of science, can be applied to all the new sub-disciplines of today, but the general philosophy holds — with the difference that a field of science is usually not overturned but expanded or integrated with other areas and the integrating elements coalesce to form new areas (examples: chemical biology, chemical reaction engineering, polymer science, and engineering). There are many such new disciplines, and the NCL's contributions to some of these disciplines will be discussed in Chapter 8.

Evolution of the Chemical Industry

A brief account of the chemical industry, such as it was during the British time, was given in Chapter 2. A slight overlap between that and the present section is unavoidable. The post-independence evolution of the chemical industry can broadly be divided into three periods:

- A short period up to 1951 when unplanned growth from the pre-independence years was continued.
- The period from 1951 to 1990, the so-called 5-year plan period, when there was considerable development along with much capability building.
- The period from 1990 forward with emphasis on globalization.

The present section will be concerned with the last two periods. The first was generally covered in Chapter 2 and nothing visibly significant occurred during the first two to three years of independence when plans were on the anvil.

EARLY HISTORY: THE PLANNED DEVELOPMENT ERA

General Comments

The chemical industry in the pre-independence era, particularly in the 1930s and 1940s, like most other industries, was largely geared to the war effort, with greater emphasis on quick local availability than cost. This in turn led to an emphasis on profit. The first government under Nehru continued the effort towards indigenous capability building, but with the object of benefiting the entire country and not individual entrepreneurs alone. Government's policies were enunciated through a series of Industrial Policy Resolutions (IPRs), Industrial Policy Statements (IPSs), Technology Policy Statements (TPSs), and modifications of the Foreign Exchange Regulations Act (FERA). Particularly pertinent to our discussion is IPR-1948 which laid the foundations for the country's development through the establishment of a socialistic pattern of society. All development, including industrial growth, would occur within this framework. The 1973 document emphasized the private sector and foreign participation, and the 1977 statement emphasized decentralization and development of small-scale and cottage industries.

Thus, the era of public sector undertakings in practically all branches of industry was launched and continued to dominate the industrial growth of the country for four decades. An integrated Ministry of Commerce and Industry was established with the resourceful T. T. Krishnamachari as its first Cabinet Minister, and he went on to immediately set up the Development Wing. By an act of Parliament in 1951, the Development Wing was empowered to assist in the country's industrial development

> *by exercising control over imports and at the same time promoting the development of any industry as desired by Government.*

According to Kane (1990), the first major decision of this Wing was to abolish the practice of payment of royalties of the order of 5% to overseas companies, merely for the sale of products by their brand names that were popular abroad. At about the same time, a new Chemicals Division of the Development Wing was created and was headed for the first ten years by G. P. Kane, a Professor of Chemical Engineering at the Bombay University's Department of Chemical Technology (re-named recently as the Institute of Chemical Technology). A controversial figure, he was the architect of the Indian chemical industry's planned development. He was involved in many major industrial decisions and was a member of the NCL's Executive Committee for a few years. In spite of a stormy relationship with the NCL's Directors, K. Venkataraman and B. D. Tilak, many committee members and senior scientists, he was respected by all. The NCL had to work hard to counter some of his arguments but always held him in high esteem for the courage of his convictions, steadfastness, professionalism, and profound knowledge of the chemical industry.

The very act of planning entailed the establishment of a flourishing intermediates industry that would enable production of a desired final product from basic raw materials. The practice before the planning era was to import the penultimate intermediate, and convert it to the final product in a single stage at minimum cost. Since this was considerably cheaper than the final product and the conversion cost was very low, the manufacturers invariably made heavy profits. Small-investment-high-profit became the guiding philosophy of production. This even applied to such conventionally large volume chemicals as sulfuric acid since it was hazardous and expensive to import them, making even small scale production of such chemicals attractive for captive use (against all principles of economics).

A serious problem with technology import was the insistence of multinational companies on establishing either a fully overseas subsidiary with no Indian capital or one in which they had the control of all financial and technical matters. Kane (1990) mentions a particularly unacceptable situation where the ICI demanded a monopoly of 51 years for establishing a unit for dyestuffs manufacture in India and hence the project fell through. The drugs and pharmaceuticals industry fared no better, with most companies preferring to import bulk drugs and convert them into formulations. Further, the overseas exporters charged royalties on the sales price of the formulations and, as mentioned previously, for the use of their own brand names!

A major step in dealing with these problems was the establishment of Development Councils for groups of allied industries by the Ministry of Commerce and Industry. Based on the deliberations of these councils and of other, more specific committees formed from time to time, an overall plan for the development of the organic chemical industry was drawn up consisting of reports for different sectors of the industry. While the operation of subsidiaries by overseas companies was allowed to continue, some of the advantages they had built in for themselves, such as payment of royalty for the use of brand names and tax-free salaries to non-technical personnel, were discontinued. The government also stipulated that the major portion of the equity capital must be held by

Indian citizens. In the words of Kane himself, as Head of the Chemicals Division of the Development Wing:

> *Gradually, it became more and more difficult to obtain sanction from the Government for overseas payments for imports of technology. Indian laboratories set up by Government claimed that they had developed technologies for processes, which entrepreneurs wished to obtain from abroad. The entrepreneurs preferred to obtain processes from abroad, as they were offered by companies that had developed the processes as pioneers, used them to produce and sell products abroad, and offered performance guarantees. The processes developed within the country, almost always represented some technical work done on processes operated abroad, but without the scientists having any experience of operating them for commercial production, and without any guarantees.*[3] *Sometimes the scientists went so far as to claim that they can develop the processes in India, and provide the knowledge in a short time. Politically, it was difficult for Government to brush aside the claims of either side, with the result that there was a stalemate and sometimes the controversy could not be settled for years. The resultant delay in organizing production of the concerned items was a price that had to be paid in the political climate of a new democracy.*
>
> Kane, 1990

With the wisdom of hindsight, Kane was not wrong all the time, though he made a fetish of almost indiscriminately blocking all indigenous technologies. This led to a difficult but predictable situation, but fortunately did not impede the progress of laboratories like the NCL. Many problems arising out of this situation were solved by a combination of policy changes and individual laboratory initiatives. How the NCL tackled them is embedded in the discussion of its history in the chapters ahead. As a precursor to these, some important procedural changes were introduced to help speed up implementation of projects:

- The hesitation on the part of overseas companies to invest in India due to delay and uncertainty in the grant of an Industries Act License was minimized by the expedient of first granting a Letter of Intent that would enable the company to immediately produce up to 50% of the anticipated capacity. If this was successfully achieved, the conversion of the Letter into a License was assured.
- The British days import duty structure which favored (to a ratio of 4 to 1) import of complete plants but penalized companies that constructed their own plants in India by importing component parts was modified to equalize the two rates. This greatly encouraged implementation of indigenous technologies such as those developed by the NCL.
- The development of technology starting from basic raw materials like ammonia was encouraged by disallowing import of these at low cost and providing incentives for their production within the country. To check any consequent increase in cost of consumer products, the prices of basic raw materials like naphtha and alcohol were regulated, a policy that was unfortunately abandoned later.

However, price control as a uniform policy proved to be disastrous in some cases, like in those of sugar and cement. Black markets flourished, leading to rationing of these commodities. Such setbacks were used to denounce the policy often referred to derogatorily as the *policy of control, license,* and *ration*, and ultimately led to significant modifications. Research institutions like the NCL bore their share of the consequences of these policy changes. As globalization became increasingly the central theme of development, it had its own effect on these laboratories. We shall see later how the NCL adapted itself, without losing its identity, to these changing policies that were a mixed bag (of varying proportions), mostly a deterrent to indigenous technology development.

Alcohol, Petroleum, and Coal Committees

To practically all countries of the world, planned development of an entire industry was altogether a new concept. The government realized, however, that development of an industry in a world with very few available technological resources to choose from, limited knowledge of raw material resources, and a slowly unfolding supply matrix was an entirely different matter compared to the situation in the 1950s. Planning would speed up the process along well-organized lines in the context of the country's current and projected demands and availability of competitive technologies based on different raw materials. As it happened, India went through a highly successful period of planned development through a dozen five-year plans and then, in 1990, moved on to open market economy spurred on by globalization.

National planning of the chemical industry was revisited with all the three available sources of nature as starting materials: petroleum, biological (alcohol), and coal. Separate committees for all the three were formed: Alcohol Committee, Petroleum Committee, and Coal Carbonization Committee. The last two were created almost simultaneously a few years after the first and hence had the advantage of each other's deliberations.

As the recommendations of the Petroleum Committee were the most extensive and perhaps the most important, the government constituted another, more powerful, committee, the Committee for Perspective Planning for the Petrochemicals Industry for the period 1986–2000, with the object of defining priorities as the country entered the 21st century. This committee was popularly known as the Apex Committee.

In the following paragraphs, we shall outline some of the major recommendations of these committees, including some brief excursions into the history of those sectors of the chemical industry with which the NCL was more directly involved. A fuller narration of the NCL's role will be deferred to later chapters.

ALCOHOL AS RAW MATERIAL

Petroleum and natural gas were recognized as the most attractive raw material sources for the production of organic chemicals. On the other hand, when planning began in the mid-1950s, petroleum was available only in small quantities from the Digboi wells and there were no known reserves of natural gas. In this situation, alcohol was tapped as the most suitable alternative till some other more viable source became available. Hence, a national level Alcohol Committee was formed in 1956 with the object of establishing an organic chemicals industry using alcohol as raw material as an interim measure. An additional impetus was the prohibition policy of the government, which resulted in a lowering of alcohol production and the consequent accumulation of molasses (from which alcohol is made) from the sugar industry. The pollution arising from this could be avoided by converting the molasses into more alcohol for industrial use.

Based on a projected alcohol availability of 40 million gallons by 1961, the Alcohol Committee recommended a minimum capacity for each alcohol distillery, regulated prices for molasses and alcohol, and a 30,000-ton plant for styrene-butadiene using alcohol. Following up on the last recommendation, the government issued a license to the Kilachand group to set up their Synthetics and Chemicals factory at Bareilly in UP. The NCL had a long and fruitful relationship with this company, particularly with its dynamic Managing Director, D. M. Trivedi, who also served on various committees of NCL. Several scientists from the Polymer Chemistry Division, including its Assistant Director, S. L. Kapur, a former student of Professor Hermann Mark, were associated with a major collaborative project of this company (nitrile rubber).

Other examples of the use of alcohol as raw material based on the Alcohol Committee's recommendations are: polyethylene plants by ICI and Union Carbide; PVC plants by Calico Chemicals, DCM, and Chemplast; polystyrene plant by Polychem, a company promoted by the Kilachand's of Bombay and Dow Chemicals of USA. As a result, most of the alcohol produced in the country was diverted to chemicals production by 1957. Acetylene from non-alcoholic raw materials (calcium carbide and water) was also used as the basic chemical for manufacturing certain organic chemicals. The first such plant was an inefficient 10-ton a day plant at Calcutta, a wrong location from all points of view. Recommendations for licensing additional acetylene units were not implemented. As no other significant raw material source was available at that time, these developments (particularly the use of alcohol) are generally regarded as the beginning of the organic chemicals industry in India.

A point worth noting here is the unsuccessful involvement of the NCL in these developments. An example is the project for the production of PVC. A technology as engineering intensive as this and involving three complicated stages was clearly beyond the NCL's reach at that time, largely because it just did not even remotely possess the required level of engineering competence and was almost clueless in its appreciation of the economic and other factors involved. And yet the NCL took on this project in its early years, with the rather naïve hope of offering it to industry, only to abandon it a few years later. Informal overtures to Polychem for involvement in their styrene technology were fruitless. Several years later, in the mid-1980s, the NCL did succeed in offering a state-of-the-art technology, the Albene process for ethylbenzene (for subsequent conversion to styrene), starting from 95% alcohol (as opposed to ethylene or absolute alcohol), to the Mallya Group (see Chapter 11). I mention these because they provide instances both for upholding and rejecting Kane's contention. His views and those of many of his ilk never changed and stayed rooted in the past (till the 1970s), in spite of the advances made by the NCL. It was a case of the static versus the dynamic.

PETROLEUM AS RAW MATERIAL: PETROCHEMICALS

The first example of the interactive nature of the petroleum and coal committees was the use of the statistical information provided by the latter in launching the petrochemicals industry by the former. It was the Coal Committee's discovery that even if all the benzene from existing and planned coke ovens in the country were available, the amount would still be far short of the requirement. This was also true of naphthalene, toluene, and the xylenes. Hence, one of the urgent recommendations of the Petroleum Committee was to set up a BTX (benzene, toluene, xylene) unit in a refinery, processing crude oil rich in aromatic and naphthenic components. Since the crude from the Ankleshwar wells in Gujarat met this requirement, it was decided to set up the first BTX unit in the Gujarat refinery. All of these plants were based on imported technology till the mid-1980s.

Carbon black, used in the manufacture of automobile tyres, was entirely imported. As the use of cars and trucks in the country increased rapidly, the Petrochemicals Committee recommended the indigenous production of this important material from furnace oil. Around the same time, on similar considerations, the NCL also took up a project for developing technology to manufacture carbon black. It was the most important work in progress when I joined the NCL in 1954 and was being carried out under the leadership of S. L. Sastry, a chemical engineering Ph.D. of a well known American university. A well-instrumented pilot plant was constructed and went operational soon thereafter. A most crucial experiment was to be started on a particular day. Sastry had spent weeks preparing for it, and on the designated day, the plant was started with every hope of success. When I arrived in the laboratory the next morning, the first sight to greet me near the plant was a disheveled Sastry sitting with his bowed head in his hands. There had been a blow-up and the experiment had failed. This was followed by a few other failures. At the same time, the required carbon black demand was being increasingly met from plants established by overseas companies in India. On the whole, the outlook was bleak, and it was not long before the NCL decided to drop the project. This was a blow to Sastry, to whom this project had become something very personal, and was perhaps one of the reasons that drove him to leave the NCL and join a neighboring public sector undertaking, the Hindustan Antibiotics Ltd., where his efforts were far more successful.

Methanol, another important basic chemical, was not produced in India either. Thus, many derived intermediates like urea, phenol formaldehyde, and chloromethanes had to be imported or made from imported methanol. The Petroleum Committee recommended the production of methanol with a capacity adequate to meet the much increased projected demand. It also recommended the establishment of capacities for PVC, polyethylene, and nylon 6, along with the raw material required for its production, caprolactam. The production of the rubbers, polybutadiene, polyisoprene, and butyl rubber, was also recommended. Around this time, the NCL had just started a competent group in rubber chemistry under Uma Shankar in the Polymer Chemistry Division, and soon made its second major mistake in project priorities. It decided to develop a process for butyl rubber. The production of butyl rubber is a highly engineering intensive technological process, more mechanically oriented than chemical, which together far outweigh in complexity the role of chemistry itself, central as it is in any chemical process. After two years of wasted effort, the project was dropped, Uma Shankar retired, and the NCL's involvement in rubber chemistry waned. Instead, its interest in polymer chemistry became a firmer commitment and paved the way in 1975 for a strong polymer science and engineering group. A major achievement of the Petroleum Committee was the firm establishment of petroleum cracking units and petrochemical complexes in India. The main purpose of a petrochemical complex is to convert the various fractions obtained from petroleum refining (methane, LPG, gasoline, naphtha, kerosene, diesel oil, furnace oil, and asphalt) to bulk intermediates, polymers, and other large-volume products. Four crackers, to be located in Bombay, Koyali, Barauni, and Madras, were recommended in the first instance, based on steam cracking of naphtha to produce ethylene, propylene, butylenes, benzene, butadiene, etc., the basic building blocks of the petrochemical industry. Several other units came up in subsequent years when Reliance Industries became the most dominant player in the refining and petrochemical industries. They also acquired the Indian Petrochemicals Corporation Ltd. (IPCL) from the public sector, one of the first major occurrences in the Indian chemical industry in the post-plan period marked by free market economy. This and other initiatives by them put India firmly on the map of the world in these industries. More details on this, and the NCL's involvement in the developments, will be given in another section on the globalization of the Indian chemical industry, as well as in Chapter 6 and Chapter 12.

The first major petrochemical complex set up by government was the IPCL at Baroda with technologies for different products from different established overseas companies. J. J. Mehta, a graduate of MIT with considerable experience in the Indian industry, was appointed the IPCL's first Chairman and Managing Director. One of the persons most responsible for the IPCL's growth and for ushering in the petrochemical era in a major way was Lovraj Kumar, Secretary to the Ministry of Petroleum and Chemicals. He was a dynamic individual who, unlike many bureaucrats, had great respect for scientists and valued their views immensely in formulating important policies. The scientists, for their part, felt completely at ease with him and made their time and advice freely available to him. (It is gratifying to know that recently, the Ministry of Petroleum and Chemicals honored him posthumously with a plaque and that a Lovraj Kumar Foundation has been established under which distinguished persons are invited to deliver lectures every year.) Thanks to his imaginative initiative, the IPCL was the first major undertaking in India to establish a large research and development center at the very inception of a project. Having declined the offer from Kumar to head the R & D Center, I was requested later to be associated with the IPCL as an advisor to the CMD, a position I held for the first few years of the company. In this capacity, I spent a few days in a month at the IPCL. This was the time when the organization recruited some of its most outstanding scientists, including S. Sivaram and T. S. R. Prasada Rao (who later became Directors of the CSIR laboratories). All these appointments and some other initiatives augured well for the R & D center. As far as the NCL was concerned, a most rewarding outcome of my association with the IPCL at that time was my contact with Sivaram, which in later years resulted in his joining the NCL. He used to visit the laboratory as the IPCL's representative to monitor some of the projects sponsored by them. It was at this stage that I broached the question of his joining the NCL as head of its Polymer Chemistry Division. His decision to accept my invitation to move to the NCL, like those of Mashelkar, Ratnasamy, and Barnabas before him, was one of the most significant milestones in the laboratory's history.

It was at this stage that, following the NCL's new policy of developing internationally competitive technologies rather than modifying and engineering old ones, the laboratory developed its own series of zeolite catalysts. This was a major achievement in catalyst development. The IPCL had been launched a few years earlier, and the NCL stepped into the picture by offering an Encilite-based process for xylene isomerization predominantly to the meta isomer used in polyester manufacture. This process marked the advent of the NCL in the internationally competitive field of petrochemicals. More information on this may be found in Chapter 11.

The petrochemicals industry has been a major success story of India, largely because of the highly efficient management style and imaginative initiatives of the Reliance Industries. I would therefore like to end this section by referring to the article by Mukesh Ambani (2002), the guiding spirit of Reliance after the death of its founder Dhirubhai Ambani, wherein he makes an excellent analysis of the Indian chemical industry as a whole.

CHEMICALS FROM COAL CARBONIZATION

The Coal Carbonization Committee was specifically charged with the task of determining the extent to which basic organic chemicals like benzene, toluene, xylenes, and naphthalene could be produced in India, based on which the size and scope of the cracking units to be established at different refineries or in their vicinities could be examined. The Committee came to the firm conclusion that existing and future coke oven units would be unable to meet more than a fraction of the requirements of these basic chemicals. Hence, notwithstanding the emergence of three major steel plants (at Rourkela, Durgapur, Bhilai) during these years and the production of hydrocarbons from the attached coke ovens, plants for cracking of petroleum were allowed to be set up at a brisk pace.

SPECIFIC INDUSTRIES

We shall conclude the survey of the Indian chemical industry by briefly describing the evolution of six specific sectors of the industry: organic intermediates and dyes; drugs and pharmaceuticals; pesticides; biochemicals; oils, fats, soaps, and detergents; and paints.

Organic Intermediates and Dyes

Germany is generally regarded as the first major producer of synthetic dyes in the world, although Perkins, Jr., synthesized the first dye, Mauve, in the UK in 1856. In India, large-scale production of dyes began in 1952, although the credit for making some small quantities must go to Arlabs about a decade earlier, and to a few other firms such as Associated Research Laboratories. The development of this industry has particular relevance to the NCL, as its first two Indian Directors, K. Venkataraman (KV) and his student B. D. Tilak, were the first renowned experts in India in dyestuffs chemistry and played a pioneering role in developing that industry in the country. Venkataraman's *The Chemistry of Synthetic Dyes,* Volumes I and II (1952–53), was one of the first books in the area and was a "must" for dyestuff chemists all over the world. It was translated into many languages (including Russian, without the payment of royalty!) Volumes III–VIII were published during 1970–78, but as volumes edited by him. In keeping with the general practice of consumer organics manufacturers mentioned previously, many dyestuffs manufacturers started from the penultimate intermediate, mostly imported, and produced the final dye in a single stage at a considerable profit. As a result, even in 2000, there were about 1000 units manufacturing dyes in the organized and small-scale sectors, mostly from penultimate intermediates. More importantly, this led to the government's stated policy of integrating the industry backwards starting from basic raw materials. As the industry showed no signs of doing this for fear of reduced profit, the government stepped in to organize a central facility for the manufacture of intermediates. We shall quickly walk through this process (with material drawn largely from Kane, 1990), as it was a major step in the development of India's organic chemicals industry, and marked the beginning of the NCL's deep and abiding involvement with it.

This central facility, known first as the Central Intermediates Project, was later renamed as the Hindustan Organic Chemicals Ltd. (HOC), the name by which it has served many small, medium, and large scale manufacturers of organic chemicals over the years. The early history of the HOC is an outstanding example of the gulf between the birth of a concept and its realization. Even at the start, the idea was opposed by dyestuffs manufacturers, as they feared that this would be the beginning of the government's control of the industry. Another more distressing hurdle was the hesitation of established dyestuffs manufacturers abroad to provide know-how, especially to a public sector undertaking like the HOC, for they too feared the long hand of the government. But the government's commitment to establishing a strong foundation for the organic chemicals industry was unwavering and they proceeded with the project.

Recognizing the fact that many major companies from UK, Switzerland, Germany, Italy, and France were regular exporters of dyes to India, the government invited Montecatini of Italy to submit a proposal. Following the submission of this report in 1956, the ICI of UK, Bayer of Germany, and other companies (including a group of Indian chemical engineers educated abroad) followed suit and submitted their own proposals, also in 1956. Then, after visits of the USSR leaders, Nikita Krushchev and Nikolay Bulganin to India, and of Nehru to the USSR, collaboration between the two countries in various fields was strengthened. One result of this was that the Soviet Union also showed interest in the intermediates project and submitted a report in the same year. Clearly, 1956 was a crucial year for the HOC. The government's decision was made somewhat easier by offers of credit to import equipment by the USSR, and by the Federal Republic of Germany, on behalf of a Consortium formed by Bayer. As a result, the formation of two major public sector undertakings was announced, Hindustan Organic Chemicals, Ltd., with 10% equity participation by Bayer, and the Indian Drugs and Pharmaceuticals Ltd. (IDPL) with Soviet assistance.

Representatives of the NCL were appointed to the Boards of both these companies. B. D. Tilak was also Chairman of the HOC Board for a number of years, from 1967 to 1976. R. B. Mitra, R. A. Mashelkar and I served on its Board too, and I also was a member of the IDPL Board. In the aftermath of a major accident in the HOC in 1993, Mashelkar, who, as Director of the NCL, was then on the Board of the HOC, was appointed Chairman of a national committee to enquire into this accident. These and many more associations, along with the HOC's acceptance of two of the NCL's technologies, highlight the role of the laboratory in the growth of the organic chemicals industry in India. More elaborate descriptions of these are given in Chapter 10.

The implementation of the HOC project was plagued by delays, largely because of disputes that arose between the government and Bayer, *Which threatened to deteriorate into a bitter international dispute* (according to Kane), and the Indo-Pakistan war of 1965. The first was resolved through the efforts of Kane and his counterparts in Germany, while the second took its own political and military course. The government then decided that the HOC should proceed with the import of know-how on its own from the best source available for each item of its product mix.

It was at this stage that a struggle arose between the NCL and the HOC, with the NCL insisting that its technology should also be considered along with tenders from abroad and the HOC insisting that the NCL lacked the capability and the resources for delivering turn-key commercial units with all guarantees. The story of how the NCL approached the problem and had its bids for acetanilide and chlorobenzenes accepted and successfully implemented will be told in Chapter 10.

Another significant feature of the NCL's association with the organic intermediates and dyestuffs industry was the involvement of Venkataraman and Tilak (the laboratory's third and fourth Directors, respectively) in the formation and initial development of a major private sector dyestuffs unit in India, the Indian Dyestuffs Industries Ltd., near Mumbai. This association started when both were at the UDCT and continued for several years after they moved to the NCL. The NCL also had significant contacts with Amar Dye Chem near Mumbai, and Atul Products (established in collaboration with American Cyanamid) near Baroda. It undertook a project sponsored by Amar Dye Chem for the development of a new process for β-oxynaphthoic acid, known popularly as BON acid and used in the manufacture of a variety of dyes. Although a process packet was supplied, the company decided to stay with their old German technology, particularly because the existing plant had to be considerably modified to accommodate the use of a solvent in the new process. The NCL also developed a fluidized-bed process for the intermediate monoethylaniline for Atul Products. A plant based on this process was operated at Atul for several years (see Chapter 10).

Several other companies were established during this period, mostly in the private sector. Starting from eight units in 1950 to 18 in the large-scale sector in 1960, the number rose to over 40 at the turn of the century. Besides the National Organic Chemicals Ltd. (NOCIL) in collaboration with Shell (this has since been closed down), and Herdillia in collaboration with Hercules and Distillers of UK, several other foreign companies also established collaborative ventures, e.g. Ciba-Geigy, Sandoz, Bayer, Hoecht, BASF, and ICI. Even so, the per capita consumption of dyestuffs remains low, around a fourth of the world average. Hence, the scope for the growth of this industry continues to be large, and the NCL gives high priority to organic chemicals projects.

Drugs and Pharmaceuticals

As mentioned in Chapter 2, there was a pharmaceutical industry of sorts in British India, but local production of pharmaceuticals for health care was not a major consideration.

It was in this situation that the first government of independent India decided that health care was a national responsibility and that drug production should be re-planned to meet national needs, a consideration superior to the dictates of trade and commercial practices. This accounts for the phenomenal rise in the number of companies in the country, from about 200 in 1950–51 to over 20,000 in 1999–2000 (Chawla 2002). It also resulted in the setting up, in 1954, of the Hindustan Antibiotics Ltd. in Pimpri near Pune for the manufacture of penicillin. Six years later, under a collaborative agreement with the then Soviet Union, the government set up the Indian Drugs and Pharmaceuticals Ltd. (IDPL), with a large antibiotics plant at Rishikesh in Uttar Pradesh, a synthetic drugs plant at Hyderabad, and a surgical instruments plant at Chennai. I had a first-hand knowledge of the IDPL through my membership to its Board of Directors for over three years in the 1970s. The surgical instruments plant attracted particular attention, for the sizes of the gloves and a few instruments were more suited to the much larger Russian hands than to the Indian hands for which they were meant! Obviously, available technologies were passed on without regard to specific Indian needs. The synthetic drugs plant at Hyderabad represented a large collection of reactors and other equipment for major unit operations with scant regard for their optimum utilization. I suspect that many of them were idle for over 50% of the time!

Some of these personal reservations notwithstanding, in retrospect, the IDPL played a vital role in the country's development of the pharma base. Indeed, in the initial stages, it was largely responsible for the proliferation of technologies for bulk drugs production in the growing private sector of the country. According to Sehgal, one of the early employees of IDPL, this public sector undertaking

> *played the role of a catalyst in the development of the drug industry to its present stage in the country and IDPL can rightly be called the kingpin and mother of the drug industry in India.*
>
> Sehgal, 2001

One may have reservations about such a sweeping statement, but it is certainly true that IDPL has been the springboard for many technologists to launch their own enterprises in the private sector. A shining example is Anji Reddy, who joined IDPL after receiving his Ph.D. under my supervision at NCL. He left IDPL to start a venture of his own, which, after an eventful progression, settled under the name of Dr. Reddy's Laboratories. This company is today one of the pharma giants of the country and is best known for its discovery-oriented approach to drug business.

The present self-reliant position of India in the field of drugs and pharmaceuticals owes much of its strength to an action taken by the Government of India in 1970. This action was free India's answer to the 1883 Paris Convention signed by 11 advanced countries of the world. Since India had no independent status at that time, it had no say in the formulation of the treaty. This Convention, which applied automatically to India under the Indian Patent Law enacted under British Regulation in 1856, effectively forbade any nation to manufacture products covered under the patents issued to any of these 11 countries. This so-called products patent seriously undermined India's ability to manufacture any drugs. Notwithstanding protests by Western countries, Indira Gandhi decided that India had the right to act in her self-interest and that the ethics of manufacture were subservient to this primary responsibility. After all, it was argued, every nation acted in its self-interest, the 11 signatories of the treaty not excluded! The Indian Patent Act of 1856 was therefore amended in 1970. This amendment abolished product patents for drugs and pharmaceuticals and granted limited process patents for seven years from the date of filing. This was a giant step, in fact the single most effective action, in India's leap forward in the field of drugs and pharmaceuticals.

Thus, from a situation where there was hardly any pharma industry worth mentioning as India became independent, the country went through a slow rise in the industrial production of pharmaceuticals till the critical year of 1970, after which there was a dramatic rise in the quantity and number of drugs produced, the number of manufacturing units, and in research and development. In fact, the years following 1970 may be described as a Pharma Revolution, almost in the manner of the green and white revolutions. If our godowns are now filled with food grains (Green Revolution) and if there is abundant supply of milk to meet the people's needs (White Revolution) despite growing increase in population, so is the country flooded today with the best quality pharmaceuticals to meet the needs of most diseases, including anti-TB drugs, antibiotics, pain killers, cardiac drugs, anti-ulcer drugs, vaccines, etc. (Israni, 2001). Nearly all the 350 drugs to combat various diseases are now made in India using indigenous technologies. Almost all the finished formulations required by the ailing population are also made within the country. This has indeed been a formidable achievement.

Having accomplished what the country had set out to do, it was now time to revisit the patent law and put the country at par with the advanced countries of the world in terms of product patent protection. It is an established fact today that international patent laws encourage the inflow of technology, stimulate research and development, and benefit both the national and global pharmaceutical sectors. Almost all countries of the world have recognized this fact and have signed the Paris Convention. India also decided to do so. With this, the pharmaceutical industry in India has come a full circle. With companies like Dr. Reddy's Laboratories, Ranbaxy, CIPLA, and Lupin leading the way, signs are propitious for India making an international debut in the field of drugs and pharmaceuticals in terms of new discoveries. It has already done so for established drugs, with CIPLA's anti-AIDS drug leading the export, and it will not be long before this happens for new drugs as well. Dr. Reddy's Laboratories' anti-diabetes drug bids fair to be the first. In fact, since attaining the landmark goal of self-sufficiency in drugs and pharmaceuticals, India has also been exporting bulk drugs to many countries, including the USA. Some figures will not be out of place here. The export of formulations over four decades from 1955–56 grew by a factor of 80 to over Rs. 1200 crores. But the proportion of bulk drugs exported came down by nearly half. This is a welcome feature since the value added in finished formulations is an additional income to the industry and the nation.

The NCL has played a significant role in this phenomenal rise, both through commercialization of its technologies and early training of chemists, who have since become captains of this industry.

Pesticides

Pesticides are one of the two major agrochemical industries, the other being fertilizers. With the country's population approaching 1.2 crores in 2010, there is a growing need to increase pesticide production. Pesticides can be classified as insecticides, fungicides, herbicides, rodenticides, nemaniticides, etc. They are never used in pure form but are always diluted with emulsifiers and other agents. Pesticides production in India is essentially a post-independence activity that started around 1958 (see *Indian Agrochemical Industry, an Overview*, 2002), but it is remarkable that a large percentage of the major pesticides are manufactured in India, some based on indigenous technology. According to the *Overview*, 145 pesticides were registered in India in 2000, of which 85 were manufactured within the country. In spite of these seemingly imposing figures, the usage of pesticides in India is low.

Environmental concerns have made it mandatory, and rightly so, to register all varieties of pesticides. The industry will have to live with this reality and find ways to make pesticides at lower costs. Due to this and several other reasons, there has been a perceptible fall in the growth rate of the industry, from 14% to single digits. The keen interest shown by the NCL and the IICT was on the wane (see Chapter 8 for the NCL's contributions), partly because the industry appears to have become self-reliant, but more so because the importing of technology has become quite straightforward.

Biotechnology

The emergence of biochemistry/biotechnology in India since independence is a huge story in itself, and no attempt will be made to describe it in detail. The beginnings of biochemistry can be traced to the efforts of B. C. Guha in the early years of the 20th century and the contributions of the Department of Biochemistry at the Indian Institute of Science in Bangalore. M. Damodharan, V. Jagannathan, and C. SivaRaman of the NCL, and Pushpa Bhargava of the then Regional Research Laboratory (Hyderabad) were among the prime initiators of the growth of this discipline. It was not until the 1960s that the concept of biotechnology took root, thanks mainly to the efforts of Tuhin Kumar Ghosh. The production of alcohol from cellulose was perhaps the most important biotechnology project of those years. The second half of the last century witnessed the Indian biotechnology community join the world race in exploring new and fascinating avenues of research and production. A large number of research and manufacturing facilities sprung up, e.g. the Vittal Mallya Research Foundation and the highly R & D oriented Biocon Ltd., both located in Bangalore. The latter company was started by Kiran Mazumdar who would soon become a pioneering industrialist of the country (and one of the first women to acquire fame as an industrialist).

No early description of biochemistry in India would be complete without a reference to the Khandala-type conferences organized by a group of biochemists under the leadership of Pushpa Bhargava. The name indicates the location of the conference, Khandala, less than a 100 miles from the NCL in the state of Maharashtra, where the group met every year for undisturbed meetings and discussions in the brazing climate of this resort town. It was re-named subsequently as the Guha Research Conference (GRC), in honor of

B. C. Guha, regarded by many as the father of Indian biochemistry. This tradition of informal meetings continues to this day. Sivaraman, as well as Barnabas and Jagannathan of the NCL's Biochemistry Division were active participants in this conference ever since its founding.

Oils, Fats, Soaps, and Detergents

The vegetable oils and soaps industry has been in existence in India for over a century. NCL's interest in this area was terminated in the early 1960s, when the entire project was transferred to the Regional Research Laboratory (now Indian Institute of Chemical Technology) at Hyderabad.

The total production of vegetable oils in the mid-1960s was of the order of 2. 5 million tons. It was estimated that by the end of the fourth 5-year plan period, i.e. by 1971, the total requirement of oils and fats would be 3.3 million tons. Unfortunately, this target could not be met and there was a scarcity of oils and fats in the country. The gap between supply and demand continued to rise. To meet this situation, cottonseed and soyabean oils were imported under the US Government's PL-480 program. Steps were also taken to double the local production of cottonseed oil to 200,000 tons a year. A committee appointed by the government recommended that greater stress should be placed on the production of rice bran oil which, in the 1960s, was at the very low level of 10,000 tones per year in spite of the availability of 2–3 million tons of rice bran corresponding to 50 million tons of rice per year. There was a steady rise of rice bran oil production and, in 1990, production was around 350,000 tons against the potential of 675,000 TPA, and in 2005 around 700,000 TPA against the potential of 1,200,000 TPA. Rice bran oil as well as cottonseed oil are suitable for the production of *vanaspati*, the most popular cooking oil in the country. By using them, the availability of edible oils and fats could be increased, which appeared to be one of the objectives.

From vegetable oil to soap is just one step. When oil is treated with caustic soda, glycerine, and sodium, soaps are formed. Soaps are compounds of saturated acids such as lauric acids and unsaturated acids such as oleic, stearic, and linoleic acids obtained from vegetable oils, which are either hard or soft depending on the nature of the constituent oils. They were among the first items to be produced in the chemicals industry, when it was not even known by that name. Since its beginnings in the small-scale sector, by 1950 it was being produced both by the organized and small-scale sectors, to the tune of 120,000 tons and 90,000 tons, respectively. Of the organized sector production, two-thirds was accounted for by one company, Hindustan Lever, and the rest by Swastic, Tatas, and Godrej. It is a historical fact that the small-scale manufacturers added in their process large amounts of bleaching earth used for the purification of oils, thus supplying additional quantities of oils otherwise rejected, and also serving as residual filler. This reduced the cost of the soaps at the expense of their fat content. According to Kane, this encouragement to the small-scale sector was *consistent with the guiding principle of the political philosophy adopted by the country*. (Kane, 1990).

Few other industries represent such a high level of conflict between the small-scale and organized sectors as the soap industry. This happened partly because the soap industry was the earliest and started out as a small-scale venture, but was soon threatened by the organized sector in progressively increasing measure.

The soaps and detergents industry as such received a big boost during 1939–40, when there was a universal shortage of natural fatty oils and waxes which led to new discoveries in Germany and other countries. Around the same time, a wide range of synthetic dyes and new synthetic fibers such as Nylon, polyester and their blends were developed. As a result, new synthetic surface active agents which could be used for such materials were also developed. The detergent industry had arrived and it was only a matter of time before it came to India. Sensing the impending introduction of detergents in India, soap makers in the country demanded that production of detergents should not be allowed, as it would adversely affect soap production. But the writing on the wall could not be erased and the government went ahead with licenses for detergents manufacture. The main reason was that foreign exchange was scarce and the government could not afford to spend it to import vegetable oils that would be needed for increased soap manufacture. Hindustan Lever was the first to start the production of detergents in 1971. The total production rose from 40,000 in 1971 to 100,000 in 1986, to almost double in 2000.

The production of detergents increased rapidly. The number of soap manufacturers too increased to around 50 in the organized sector and 35,000 in the small-scale sector, the latter accounting for almost one-and-a-half the former.

Paints

Along with the soap and pharmaceutical industries, the paint industry has also just completed a century of existence. All these industries, which started a hundred years ago, did so in the small-scale sector and continue to manufacture a significant portion of their products in this sector. However, with increasing demands and the modernization of manufacturing methods, the organized sector grew at a much faster pace. In the paints industry, for instance, the small-scale sector contribution dwindled from 100% in 1900 to 30% in 2000. The paints industry as a whole has been growing at a remarkable rate and is the third fastest growing industry in the country, next only to the lubricant oil and automobile industries.

The public conception of paints is usually as an item of aesthetic or decorative value. Its importance as an item of protective value is scarcely appreciated, and yet its greatest use today is in protective coating. According to the Central Electrochemical Research Institute at Karaikudi, India loses over Rs. 22,000 crores annually due to corrosion, a wealth of money that can be saved by both increasing awareness of the protective aspect of paints and by making them more affordable (Saini, 2002). As a result of the realization of the importance of both the protective and decorative aspects of paints, the number of companies in the organized sector rose over the years, but only about half a dozen companies dominate the scene. As mentioned in Chapter 2, Shalimar Paints (in collaboration with Pinchin Johnson Ltd. of England) is the oldest of these and was started in Calcutta in 1902. This was followed by Jensen Nicholson Ltd., Goodlass Wall Ltd., British Paints Ltd., Blundell Ecomite Paints Ltd., and ICI Ltd. Asian Paints Ltd. was established in 1942. Historically, the first four major paint companies in India were UK based and

Asian Paints is the only Indian company. It became the largest paints company in the mid-1970s and has retained its number one position since.

The paints industry is basically a service business and hence proximity to customers is essential for providing good service. Thus, an important historical feature of the paint companies is the multi-site production facility of each company (Marphatia, 2002). Four of them have five centers each, one has three, and the last, two. Yet another historically important aspect of the paints industry is that Asian Paints, an Indian company, has established its operation in several overseas locations, namely, south east asia, pacific rim, middle east, Sri Lanka, Bangladesh and Egypt.

TRANSITION TO GLOBALIZATION

Some Salient Features of Globalization

Signs of transition to a market economy were clearly discernable in the policy statement of 1980, which encouraged competition in the domestic market, modernization, and foreign investment in high-tech areas. The complete liberalization measures announced later can be succinctly summarized as follows:

- Industrial licensing was withdrawn for almost all chemical products and restrictions such as FERA became history.
- Import tariffs were brought down in steps almost to a fourth (from 140%).
- Import of chemicals was brought under OGL and physical controls on import were withdrawn both for traders and actual users.
- Import of technology and capital goods was made much easier, with automatic approvals within stated limits.
- Foreign direct investment was not only facilitated but encouraged.
- Export promotion received greater thrust and schemes were formulated to enhance local value addition.
- Restrictions on pricing of primary issues were eased and market forces were allowed to determine the premium that could be charged to equity shares.

(Pandia, 2002)

Automatic approval of foreign technology import and 51% equity cover a wide variety of technologies, with which the NCL is concerned. Hence the incentive for companies to approach the NCL for a technology was considerably reduced. As a result, a large number of overseas companies, including multinational companies (MNCs), have established plants through various kinds of arrangements with local companies.

How did a laboratory like the NCL survive, and even continue to excel, albeit in a different way, in the new free market environment? Being a signatory to the Paris Convention, the earlier strategy of evolving new processes for known chemical entities was no longer acceptable. It is estimated that the cost of developing a new pharmaceutical entity and taking it from laboratory to commerce can be over $500 million, which only an MNC can afford, certainly not the NCL. So what were the options? Discover a new entity and then enter into an agreement with an MNC for further developing it (after patenting it, of course), or enter into a contractual agreement with a company right from the beginning, or agree to work on a project farmed out by a company? We shall see in Chapter 12 how the NCL dealt with this emerging problem. The days of acetanilide were gone forever (see Chapter 10). Even catalytic research, which took the NCL to great heights and put it on the world map (see Chapter 11), must be increasingly geared toward discovering a new entity and not restricted to producing a known entity with a new catalyst at a lower cost.

Globalization might have been good for the country's economy and prosperity. Whether it has sapped the roots of the country's demonstrated ability to develop world class technologies without the involvement of multinationals is a different matter altogether, and no clear cut answers are yet available. Laboratories like the NCL have become richer in many ways by these associations. They have equally been the poorer in many other ways. Several analyses by renowned economists are available, but I choose to rely on the analysis in a series of articles by an economist who worked with Venkataraman, Tilak, and then with me, and is fully conversant with all aspects of technology transfer: J. V. Rajan (1994–95) (see also: Jain, Qureshi, and Pruthi, 1994; Haggin, 1993; *Angew. Chem.* Intl. Ed. English, 1990; Nath and Kumar, 1993; Atiyah, 1993). His articles provide cogent arguments on both sides, leaning largely towards the latter. Mashelkar, a former director who went on to become the CSIR's director-general, has also spoken and written extensively on this matter and is firmly of the view that market economy has helped laboratories like the NCL. We shall examine various aspects of this all-important problem in Part IV, while briskly walking through the process development efforts of the NCL.

Before leaving this section, it would be instructive to survey the increase in capacities of some of the major industries in the free market era over a specific period (1996 to 2002) (Chawla, 2002; Masood, 2002). In the case of petrochemicals: in 2002, there were eight naphtha and gas cracker complexes with a total ethylene capacity of 2.4 million TPA, and four aromatic complexes with a total capacity of 1.9 million TPA of xylenes; polymers; the total production rose from 1.36 million tons in 1996–7 to 3.44 TPA in 2002; synthetic fibers: the total production rose from one million tons in 1996–7 to 1.58 million tons in 2002; elastomers (rubbers): the total production rose from 55,000 tons in 1996–7 to 65,000 tons in 2002; downstream plastics processing industry: about 15,000 units in 1996–7 to about 25,000 in 2002.

Is Globalization New?

If this brief introduction to globalization has left the impression that it is a new phenomenon, we will do well to divest ourselves of this belief. Globalization has been a multi-directional phenomenon from ancient times. A sense of this must have emerged from the material presented in Chapter 1 — that globalization in the ancient world happened when science and technology went from East to West. A more complete discussion of this is given by the Nobel Prize winning Amartya Sen, the 16th chapter of the *Argumentative Indian* (2005).

As discussed later in Chapter 6, globalization is neither a demon nor a folly, nor is it a harbinger of unmitigated good. Its shortcomings must be realized and unlimited practice not be allowed to impinge on local inventive talent. How the NCL dealt with this problem is recounted in Chapter 12.

THE NCL'S EARLY RELATIONSHIP WITH INDUSTRY

The NCL's early relationship with industry was not always on an even keel. The industry was uniformly appreciative of the NCL's basic research, but some were frustrated with the laboratory because they felt that it came in the way of importing technology by offering its own "half-baked ones," as they sometimes termed the laboratory's endeavors. They were not prepared to take a risk with untried technology, even if it had been tested on a semi-commercial scale, mostly because it did not have a foreign stamp on it. To some extent, this was understandable, particularly because the NCL had occasionally offered technologies that were incomplete, leading to on-site troubleshooting at heavy costs. A case in point was the problem faced in making a success of the Endosolfan project (a relatively complicated engineering-and-corrosion-intensive technology), resulting in a series of changes to plant and process by continuous association of the NCL scientists over a period of 2–3 years. On the other hand, the NCL did make highly visible and successful turn-key offers and was involved in many other successful technology transfers.

The NCL had several more interesting experiences in dealing with the industry, particularly in the first 2–3 decades of its existence, some of them rather strange. The NCL had successfully transferred a technology to a firm. The process worked smoothly with minimal on-site modifications and the CMD of the company expressed complete satisfaction. Several months later, rumors were afloat that this company was harshly critical of the NCL process and claimed that its success was largely the result of the changes made by their chemists and engineers. Tilak was furious and confronted the CMD with this rumor. The CMD smiled and talked to Tilak as though the NCL chief was some wholly uninformed novice in the ways of industry and explained, as to a 101 class in business:

> *Tilak Saheb, your technology is working beautifully and there are a few others wanting it. Would I be so naïve as to praise your technology and create competition for myself? Come on, Sir*!!

In another instance, the general manager of a firm had openly, and quite unjustifiably, made some negative remarks about the NCL. In a follow-up action, he wrote to KV, the then Director, terminating his firm's relationship with the NCL. Taken aback and gently angry (anything KV did was gentle, unlike his successor BDT), KV wrote back to this effect (I do not have the letter with me, so I may be misquoting the words but not the content):

> *It is only from a company like yours that at this stage in my life and after such close association with your industry, can I get such a letter. Yes, the relationship is canceled*!

Quickly thereafter the general manager apologized and things moved back to normal — or nearly so.

The NCL's relationship with most other companies was quite friendly and a sense of mutual respect and trust was building up. A rather powerful illustration of this was the relationship with HICO Products Ltd. in Bombay, which was producing, among other chemicals like silicone products, a range of ethylene oxide condensates based on the NCL's technology developed by B. C. Subba Rao, who subsequently joined the Hindustan Lever research center as a divisional head.[4] M. G. Abhayankar, the Managing Director of HICO, was a very perceptive and successful leader of the chemical industry. Having come to know of the NCL's efforts in developing a novel technology for chlorosilanes used in the manufacture of silicone products, he approached BDT (a close friend of his) to release the technology to HICO. As the process is highly engineering-intensive, BDT told him that he would be guided entirely by my advice. For some reason, the chemistry between Abhayankar and me was not particularly good and I did not have a positive opinion of the company's engineering competence. Thus our discussion led nowhere. But Abhayankar was nothing if not persuasive. He arranged a meeting in Bombay where we continued the discussion in his house. I then began slowly to see the man for what he really was, sincere, fired with an ambition to serve the country, and prepared to take whatever risk was needed to commercialize a novel Indian technology. Details of the troubles faced by the NCL and HICO as they piloted the project through the maze of Delhi's bureaucracy (for some reason not very friendly this time), strong objections from overseas competitors, principally ICI, and start-up difficulties are told in Chapter 11. During this period, Abhayankar died (due to high blood pressure caused by strong emotional involvement in all the things he did) and I had taken over as Director of the NCL. It was a fine moment for the NCL when the new Managing director, M. D. Dhamankar, invited me to inaugurate the plant in the presence of a vast and distinguished gathering. There were a lot of teething troubles, but the process worked! A really novel technology had been commercialized. But the satisfaction was short lived, as we shall see in Chapter 11.

The NCL enjoyed good relationships with project engineering firms. R. L. Dalal and Co. (RLDC) were the first project engineers to be associated with the NCL. Ramesh Dalal, a civil engineer, who was the Managing Director of the firm, was one of the few leaders of industry to whom national considerations were a higher priority than profit motives. He was also a risk-taker and the first to invest a company's fortunes in an untried technology. R. Jaiashankar, the chief chemical engineer of the company, who was associated with all the NCL projects for which RLDC were project engineers, was a talented engineer who worked very hard to make the projects a success. All the NCL engineers associated with the projects engineered by RLDC — GRV, Mukherjee, and N. Sadasivan — had an excellent rapport with him. A high degree of mutual respect prevailed between the two organizations, which stood them in good stead through the troubling times they had to go through with Hindustan Insecticides Ltd. on the Endosulfan project. The NCL's relationships with other project engineering firms were also mutually respectful and friendly. Humphreys and Glasgow, who engineered the chlorosilanes plant for HICO, were a source of great support to the NCL in dealing with the many problems faced with the government after the plant was successfully inaugurated and operated for almost two years. The NCL also had dealings with public-sector engineering firms, e.g. Engineers India Ltd., National Industrial Development Corporation (NIDC), and Mechanical Engineering Consultants (MECON). Its experience with a number of public and private project engineering firms brought out the clear distinction between the approaches of the two types of undertakings — one willing to make commitments and stake its most, and the other overly careful and self-protective. Viewed in a larger context, public-sector undertakings in general needed to change their approach. With the advent of globalization in the late 1980s and its fierce penetration into the politics of India, this seems to have happened almost as a matter of course, either by acquisition of the errant firms by the private sector or by massive induction of the private-sector philosophy.

Technology transfer is a complex process, particularly where horizontal transfer is involved. It is not enough for the technology to be up to claims and expectations. The receiving culture, particularly the chief executive, must be honestly and fully committed, or the transfer will be contentious. Complete commitment or the part of Subrato Ganguly, the CMD of IPCL, and T. S. R. Prasada Rao, the chief scientist involved in the transfer of the xylofining technology (and who later became a very successful Director of The Indian Institute of Petroleum of the CSIR), were major factors in the phenomenal success of the technology and the Encilite catalyst used. The same was true of the second state-of-the-art technology, the Albene technology for ethylbenzene, for which P. R. Krishnaswamy, a senior manager of the Mallya Group, was the person who initiated the process that resulted in the acceptance of the technology by Hindustan Polymers, a Mallya undertaking located in Vishakapatnam.

The transfer of the NCL's technology for chloromethanes to Standard Alkali, a Mafatlal Group company, would not have been possible without the full support of Arvind Mafatlal, the guiding spirit of the Mafatlal Group of companies and Chairman of the NCL Executive Committee for the years 1969–73. Even more importantly, the success was due to the unqualified support and technical help of Vice-President V. Ramadurai, ably assisted by the Works Manager, A. Swaminathan.

THE RAW MATERIAL POLITICS

In the days gone by, natural wealth was central to the very life of a nation. Neither the basic needs nor the tools of luxury were independent of it. As inter-regional and international commerce grew over the centuries, the world of man began to shrink. Regional richness in natural wealth, though a major determinant of prosperity, was no longer central, something else became important: internal and international politics. Oil, coal, and biomass vied with one another for a nation's budgetary bounty to uncover their hidden presence and tap their potential. Oil led the way, with technology to match purse and availability. The others, even though plentiful, lacked the technical accompaniment to sustain competition. Surges in monetary inputs were as much a response to international pressures as to local political compulsions. For instance, price and production fixing by OPEC (Oil Producing and Exporting Countries) increasingly drove nations to find their own reserves. The politics of natural wealth had come to stay.

India's response was no different from any other nation's. The Ministries of Petroleum and Chemicals, Oil and Natural Gas Commission, and Coal and Energy (known by different names in different regimes), Department of Biotechnology and many more came up. The various committees described made their own recommendations. S. L. Venkateswaran and others wrote several articles (see, for example, SLV, 1960) on the variety of chemicals that could be produced from petroleum, coal, and biomass. As in most countries, in India too, coal seems to have been relegated to the back burner. Petroleum continues to lead with both internal production and imports on the rise. Alcohol from biomass for subsequent conversion to a whole series of industrial chemicals has had its moments of surge. Indeed, the production of synthetic rubber started with alcohol as the basic material. Then, it was petroleum all over, with an intensified exploration for oil and the setting up of huge refineries and petrochemical complexes. Although the use of biomass did not increase significantly, efforts in this area continued to rise. All this tells its own story of raw material politics, not only in India but in many other countries as well. I reproduce in the footnote excerpts from the conversational lecture of George Tyler, the "rubber man," during a one-on-one discussion he had with Senator Kimball Bland of the US Senate.[5] He recommends the use of oil, but some South American countries and a few others favor biomass (alcohol) as raw material.

The NCL was technically involved in raw material politics by its involvement in both of the alcohol and petroleum committees set up by the government from time to time, as mentioned in an earlier section, and its strong links with Synthetics and Chemicals Ltd. of Bareilly in UP, which produces styrene from alcohol, and the IPCL, which produces bulk chemicals and polymers from petroleum feed-stock. It was also more directly involved with these, right from its inception, starting with an ill-conceived project for PVC using ethylene from alcohol, and going on to highly successful petrochemical projects such as isomerization of xylenes. To this day, I am not sure which is the better route, particularly for non-oxygenated chemicals. It would seem illogical to remove oxygen from alcohol, so conveniently put there by nature. The weight of technical argument would seem to be in favor of petroleum, provided the long-term politics of it (that determines continued availability) can be favorably settled.

Some Troubling Questions

As a result of the conflicting experiences of the NCL with the industry, many questions arose. Should turn-key offers be the normal practice? Should there be other levels of technology transfer, including those in vogue from time to time, that needed to be equally streamlined? Are turn-key offers, indeed the very concept of developing a "full technology," by a research laboratory relevant in today's industrial scene? Should the NCL channel its efforts exclusively to developing new reactions and catalysts, novel procedures, innovative ideas, and the like, and pass them on to industry for exploitation, without being involved in technical and non-technical peripherals? If so, what level of engineering should it do? These were questions that troubled the NCL over the years as it evolved into the 21st century. Such decisions were by no means easy for the laboratory, for it meant different things to different people. With funding increasingly coming from industrial sponsorships, collaborations, and consultations, and with the country attempting to reap the benefits of both free market and planned economies, no single course seems fully acceptable. Is it time to discard some existing practices and install new ones? The NCL has been making significant changes in policy from time to time. These need to be re-examined in the context of the unimaginative present day thinking in management circles, actually a lot of old thinking repackaged in new phraseology with sharper definition — and greater punch. The answers may emerge as the reader ploughs through the chapters — which have been kept largely, if not fully, clear of my own views. I have kept, though not very well, my own counsel till the final chapter (Chapter 18), in which I have attempted to make some didactic suggestions that are marked as much by realism penetrating through a haze of idealism as by the inescapable need for drastic deviations from the present course.

❄

5

RING OUT THE OLD — WITHIN REASON, RING IN THE NEW

A MODERN LABORATORY ARRIVES

Believe nothing, O monks, merely because you have been told it. Or because it is traditional, or because you yourself have imagined it. Do not believe what your teacher tells you merely out of respect for the teacher. But whatsoever, after due examination and analysis, you find to be conducive…cling to it, and take it as your guide.

The Buddha
(see *Life*, 1955).

Something there is that doesn't love a wall
That sends the frozen groundswell under it
And spills the upper boulders in the sun.

Robert Frost, 1915, *Mending Wall*

The NCL had physically arrived and was soon running as well. But in terms of its impact it had hardly even begun. What was its research program like as McBain started off the laboratory on its way, and what were its priorities, if any? Then, as the industrial scene changed and as the NCL came increasingly under scrutiny and criticism that it was functioning more as a university than as the industrially-oriented laboratory it was meant to be, how did it react? Later, as the chemical industry became more sophisticated and multinational firms brought in many state-of-the-art technologies, what was the laboratory's response? Finally, as the age of globalization dawned in India and a critical stage had been reached in the NCL's evolution with decreasing government patronage for indigenous technology development and increasing emphasis on cutting-edge research, how did the laboratory continue its premiere status in research and engagement with industry? To meet these challenges, the NCL needed to be made more modern and sophisticated to keep pace with the best in the world, and to be transformed into a state-of-the-art institution. As a prelude to addressing these issues, it is necessary to reassess the *raison d'etre* of the NCL — the rationale, the justification for its existence — in the country's changing context.

The government had stated its position on industrial development from time to time in its Science and Technology Policy Statements. Till around 1990, these policies remained generally stable despite minor variations, but the bureaucracy's implementation of them was a matter of debate. Given this situation and the increasing privatization of government institutions and corporations, the question of the relevance and role of government laboratories not connected with specific industries was always rankling in the minds of legislators and planners. Hence, for a laboratory like the NCL, its *raison d'etre* had to be redefined to reflect its continuing relevance and credibility. Shifts in policy and implementation would be a moving shell within the core in which such an accommodating rationale must permanently thrive.

It is relevant to recall here a personal experience I had around 1960, when I spent several months at the Chemical Engineering Department of the University of Toulouse in France. I had the good fortune of interacting extensively with Professor J. C. Cathala, a founding father of modern chemical engineering in Europe. He was a sad, lonely figure, his entire family having been wiped out in the second World War. He had a passion for books and had his own interpretation of every book he read or browsed — and he read and browsed many.

On one particular book in chemical engineering which I happened to greatly admire, he had an uncomplimentary comment to make: *This is a book that is dead on arrival*, or words to that effect. Seeing my discomfiture, he explained (and I use my own language here): This book gives a fixed set of reasons for writing it. And solves a fixed set of problems that may no longer exist tomorrow. The true intent of a book should be to embody in itself the current and changing reasons for writing it, and the author should be able to address them himself or provide the wherewithal to others more gifted than he, to do so. In other words, and here I quote: *The problems and their solutions should be dynamic and not static and therefore dead.*[1] I do not know how much of this is fully comprehensible, but looking back it certainly seems perceptive. Nearer home, it tells us that an institution like the NCL must constantly redefine itself to stay relevant to changing times. As changing needs cannot be foreseen, staying relevant by appropriate management decisions is itself the first part of the laboratory's *raison d'etre.*

The second part is the operative one: to always remain state-of-the-art in the pursuit of relevance. Some aspects of this, like the quality of scientists and of research, must indubitably be of the highest standards, high enough to be called excellent in the true sense of the word, and not as used casually to describe good work. The NCL's interpretation of excellence and how it has practiced it over the years is an integral part of its history — and continuing relevance. This chapter is concerned with both these aspects of its evolution.

Perhaps the most important single feature of the NCL's evolution is that it has persistently strived to break disciplinary walls (often quite rigid). Recognizing that *while good fences make good neighbors*, the great poet Robert Frost wrote the lines with which this chapter began. To the NCL, the recognition and practice of this approach have been fundamental to remaining state-of-the-art and an evolving feature of its history. There was a time, however, when the word indigenous was over-used and over-practiced, but in retrospect it was a constructive and necessary stage in the NCL's ascent to excellence.

Staying Relevant

Embedded in the NCL's core since its inception is that indefinable quality which upholds the importance of excellence and defines its character. Its motto, *To advance knowledge and apply chemical science for the good of the people*, that greets worker and visitor alike at the majestic high-ceiling, marble-floored entrance to the laboratory is just an outward expression of this quality, an intent inscribed on the mezzanine overhanging the lobby. Sometimes the intent of such inscriptions does not percolate from surface to core. In any case, it is the passage from core to surface that is the real measure of depth. The NCL is an entity of mixed passages, with core meeting surface in a confluence of reality, intent and relevance.

The charge to the laboratory, as given by Bhatnagar, was reproduced in Box 3.2. The initial difficulties in implementing this charge can, in a sense, be appreciated from the following incident. An unproductive scientist of earlier years persistently complained, to justify his own non-performance, that at the NCL, work was possible with only air and water as raw materials since chemicals were hard to come by and time-consuming to procure. Had he but known how unintentionally prophetic he was, his incompetence and anger at the NCL might have found a different expression! Today, a small part of NCL's research program is concerned with doing precisely that: to ultimately make the simplest available molecules, such as methane, water, carbon dioxide, carbon monoxide, the principal raw materials for a variety of chemicals and energy!

To make such things happen, or to compress nature's complicated laws into simple relationships, is often a formidable task. One starts out with a simple theme, wanders into complexities, only to return to the simple theme, but this time armed with the most complex theories and experiments available. For example, the use of small particles has been known for a long time. Its progressive evolution through studies on colloids, fumed silica, microfine calcium carbonate, microfine catalysts, carbon fiber, all the way to the nanotechnology of today — the science of smart particles, is in itself a story of the NCL's continuing *raison d'etre*.

In spite of the great strides in theory, it is the incredibly high quality of experimentation that has revolutionized the world and our perception of life and the universe. First, let us look at some of the most astounding theories conceived by the mind of man, such as Newton's concept of gravity, mass-energy relationship of Einstein, the origin of elements, the concept of black holes, and nearer home, the atomic theory of matter, Bohr's quantum theory, Schrödinger's wave equations, order and chaos, our continuing search for a single universal law out of the ruins of Einstein's failed attempts, Maxwell's theory of electromagnetism, Pauli's exclusion principle (the first step in our real understanding of chemical reactions), Pauling's theory of chemical bonding, Godel's theory of incompleteness, Feynman's theory of quantum electrodynamics, and a myriad others; some extraordinarily important, some less so. The strides made in this direction are truly remarkable. In his incisive analysis of the evolution of theory, Fritz Zwicky, the eccentric genius, had a private theory of everything, which he called the morphological theory.[2] The theory and its application decades later by the chemical engineer Octave

Levenspiel, who probably never heard about this, and by the NCL to reactor choice are outlined later in this section. Based on the frequency of success of his theories, it would seem fair to say that a sound theory at the outset of an experiment is the way to go. As a cautionary note, in the words of Freeman Dyson: *The disadvantage of the method is that it does not seem to work so well if your name is not Zwicky.* (Dyson, 1998)

Take, for example, nanoparticles again. Experiment has far outpaced theory. It is almost certain that, sooner than later, theories will be developed and models proposed based on experimental findings. In general, techniques/instruments have been developed to perform experiments of the highest precision, to measure molecular behavior and particle movements at incredible speeds, to estimate the compositions of stars and planets, to study solid surfaces and interfacial phenomena, to identify and quantitatively measure components in less than a part per billion, and to make many other physical, chemical, and engineering measurements.

On the other hand, as will be described later, a Zwicky is not always needed to make his theory work. It has worked admirably at the NCL, albeit at a less esoteric level.

For a laboratory like the NCL, conceived in high hope, inaugurated with the blessings of the best, and nurtured as a shining light of the CSIR, an inspirational excursion that recalls the best in theory and experiment, is not out of place. A few great findings in theory as seen by me were mentioned above. However, true concept-driven revolutions were fewer, indeed just about six over the last half a millenium as seen by Freeman Dyson (1998) (see also Kuhn, 1962): those associated with the names of Copernicus, Newton, Darwin, Einstein, Bohr, and Freud. Tool-driven revolutions, which somehow are less fascinating to the common mind, were closer to 20. Two of them are particularly noteworthy: Galileo's revolution resulting from the use of the telescope in astronomy, borrowed from the emerging technology of eye glasses, and Watson and Crick's revolution resulting from the use of X-ray diffraction borrowed from physics to determine the structure of big molecules in biology. In general, the effect of a concept-driven revolution is to explain old things in new ways and that of a tool-driven revolution is to make new discoveries.

This brief excursion into the lofty portals of science is less a statement of the NCL's capabilities, or even ambitions, than a focus on the beacon lights in the glare of which it must always function. As I said in the Preface, I have tried to be impersonal in my narration. The sentiment expressed in the single offending line at the beginning of this paragraph justifies this statement — *almost* — and is intended to show how one can falter in the absence of a sense of proportion. The best that most researchers do today, certainly even the best amongst them in India, is to explain an observation from existing knowledge. A new discovery often cannot be straightaway explained and a theory is not "new" unless it can completely dismantle an existing one. In that sense, most research today is not archival, and the NCL is no exception. This in no way diminishes the front-runner status of the NCL in the country, but puts it in perspective against the best.

The NCL has kept pace with the latest developments in its own broad areas in a way matched only by a few other laboratories in the country. Indeed, within the limitations mentioned above, theory just for the sake of improving our understanding of phenomena (including even the evolution of life), experimental research of high sophistication, and combinations of the two are all being pursued vigorously at the NCL. More and more, the laboratory moved in the direction of combining experiment and theory, although the transition has been rather slow. These changes in the NCL are all evolving variations of its *raison d'etre*.

In general, since the NCL is home to different categories of scientists, and no particular class of research is singled out *a priori* for special treatment, the encouragement is determined as much by the scope and quality of the work as from considerations of demand and external funding.

Without aggressive responses to changing situations, the NCL might have remained a placid, unremarkable laboratory evoking little attention. Where the NCL responded dynamically to the changing needs of the projects, it succeeded and earned the industry's respect and goodwill. Where it stuck to a static role, it failed. In many, if not all, of the important projects which were pursued as laboratory undertakings and not just as divisional ventures, it seems to have largely succeeded. On the other hand, one can cite a number of projects of lesser magnitude, where the senior management did not evince any great personal interest and left them entirely to the limited resources of the project leaders. Such projects got killed by inaction at the higher levels, or by the lack of a total commitment that deprived them of appropriate engineering or other assistance. Often they were reduced to pointless patents or routine publications that brought little recognition.

The story of how the NCL fared on many of its projects, including the lessons learned and the different strategies adopted, is told in Chapters 10 and 11. Its performance in the different broad areas of research undertaken by it over the years is described in Chapter 8. The relationship of the success or failure of these projects to the strategies adopted upholds the truth of the statements made in the previous paragraph.

Building Excellence

> If you want to achieve excellence, you can get there today. As of this second, quit doing less-than-excellent work.
>
> Thomas Watson, founder of IBM

Excellence is next to perfection. In any meaningful perception of excellence, it should never be applied to highly commendable performances such as delivery of a timely result, a job well done, even a performance that considerably exceeds expectations. There should be appropriate appreciation and rewards for such performances, as indeed there always is, but excellence is something more. The entire timber and tenor of an organization can be placed in perspective and its credibility enhanced by such a strict code of evaluation. Excellence must be self-evident and not be just a word or a quality forced on a performance laboriously identified from a milieu of *good* ones, as is done by most institutions. It is against this overall background that the evolution of excellence at the NCL will be traced.

IS THERE EXCELLENCE AT THE NCL?

Numbers do matter — like the number of papers, patents, recognitions, etc. But excellence is different. If it exists at the NCL, is it the inner drive of the scientists? Do the directors have a role? Before addressing these questions, let us get down to the most basic one. Is there excellence at the NCL in the first place? If so, what is the evidence? To answer this question, views of several highly knowledgeable persons, connected directly or indirectly with the NCL, were sought to minimize subjectivity. The list of persons interviewed is given in Box 5.1. Their views were sought on the NCL in general, not specifically on excellence.

Box 5.1: Names of persons interviewed for their impressions of the NCL

Name	*Designation*
Aris, R*	Regents Professor Emeritus, University of Minnesota (deceased)
Chaudhari, R.V.	Head, Homogeneous Catalysis, NCL
Dev, Sukh	Former S. N. Bose Professor, INSA
Glatz, C. E.	Department of Chemical and Biological Engineering, Iowa State University
Hamied, Y. K.	Chairman, CIPLA
Hill, J. J.	Department of Chemical and Biological Engineering, Iowa State University
Hirwani, R. R.	Head, Unit for Research & Development of Information Products
Jagannathan, V.	Former Head, Biochemical Sciences
Joshi, S. K.	Former Director General, CSIR, and Secretary, DSIR
Joshi, J. B.	Former Director, UICT, Mumbai
Kulkarni, B. D.	Head, Chemical Engineering & Process Development, NCL
Kulkarni, M. G.	Head, Polymer Science Engineering, NCL
Lele, A. K.	Scientist, Polymer Science Engineering, NCL
Lightfoot, E. N.*	Hilldale Professor Emeritus, University of Wisconsin
Mashelkar, R. A.	Former Director General, CSIR, and Secretary, DSIR
Mitra, A. P.	Former Director General, CSIR (deceased)
Pal, S.	Head, Physical & Materials Chemistry, NCL
Rajagopal, N. R.	Former Head, HRDG, CSIR
Rajan, J. V.	Former Scientist, NCL
Ramasami, T.	Former Director CLRI; Secretary, DST
Ratnasamy, P.	Former Director, NCL; Ramanujan Professor, INSA
Reilly, P. J.	Department of Chemical and Biological Engineering, Iowa State University
Sharma, M. M.	Professor of Eminence, University of Mumbai
Sivaram, S.	Director, NCL
Srinivasan, K. R.	Former Scientist, NCL
Venkatakrishnan, G. R.	Former Head, Process Development, NCL
Verma, A. J.	Scientist, Polymer Science Engineering, NCL
Varadarajan, S.	Former Director-General, CSIR; Former Secretary, DST

*Indicates people with whom informal discussions were held.

Only a few dealt with the subject directly. The general opinion appears to be that excellence does exist in certain well-defined areas of the NCL. This view is borne out by the number of publications in some of the most prestigious scientific journals of the world. Box 5.2 lists the names of the major journals in which at least 10 papers were published (not to mention the many other less prestigious ones). Figure 5.1 shows the increase in the number of publications in general from 1970 to 2007.

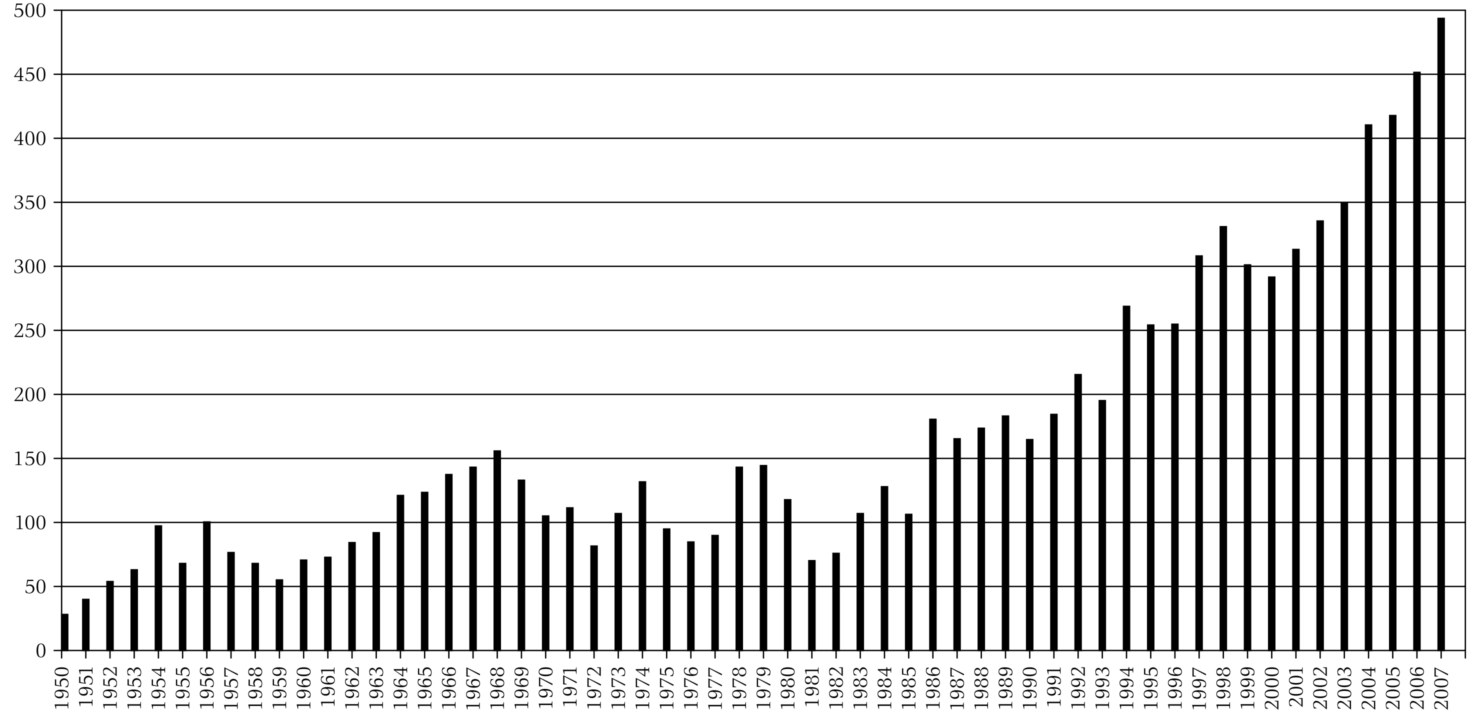
Box 5.2: List of journals (1955–2005) in which 10 or more papers were published by NCL scientists

Ind. J. Chem. (664); *Tet Lett.* (374); *J. Sci. Ind.Res India* (368); *Tetrahedron* (232); *J Catal* (126); *Syn Commun* (120); *Indian J Technol* (114); *Curr Sci* (113); *J Appl Polym Sci* (13); *Appl Catal A Gen* (101); *J Mol Catal A* (99); *Catal Lett* (85); *J Org Chem* (84); *Stud Surf Sci Catal* (84); *Langmuir* (78); *Indian J Chem B* (69); *Chem. Eng. Sci.* (63); *J Indian Chem Soc* (58); *Indian J Pure Ap Phys* (57); *Polymer* (56); *Zeolites* (52); *Acta Cryst.* (51); *Biotechnol Lett* (49); *Chem Eng Sci.* (49); *Macromolecules* (47); *Mater Lett* (45); *Biochem Biophys Res Comm* (44); *A.I.Ch.E.J* (43); *Chem Commun* (43); *Enzyme Microb. Tech.* (43); *J Chem Phys* (41); *J Mol Catal* (39); *J Polym Sci A Polym Chem* (38); *Perfum Essent Oil Rec.* (38); *Phytochemistry* (38); *Thin Solid Films* (38); *J Phys Chem B* (37); *Tet Asym* (36); *J Chem Soc Chem Comm* (33); *Indian J Chem A* (32); *J Chem Tech Biotech* (32); *Microporous Mesoporous Mater* (32); *Paintindia.* (32); *Syn Lett* (32); *Catal Today* (31); *J Phys Chem* (31); *Synthesis Stuttgart* (30); *J Am Chem Soc* (29); *J Polym Sci* (29); *J Indian Chem Soc* (28); *Chem. Ind.* (27); *J Mater Chem* (27); *Brit Chem Eng.* (26); *Catal Commun* (26); *Indian J Biochem* (25); *J Chromatogr* (25); *J Colloid Interface Sci* (25); *J Mater Sci* (25); *Ind. J. Chem.* (24); *J Appl Phys* (24); *Org Lett* (24); *Proc Indian Acad Sci Chem Sci* (24); *Chem Ind-London.* (23); *J Chem Eng Data* (23); *Mater Chem Phys* (23); *Synthesis* (23); *Can. J. Chem. Eng.* (22); *Indian J Biochem Biophys* (22); *Indian J Chem Technol* (22); *Indian J Pure Ap Phy* (22); *Appl Biochem Biotech* (21); *Biotechnol Bioeng* (21); *Ind Eng Chem Res* (21); *Makromol Chem* (21); *Plant Cell Rep* (21); *Thermochim Acta* (21); *World J Microbiol Biotechnol* (21); *Appl Phys Lett* (20); *Bull Mater Sci* (20); *Ind. Eng. Chem. Res.* (20); *Makromol Chem* (20); *Biochim Biophys Acta (BBA)* (19); *Bull Chem Soc Jpn* (19); *Polym Int* (19); *Eur Polym J* (18); *Nature* (18); *Chem Phys Lett* (17); *J Memb Sci* (17); *Angew Chem Int Ed Engl* (16); *Chem Age India* (16); *Ind.Eng.Chem. Res.* (16); *J Chem Res S* (16); *J Organomet Chem* (16); *Org Prep Proced Int* (16); *React Kinet Catal Lett* (16); *Chem Ind-London* (15); *Chem. Phys. Lett* (15); *Green Chem* (15); *J Chem Soc Faraday Trans* (15); *J Phys Chem A* (15); *J Phys Chem Us* (15); *Carbohyd Res* (14); *J Colloid Interf Sci* (14); *J Heat Recov Syst* (14); *J Magn Magn Mater* (14); *Sensor Actuator B Chem* (14); *Solid State Commun* (14); *Theor Appl Genet* (14); *Indian J Med Res.* (13); *J Chem Soc Perkin Trans* 1 (13); *J Inorg Nucl Chem* (13); *Macromol Chem Physics* (13); *Nucleos Nucleot Nucleic Acids* (13); *Organometallics* (13); *Polym Degrad Stabil* (13); *Angew. Makromol. Chem.* (12); *Chem. Eng. Commun.* (12); *J Chem Soc* (12); *J Chem Soc Chem Commun* (12); *J Macromol Sci Chem* (12); *J Mater Sci Lett* (12); *Polyhedron* (12); *Res Ind.* (12); *Spectrochim Acta* (12); *Tetrahedron Lett* (12); *Acta Crystallogr B.* (11); *Anal Chem* (11); *Biotechnol Tech* (11); *Carbohyd Polym* (11); *Chem Mater* (11); *Eur J Biochem* (11); *J Appl Chem* (11); *J Chem Res* (11); *Mater Res Bull* (11); *Polym Eng Sci* (11); *Biol Plant* (10); *Chem Eng J* (10); *Fuel* (10); *Ind.J. Tech.* (10); *J Polym Mater* (10); *JCS Chem.Comm.* (10); *Pop Plast* (10); *Process Biochem* (10); *Res Ind.* (10).

Box 5.2 may be regarded as a measure of quality, while Figure 5.1 is unfortunately what impresses most people. I have never seen a simpler and more cutting difference between quality and quantity than in the following beautiful words of Antoine de Saint-Expuery:

Big people love numbers,
When you tell them about a new friend
They never ask you the essential things.
They never say:
What is the tone of his voice?
What games does he like?
Does he collect butterflies?
They ask you:

Figure 5.1: Trends in research output (1950–2007) — Plot showing increase in the number of papers published over the years



How old is he?
Does he have any brothers?
How much does he weigh?
How much does his father make?
Only then do they think they know him.

Quoted in Marc-Alain Quankin, 2004

Real excellence has the habit of leaving a trail. Thus an important criterion for judging excellence is whether it has been self-propagated either within the institution of its birth or outside, wherever the talent created or nourished by it has chosen to be. The following facts, including the above, assembled from different areas of the laboratory's scientific activities and its scientists' performances both within and outside the NCL, lend strong support to excellence at the laboratory.

In Support of Excellence at the NCL

- Three directors were Fellows of the Royal Society: McBain, Finch, and Mashelkar. Mashelkar was also elected to the National Academies of Science (NAS) and Engineering (NAE), USA. Doraiswamy was elected to NAE, and received two of the highest awards of the American Institute of Chemical Engineers: the Richard Wilhelm and William H. Walker awards. Ratnasamy was named Zeolite Ambassador by the World Zeolite Society and also Srinivasa Ramanujan Professor by INSA. Many directors (McBain, Finch, Doraiswamy, Mashelkar and Sivaram) received Honorary Doctorates from Indian/foreign universities. All Indian directors were/are Fellows of the Third World Academy of Science (in Trieste), the Indian National Science Academy, and the Indian Academy of Science. No other laboratory of the CSIR, indeed no other institution in India (with the exception of the Indian Institute of Science and the Tata Institute for Fundamental Research) can boast of such continued excellence in its directors.
- A senior NCL scientist, Sukh Dev, one of the most outstanding organic chemists of India, received the prestigious Ernest Grunther Award of the American Chemical Society, perhaps the only Indian organic chemist to be so honored. Rajani Nadgauda was elected to the renowned Lineal Society of London. K. N. Ganesh was awarded the prestigious Chemistry Prize of the Third World Academy of Sciences.
- All six Indian directors of NCL so far were honored with the Padma Awards, the hallmark of distinguished service to the nation. Venkataraman, Tilak, Doraiswamy, and Mashelkar received the Padma Bhushan and Ratnasamy and Sivaram received the Padma Shri Awards. No other scientific institution in the country has been so honored by the President of India.
- Over 20 papers were published in *Nature* and one in *Science*, the two most prestigious journals of the world that are known to publish only groundbreaking research (Box 5.3). This does not include the publications of McBain and Finch before they came to the NCL.
- An extended description of the most prestigious papers from the NCL is given in Chapter 8. One of Ratnasamy's papers is perhaps the most cited in the recent history

Box 5.3: List of NCL papers published in Nature and Science

Authors	*Full title*	*Journal*	*Year*	*Volume*	*First page*
Sethi, S. C., Aggarwal, J. S.	Stabilization of edible fats by condiments of spices	*Nature*	1950	166	518
Kulkarni, S. B.	Molecular weight determination by thermistors	*Nature*	1953	171	219
Hiralal	Moving-boundary electrophoresis of colloidal electrolytes using concentration boundaries	*Nature*	1953	171	175
Kulkarni, A. B., Shah, R. C.	Structure of Pristimerin	*Nature*	1954	173	1237
Dutta, N. L.	Separation of saponins by paper chromatography	*Nature*	1955	175	85
Verma, J. P., Bhola Nath, Aggarawal, J. S.	Structure of sterculic acid	*Nature*	1955	175	84
Guru Moorthy, V. R., Gharpurey, M. K.	Revealing of surface texture by metal deposition	*Nature*	1957	179	529
Sinha, K. P.	Electronic configuration of cations in some distorted spinels	*Nature*	1958	181	835
Singh, Lakhbir	(i) Electronic mechanism of addition reactions	*Nature*	1958	181	110
	(ii) Color problem of ruby	*Nature*	1964	181	1264
Deo, A. V., Sanjana, N. R., Kulkarni, S. B., Gharpurey, M. K., Biswas, A. B.	New compounds for water evaporation control	*Nature*	1960	187	870
Bhattacharyya, P. K., Prema, B. R., Kulkarni, B. D., Pradhan, S. K.	Microbiological transformation of terrenes: Hydroxylation of α-pinene	*Nature*	1960	187	689
Deo, A. V., Kulkarni, S. B., Gharpurey, M. K., Biswas, A. B.	Compressibility and specific evaporation resistance of the monol	*Nature*	1961	191	378
Goswami, A.	Epitaxial growth of crystals on one degree oriented substrates	*Nature*	1961	191	160
Nadguada, R. S., Parasharami, V. A., Mascarenhas, A. F.	Precocious flowering and seeding behavior in tissue-cultured bamboos	*Nature*	1990	344	335
Chaudhari, R. V., Bhanage, B. M., Deshpande, R. M., Delmas, H.	Enhancement of interfacial catalysis in a biphasic system using catalyst binding ligands	*Nature*	1995	373	501

(*Continued*)

Box 5.3: (*Continued*)

Authors	*Full title*	*Journal*	*Year*	*Volume*	*First page*
Rajiv Kumar, Asim Bhaumik, Ranjeet Kaur Ahedi & Subramanian Ganapathy	Promoter-induced enhancement of the crystallization rate of zeolites and related molecular sieves	*Nature*	1996	381	298
Choudhary, V. R., Kinage, A. K., Choudhary, T. V.	Low-temperature nonoxidative activation of methane over H-galloaluminosilicate (MFI) zeolites	*Science*	1997	275	1286

of catalysis and one of Doraiswamy's is the fifth most cited paper in the history of Industrial and Engineering Chemistry Research since 1995 (I & E C Research 1999: 1215)

- Varma and collaborators' findings 2002, attracted the following comments in *Nature Science Update* (2002):

  > *Sugar turns plastics biodegradable. Bacteria make a meal of sweetened polyethylene and polystyrene.*

  Full comments are reproduced in *Nature*, Nature News Service/Macmillan Magazines Ltd., December 11, 2002 (www.nature.com). This was also reported in the following journals, newspapers, and other media outlets: *Appropriate Technology*, UK, March 2003; *Plastics in Packaging*, Europe, October, 2003; *Asian Technology News*; *Down to Earth*, New Delhi, June, 2003; *Chemical Industry Digest*, Bombay, July, 2003; website: www. convertingloop.com; website: www.scidev.com; Major newspapers in India, e.g. *Times of India, Indian Express, Deccan Herald*, etc.; Varma was interviewed by BBC, *Wall Street Journal*, a French newspaper, *India Today, Asian Technology News*, etc.
- R. V. Chaudhari and co-workers proposed a novel concept in homogeneous catalysis, *J. Amer. Chem. Soc.* 124, 9692 (2002), and *Chemistry of Materials*, 15 (9), 1766 (2003). The following journals have commented on these papers:

  - *Science, Editors' Choice*, 297, 899 (2002), on the JACS paper under the title "Chemistry Gaining Support Openly"
  - Alchemist web magazine, *The Alchemist* (webmagazine), May 2 (2003) where there are comments on the paper from *Chemistry of Materials*

The comments are reproduced in *Science*, vol. 297, August 9, 2002 (www.sciencemag.org).

- Rajani Nadgauda, V. A. Parasharami and Anthony Mascarenhas accomplished one of the most spectacular breakthroughs from the NCL, propagation of bamboo by tissue culture, which they published in *Nature* (1990). This attracted worldwide attention including a *News and Views* report in *Nature* by David E. Hanke (1990), "Seeding the bamboo revolution" in *Nature*.

The actual comments are reproduced in *Nature*, 'News and Views', March 22, 1990 (www.nature.com). It also led to news and articles from a host of media outlets all over the world, *The New York Times*, Thursday, March 22, 1990; *London Times*, March 23, 1990; *Japan Times*, March 24, 1990; *The Economist*, UK, March 31, 1990; *Mainichi Daily News*, March 24, 1990; *Bangkok Times*, March 24, 1990; *New Scientist*, March 31, 1990; *News Week*, USA, April 2, 1990; *Figaro*, France, March 26, 1990; *Arab News*, April 13, 1990; *The Guardian*, April 13, 1990; *Cologne Gazette*, W. Germany, May 5, 1990; *The Times of India*, New Delhi, May 1, 1990; *The Times of India*, May 2, 1990; *The Times of India*, Bombay edition, 15 May, 1990; *Financial Express*, Madras Edition, Saturday March 24, 1990; *The Hindu*, Madras, March 31,1990; *National Herald*, New Delhi,Tuesday May 1, 1990; *The Illustrated Weekly of India*, April 29, 1990, page 67; *The Economic Times*, Bombay, Wednesday, May 9, 1990, page 8; *Patriot*, New Delhi, Tuesday, May 1, 1990; *Sunday*, 22–28 April, 1990; *Maharashtra Herald, Saturday March* 24, 1990; *PTI Science Service*, May 16–31, 1990; *Science and Technology*, April 10, 1990.

The first page of the article appeared in the *New York Times*, Thusday, March 22, 1990, LCXXXIX, No. 48, 182.

- The NCL's work on nanoscience received wide international acclaim, eg. the editorial comment on the following two papers: (1) Shiv Shankar, et al., *Chem. Mater.*, 17, *566 (2005)*, and (2) Mandal, *et.al.*, *J. Amer. Chem. Soc.*, 125, 8440 (2003).

  Materials Today, 8(3), 10 (2005), for paper 1: Spicy Route to Controlling Optical Properties: Nanotechnology

  Science: *Editors' Choice*, 301, 279 (2003), for paper 2: Chemistry Lightly Reduced

The actual comments are reproduced in *Materials Today*, 8(3), March 2005 and *Science*, 'Chemistry Lightly Reduced', vol. 301, July 18, 2003.

- Several NCL discoveries were selected by prestigious journals to appear on their cover pages:

  Muralidharan et al., *FEBS Letters*, 1994; Kapildev et al., *Journal of Organic Chemistry*, 68(24), November 28, 2003 (http://pubs.acs.org/joc); Rautaray et al., *Langmuir*, 19(24), November 25, 2003 (http://pubs.acs.org/langmuir); Giria et al., *Phytochemistry*, 2003; Varughese and Pedireddi, *Chemical Communications*, 2005; Meadows et al., *Journal of Heredity*, 2005; Kumar, *European Journal of Organic Chemistry*, 2002; Aharoni et al., *The Plant Cell, 2004;* Baskaran, *Macromolecular Chemistry and Physics*, 2001; Sastry et al., *Journal of Materials Chemistry*, 2005; Varughese and Pedireddi, *European Journal*, 2006; Kendhale et al., *Chemical Communications*, 2006.
- A process developed by L. K. Doraiswamy (LKD), G. R. Venkitakrishnan (GRV) and S. P. Mukherjee (SPM) was highlighted in the editorial section of McGraw-Hill journal, *Chemical Engineering*, 'Chementator,' September 8, 1980.
- Structures of several organic molecules were determined for the first time, and many new equations and algorithms were proposed. Most of these were published in

renowned journals. K. Venkataraman (KV) was one of the few Indians to have an organic reaction named after him, the Baker-Venkataraman reaction (see Li, 2005).

- Eight NCL scientists were elected to the Third World Academy of Sciences, Trieste, one of the largest numbers in the country and the largest in the CSIR. Twelve scientists were elected to the Indian Academy of Science, one of the largest numbers from any institution in India and the largest in the CSIR, and to the National Academy of Science.
- Fourteen scientists received the prestigious Bhatnagar Prize, the hallmark of excellence, one of the largest numbers in the country from any institution and the largest in the CSIR. Several scientists received the CSIR Young Scientist Award. The details are given in Box 5.5.
- B. D. Kulkarni and colleagues postulated a new algorithm for reducing noise in a host of process-monitoring and fault-detection applications. This was highlighted in John Wiley's *Technical Insights*, quoted in *Inside R & D*, *AIChE J*, 29, No.4 (1999). The John Wiley report is reproduced in *AlChJ*, 24(4), 1990.
- NCL scientists have written a large number of books and edited many more. A few selected books authored (not edited) by them, before, during, or after their stay at

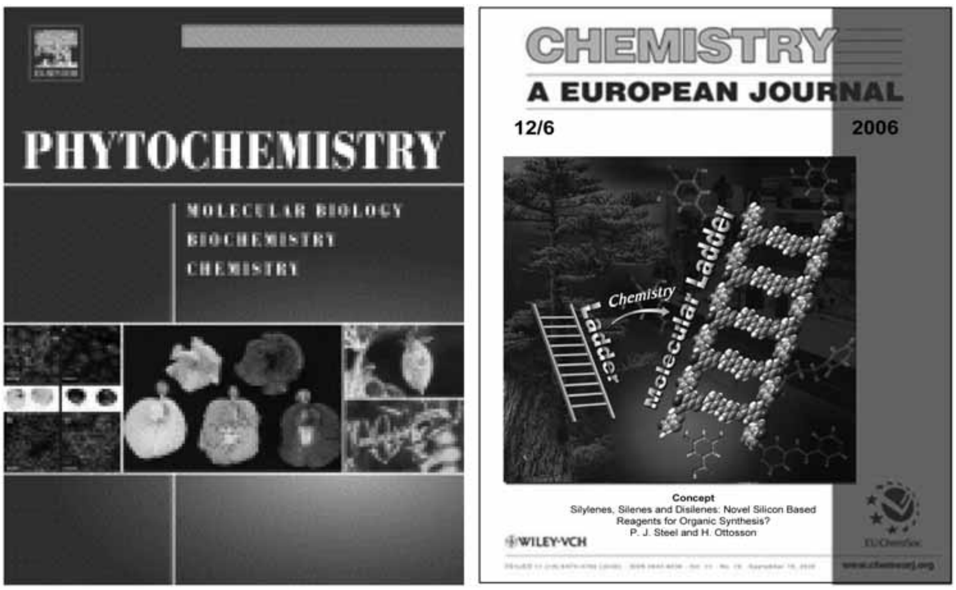
Figure 5.2a: Selected cover page display of the NCL's research papers

Source: Image reproduced by permission of Sunil Varughere and V. R. Pedireddi and The Royal Society of Chemistry from *Chem.comm*, 1824–26, DOI: 10.1039b417754a, vol. 14, April 24, 2005 (www.rsc.org/chemcomm).

Figure 5.2b: Selected cover page display of the NCL's research papers

Source: Image reproduced by permission of Murali Sastry and The Royal Society of Chemistry from *J. Mater. Chem.*, 15, 3161–74, DOI: 10. 1039/b502704g, 15(31), August 21, 2005 (www.rsc.org/materials).

Figure 5.2c: Selected cover page display of the NCL's research papers

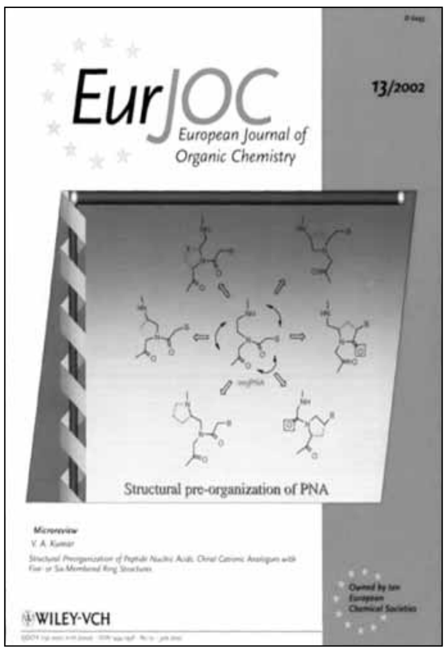


Source: (Left) Front Cover, *Phytochemistry*, 63, 2003. With permission of Elsevier Limited.
(Right) *Chemistry-A European Journal*, 12(6), 2006 (www.chemeurj.org). With permission of Wiley-VCH Verlag GmbH & Co. KGaA.

Figure 5.2d: Selected cover page display of the NCL's research papers

Source: (Left) Front Cover, *FEBS*, 346(20), June 13, 2004. With permission of Elsevier Limited.
(Right) Front Cover, *American Genetic Association-J Heredity*, 96(5), September–October 2005 (www.jheredox-fordjournals.org). With permission of Oxford University Press.

Figure 5.2e: Selected cover page display of the NCL's research papers



Source: Front Cover, *EurJoc*, 13, 2002. With permission of Wiley-VCH Verlag GmbH & Co. KGaA.

Box 5.4: Names of the NCL scientists elected to the Third World Academy of Sciences, Trieste, and to the various scientific academies of India

Sr. No.	*Name*	*IASc, Bangalore*	*INSA, New Delhi*	*NAS, Allahabad*	*FNAE, New Delhi*	*TWAS, Italy*
1.	Anil Kumar	2001	2009	2000		
2.	Barnabas, J		1979			
3.	Bhattacharya, PK		1976			
4.	Bhattacharya, SC		1966			
5.	Chaudhari, RV	1992	2005		1993	
6.	Chaudhary, VR	1993	2003	1995		
7.	Doraiswamy, LK	1974	1977	1988		1997
8.	Ganesh, KN	1993	2000	1996		
9.	Ganguly, P					
10.	Gurjar, MK	1996		1994		
11.	Jagannathan, V	1974	1973	1988		
12.	Kulkarni, BD	1988	1991		1989	2001
13.	Kulkarni, MG	1996			2005	
14.	Lele, Ashish	2009			2004	
15.	Mathur, HB		1974			
16.	Mashelkar, RA	1983	1984	1989	1987	1993
17.	Nadgauda, Rajani			1998		
18.	Nadkarni, VM					
19.	Pal, Sourav	1996	2003	1998		
20.	Patwardhan, VS					
21.	Ranade, VV				2005	
22.	Pandey, Ganesh	1993	1997	1993		
23.	Pradeep Kumar			2007		
24.	Rajappa, S	1982	1985			
25.	Ramarao, AV	1985	1986	1989		1994
26.	Ranjekar, PK			1995		
27.	Ratnasamy, Paul	1989	1987	1989	1999	1996
28.	Sastry, Murali	2002				
29	Shah, RC		1941			
30.	Sinha, APB		1978			
31.	Sivaram, S	1992	1998	1992	2002	2000
32.	Sivaraman, C	1977	1986			
33.	Sivasanker, S	1995				
34.	Srinivasan, MC		1995			
35.	Sukh Dev	1974	1968			1991
36.	Tilak, BD		1962			
37.	Venkataraman, K		1939			
38.	Vijaymohanan, K	2008				
	Total	**22**	**25**	**15**	**8**	**7**

the NCL are listed in Box 8.7. Several books were edited by them, over 250 invited chapters contributed in reputed edited books, and about 10,000 papers published in refereed journals (many of them highly renowned).[3]

- Paul Ratnasamy developed the novel Encilte series of catalysts used in a variety of reactions and made famous by its first use in the IPCL's isomerization reactor

Box 5.5: Names of the NCL scientists who received the Bhatnagar Prize and also the CSIR Young Scientist award

Shanti Swarup Bhatnagar (SSB) Prize	
Name of SSB Awardee	*Year*
S. C. Bhattacharya	1962
B. D. Tilak	1963
Sukh Dev	1964
A. P. B. Sinha	1972
H. B. Mathur	1973
R. A. Mashelkar	1982
Paul Ratnasamy	1984
B. D. Kulkarni	1988
K. N. Ganesh	1998
G. P. Pandey	1999
Sourav Pal	2000
Murali Sastry	2002
V. V. Ranade	2004
A. K. Lele	2006
Young Scientist (YS) Awards	
Name of YS Awardee	*Year*
T. N. Guru Row	1987
K. Ravindranath	1987
G. P. Pandey	1988
Sourav Pal	1989
V. V. Ranade	1992
M. I. Khan	1992
Murali Sastry	1993
S. P. Chavan	1993
A. K. Lele	1996
C. V. Ramana	2003
U. Natarajan	2003
Mohapatra Debendra K	2004
K. Guruswamy	2005
Hotha Srinivas	2006
Pankaj Poddar	2008
K. R. Kamble	2010

for the conversion of the *ortho* and *meta*- isomers to the *para* isomer, used in the manufacture of synthetic fibers.

- With CIPLA's commercialization of processes for vinblastine and vincristine developed by Rama Rao at the NCL, anti-cancer drugs based on indigenous technology were marketed on a sustained basis for the first time in India.
- V. Jagannathan started a school of research in plant tissue culture, one of the first in the country, that put the NCL firmly on the map of the world in the field of biological research.
- The NCL was appointed as a consultant to national governments as well as some of the most prestigious multinational companies in practically all continents of the world. These global consultancies included:[4]

- China, for strengthening R & D institutions
- Africa, for exploitation of biodiversity
- Indonesia, for restructuring of R & D institutions
- Egypt, for setting up a plant tissue culture laboratory
- Europe, for R & D management

not to mention the innumerable consultancies within India. This marked the first time an Indian laboratory was appointed as a paid research management consultant to a major institution outside the country.

- Govardhan Mehta, who got his Ph.D. under Sukh Dev as a junior research fellow at the NCL, went on to hold some very high positions, including the directorship of the Indian Institute of Science. He was elected to the Royal Society in 2006. He is perhaps the only instance of this kind in the entire CSIR, a JRF becoming an FRS. Many other NCL scientists went on to hold top scientific/industrial positions in India/USA. R. A. Mashelkar became Director-General of the CSIR and then was awarded the prestigious Bhatnagar Fellowship (named after the first head of the CSIR); and received over 10 honorary doctorates and some of the topmost international awards (such as the Star of Asia Prize by former President George Bush of USA); Paul Ratnasamy was given the prestigious Srinivasa Ramanujan Professorship (named after the famed Indian mathematical genius Ramanujan) of INSA; R. B. Mitra, A. V. Rama Rao, S. Devotta, and J. D. Yadav were appointed Directors of CSIR laboratories: Sukh Dev left the NCL to take up the directorship of a modern chemical laboratory in the private sector (Maltichem Laboratory) and then was awarded the S. N. Bose Research Professorship (named after the discoverer of boson and co-author of the *Bose-Einstein statistics*, Satyendra Nath Bose) of INSA at Delhi University: S. C. Bhattacharya became Director of the Bose Research Institute (named after the famous Indian scientist Jagadish Chandra Bose) in Kolkata, H. B. Mathur left to become Director of a Defense Research Laboratory at Kanpur, L. K. Doraiswamy was appointed Anson Marston Distinguished Professor of Engineering at Iowa State University in the USA, A. P. B. Sinha left for the USA to take up a senior position with Morris Electronics in California, K. N. Ganesh was appointed Director of the Indian Institute of Science Education and Research (Pune) and is currently also the J. C. Bose Fellow at the NCL, and R. V. Chaudhari was appointed Deane E. Ackers Distinguished Professor of Chemical and Petroleum Engineering at University of Kansas in USA. Many students who got their Ph.D. degrees working at the NCL went to the USA on post-doctoral fellowships, and a considerable number stayed on there to occupy responsible positions in the industry or academia.
- Anji Reddy, who got his Ph.D. at the NCL under Doraiswamy, started a small company which has now grown under the name of Dr. Reddy's Laboratories into a pharma giant and one of the largest, most modern, and most research-oriented pharmaceutical companies in India, with a research center that rivals the best anywhere in the world, and which has been exporting drugs to many countries.
- A. V. Rama Rao, who got his Ph.D. under Venkataraman at the NCL rose to be Deputy Director of the laboratory (later becoming Director of the Indian Institute of Chemical Technology at Hyderabad). He started an R & D company in drugs

and pharmaceuticals under the name Avra Laboratories. In a very short time, this company acquired a national reputation for developing novel processes for known drugs, some on contract basis for well known drug manufacturers in the USA and Europe.

- N. Kumar, who worked at NCL and obtained his Ph.D under Professor K. P. Sinha, went on to become the Director of Raman Research Laboratory at Bangalore.
- S. Devotta, who worked at the NCL on heat energy recycling and later on environmental issues, moved on to the National Environmental Engineering Research Institute as its Director after over 15 years' stay at the NCL. He continued his work on the environment and climate change as a member of the International Panel on Climate Control (IPCC). This Panel was awarded the 2007 Nobel Peace Prize along with Al Gore, former Vice-President of the USA. The Government of India recognized the contributions of the Indian members of IPCC by awarding certificates to them at a special ceremony organized by the Prime Minister. In a sense, as intimated to him by the co-chairs of the IPCC, Devotta is a Nobel Laureate. This is great accomplishment by a former divisional head of the NCL.
- V. M. Nadkarni, who joined the NCL in the 1980s and who, along with Mashelkar, was responsible for establishing a thriving polymer science and engineering group in the laboratory, left the NCL to start an industrial consultancy agency of his own. He now owns two such companies (Techcellence Consultancy Services and Vikas Technologies), and was for several years a consultant for Polyester Business of Reliance Industries Ltd. and is a consultant to the World Bank and UN Center for S & T for Development.

THE ROOTS OF EXCELLENCE

Now to get back to the questions raised before; some scientists recruited in the earlier years of the NCL were outstanding researchers who worked with some of the greatest scientists of the day (some name dropping is not out of place here!):

- A. B. Biswas with Linus Pauling, Nobel Laureate
- H. B. Mathur with Glenn Seaborg, Nobel Laureate
- A. P. B. Sinha, M. K. Gharpure, and R. P. Agarwala with George Finch, FRS
- Gopala Rao (who did not stay long) with Carl Djerassi, Nobel Laureate
- H. J. V. Krishna with Paul Karrer, Nobel Laureate
- S. Rajappa and B. D. Tilak with R.B. Woodward, Nobel Laureate
- K. Venkataraman, B. D. Tilak and T. Ravindranathan with Sir Robert Robinson, Nobel Laureate
- Sukh Dev, A.V. Rama Rao, R. B. Mitra and T. Ravindranathan with E.J. Corey, Nobel Laureate
- R. A. Mashelkar with M. M. Sharma, FRS
- B.C. Subba Rao, N. R. Ayyangar, M. K. Unni, P. C. Sethi and S. Sivaram with Herbert C. Brown, Nobel Laureate
- L. K. Doraiswamy with Olaf A. Hougen

In addition to this, the NCL had many scientists who worked in some of the most famous schools in USA and/or started their own schools at the NCL. V. Jagannathan worked at Stanford and Wisconsin and was one of the founders of tissue culture research in India; Doraiswamy worked at Wisconsin with Olaf Hougen, a pioneering figure in chemical engineering, and is credited with starting the first school of research in modern chemical engineering science (particularly chemical reaction engineering) in India; M. K. Gharpure worked with Paul Emmett, one of the founders of modern catalysis; Ratnasamy was the first to start a truly outstanding school of research in catalysis in India; R. A. Mashelkar was the first to establish a continuing school of research in polymer science and engineering; B. D. Kulkarni, a fully home-grown researcher of world class, was among the first to start a truly high level program in the mathematical modeling of chemical reactions; and S. Sivaram, who came from the industry (IPCL) considerably strengthened NCL's research program in polymer chemistry.

Many of them, besides creating outstanding schools at the NCL, inculcated the spirit of excellence in the laboratory, and some went on to become directors. But credit should also go to the Directors Finch, Venkataraman, Tilak, and Doraiswamy who were able to attract and retain talent of a high order. This spirit of excellence was continued by all succeeding directors who also attracted many outstanding scientists.

A particularly unique feature of the NCL is that all its directors fostered excellence by example. All of them were researchers of international repute. The present director continues that tradition which, one hopes, will remain the laboratory's forte and requirement. The answer to the questions raised earlier should now be obvious: the directors and the scientists were both responsible for creating excellence at the laboratory.

The NCL is not a laboratory with objectives specific to a commodity (such as the Central Glass and Ceramics Research Institute, Central Leather Research Institute, Central Food Technology Research Institute, Central Fuel Research Institute and many others) or to a specific area (such the Central Electrochemical Research Laboratory). The wide range of subjects covered by it will be clear from Parts III and IV. Also, there has never been any true customer identification. As a consequence, the NCL attempts, with an unavoidable dispersion of focus, to cater to an assorted set of customers, well-wishers and planners, such as large-scale and small-scale manufacturers, rural development enthusiasts, those who require turn-key offers, those who desire a specific aspect of a process to be studied, those who need consultation on projects or institution building, academics and scholars who want the NCL to expand its basic research programs, those who wish to see the NCL's excellence reflected in selected areas of R & D, those (mostly the government) who want the laboratory to earn a large portion of its budget and increase its cash flow, those who would like a drastic change in light of the compulsions of globalization, and many more who would like the NCL to engage in a host of other often disparate activities. In a nutshell, unlike many other institutions (and as already mentioned), the NCL meant different things to different people. Seeking excellence in all areas of scientific work in the laboratory was an unattainable goal. Hence it was always recognized that while performing well in many areas, excellence was realizable only in a few. These would not be fixed areas and would change depending on many factors such as the ability of the leaders to sustain an atmosphere of excellence and to attract new talent. It has been suggested that surgery of some form would be needed from time to time to more effectively deploy resources. The different areas in which the NCL was engaged and which are listed in Chapter 8 do not represent areas in which it was simultaneously engaged at any given time. There was surgery from time to time, and not more than 20 areas were actively pursued at any given time.

Notwithstanding all that has been said or unsaid in the previous paragraphs about excellence, the four most important factors that determine excellence are:

- A talent pool that is continually renewed
- Continually updated computational and instrumental facilities
- A continually updated information technology base
- An interactive atmosphere helped and not hindered by the organizational structure

It has been a fortunate circumstance for the NCL that all its directors were deeply conscious of these factors. Although they had had to deal with difficult budgetary situations and deadwood among its scientists from time to time, they were resourceful enough to overcome these problems in varying degrees and in their own ways. Thus, the NCL was one of the few laboratories that never had a real down-turn in all the years of its existence. There were times when there was a rush to push projects to the industry, thus creating the impression that novelty was not an important issue. Although there never was such an intention, such a feeling did prevail for a time, but the situation was quickly corrected.

Item 1, briefly considered above, is discussed in considerable detail below, the 2nd and 3rd items are elaborated under the more general title: the progressive sophistication of the NCL; item 4 is also discussed in fair detail.

CREATING AND MAINTAINING A STRONG TALENT POOL

> *In a long time past, as well as today, we think a great deal about bricks and mortar than of human beings. More money is spent when bricks and mortar are put together. I would like our public buildings to be stoutly built and be enduring monuments and not to be ugly and not good enough. Nevertheless, I think it is more important that money should be spent on human beings and not on mortar…This laboratory started functioning even with disabilities. We must have that psychology and the sense of urgency of work as soon as the slightest opportunity is available.*
>
> Jawaharlal Nehru, Prime Minister of India
> at the Inaugural Ceremony of the NCL, 1950

Attracting and retaining talented scientists is a tradition at the NCL. In fact, Finch went to the extent of offering huge inducements to a scientist without a formal university degree in view of his mastery in designing a variety of instruments. A. U. Momin, who had once worked in C. V. Raman's laboratory and was recommended by him to Finch, received every possible encouragement to join the NCL and then to remain there (in spite of some grumbling that an unqualified person was being encouraged beyond reason). Undaunted by such criticism, Finch held on to him for some years, but eventually the

NCL lost him to the lure of the USA. Finch also brought in A. P. B. Sinha, a brilliant physical chemist and a former student of his, from the Imperial College, London. Sinha stayed on for close to 40 years to make some outstanding contributions and raise the general level of research at the NCL. On the other hand, McBain's efforts were not so well founded. He brought in S. S. Marsden as head of the Physical Chemistry Division, and J. H. Truttwin and J. Gedeon for the Chemical Engineering Division. None of them stayed long and did not leave any mark. Gideon proved to be a good practical engineer but failed to provide any leadership in research or process development (he was still at the NCL when I joined in 1955).

A particularly enlightening incident, as Finch was stepping down and Venkataraman was preparing to take charge as Director, emphasizes the importance placed on talent in the NCL since its inception. The story, which might have gathered some moss through repetition, has it that as Finch was returning to England, he sought a meeting with Venkataraman in Bombay. When the two met, Finch gave KV three lists of scientists. List 1 contained the names of about a dozen scientists who, he advised, should be wrapped in cotton and retained at the NCL at any cost. A. P. B. Sinha, S. C. Bhattacharya, V. Jagannathan, P. K. Bhattacharya, and LKD were among the names listed. List 2 contained around 80 names of scientists who were good workers (foot soldiers, as he called them) who were highly reliable, quite efficient, and who were essential for any laboratory to survive. Finch advised that they should be encouraged. List 3 (rest of the scientists) was the crowning example of Finch's commitment to excellence. He advised that they should be pensioned off. If continued, they would have a negative influence on the laboratory. Others have expressed similar strong feelings on various aspects of the NCL (including deadwood), but never with the force and forthrightness of Finch — with the possible exception of his successor twice removed (Tilak, who was equally forceful in a different context and about whom I will have more to say in a subsequent chapter). They did not use diplomatic or politically correct language. The point is that Finch placed a premium on talent.

The procedure for appointing scientists in those days was quite cumbersome (the years have helped but not much). Interviews took place in Delhi and even for a relatively junior position as Senior Scientific Officer, the minister of Education or Science and Technology was the chairman of the selection committee. Finch, however, made it a point to interview at the NCL, any candidate who showed a keen desire to join the laboratory, before the formal interview in Delhi. I should know, because I was one of the victims of this policy. I was ushered into his office at 9 a.m. sharp on a certain morning. He was seated at a large desk facing the door about 15 feet away (it was a huge well-appointed office, almost a thousand square feet in area) and peered at me from above his half-moon glasses. If he meant to intimidate a prospective employee, he must have succeeded in most cases, but I was not particularly affected — although I could not help feeling his compelling presence from behind the desk. Leaving me at the door, his neatly attired, blue-turbaned secretary with his well-groomed beard retreated into his own office. I stood hesitating at the door, when a strong voice poised midway between humor and urgency beckoned me to his desk. He looked at me for a full minute and said *Won't you sit down?* He then made some small talk and called in his second secretary to bring some tea. Most people in India drank coffee, but not so in an Englishman's office in the mid-20th century! The interview "discussion," (as Finch chose to call it) lasted the whole morning. It was a rigorous discussion on thermodynamics and kinetics (my choices for his attack!). When at last around 1 p.m. his secretary returned to say it was time for the Director's lunch, I heaved a sigh of relief which, I suspect, did not go unnoticed by Finch. But he was unmoved and rose, with the cryptic remark softened by a half-smile and a twinkle in his eyes: *We shall continue the discussion after lunch. 2:30, okay*? Less concerned than shocked, I nodded. The afternoon discussion went on till 5 p.m. and was no less rigorous. He then got up suddenly and said good-bye. I left in a hurry — lest he change his mind and summon me for a third session! I came out with a good feeling — that was unambiguously confirmed when he called out: *I like you and want you in my lab.* He had made up his mind and nobody on the selection committee or the CSIR was going to come in the way!

The NCL's appointments were not always through the regular channel, although these had to be used to formalize an appointment. Some examples of such appointments, and the recognition the concerned scientists brought to the NCL, are cited below to emphasize the premium placed by the NCL on talent. Sukh Dev, from the Indian Institute of Science, one of the most talented and respected organic chemists of India (whose principled rejection of self-promotion deprived him of the higher honors he deserved), was offered a senior position by KV as soon as the latter joined NCL in the early 1960s. S. C. Bhattacharya, who was already at the NCL and was regarded as one of India's foremost organic chemists at that time, and Sukh Dev formed a formidable twosome who worked independently of each other and, along with KV, made the NCL the Mecca of organic chemistry in India. He also brought in Madhavan Nair, a brilliant physical organic chemist from Caltech, to start NMR research at the laboratory; K. G. Das, a first-rate organic chemist; and H. B. Mathur, a brilliant physical chemist, from the University of California at Berkeley. And, of course, he brought in Tilak — who would change the NCL forever. Tilak brought in R. B. Mitra, a reputed organic chemist from the industry, to head one of the organic chemistry divisions of the NCL and to provide the industrial bias he so strongly desired. Mitra headed the highly successful pesticides group that developed several processes for the industry. Doraiswamy, with the full approval and assistance of Tilak, offered a senior position to R. A. Mashelkar to start the first school of research in polymer science and engineering in India. Among the other offers made at a senior level, all by Doraiswamy, were those to Paul Ratnasamy, John Barnabas, S. Sivaram, S. Ganapathy, S. Krishnan, P. Ganguly (from the International Institute of Physics in Trieste, Italy), J. S. Yadav (from Wisconsin), S. Devotta (from Salford), S. Sivasankar and V. Ramaswamy (both from IIP, Dehradun, at the instance of Ratnasamy who also worked there), and A. V. Rama Rao (by internal double promotion in the face of widespread opposition from organic chemists). Others who were appointed at various times and who were later to embellish the NCL were M. C. Srinivasan, A. Somashekar Rao, S. H. Iqbal, S. K. Dates, T. N. Guree Row, C. Gopinathan, V. G. Neurgaonkar, M. S. Shetty, N. G. Ghatge, G. R. Venkitakrishnan, S. R. Sainkar, K. N. Ganesh, Murali Sastry, B. L. V. Prasad, V. S. Gupta, P. K. Ranjekar, Neelima Iyer, K. V. Krishnamurthy, B. D. Kulkarni, R. V. Chaudhari, V. R. Choudhary,

S. Ravi Kumar, V. K. Jayaraman, T. Ravindranathan, K. Ravindranath, S. Ponrathnam, M. G. Kulkarni, Mala Rao, M. K. Gurjar, R. N. Sharma, S. Ganapathy, Sourav Pal, K. N. Ganesh, A. J. Varma, Asish Lele, V. V. Ranade, and a few more. There was a time in the 1980s when Mashelkar, Ratnasamy, and Barnabas were all scientists in the director's grade (a position created to recognize merit of the highest order), the only instance in the CSIR of three scientists at the same level as the director in any laboratory, with not more than 10 in the entire CSIR. Two of them went on to become directors of the NCL. Rama Rao and Yadav became Directors of the IICT, and Devotta became the Director of the NEERI.

Among those named above, B. D. Kulkarni (BDK), R. V. Chaudhari (RVC), and M. G. Kulkarni (MGK) (all students of LKD), deserve particular mention. BDK turned out to be truly brilliant and published several outstanding papers, with no matching accomplishments from any other Indian chemical engineer (although some of them became more famous). He became the Head of the Chemical Engineering and Process Development Division. RVC did some outstanding basic and applied work in homogeneous catalysis and attracted much funding. A new Division of Homogeneous Catalysis was created with RVC as Head. MGK was made the Head of the Polymer Science and Engineering Division. Another student V. R. Choudhary, who did brilliantly, with the largest number of publications in reputed journals and the highest number of citations (over 3000) somehow did not receive the encouragement he deserved but he did become Scientist G. M. K. Gurjar, who came back to the NCL from IICT during Mashelkar's regime, and K. N. Ganesh, who was brought to the laboratory from the CCMB by Doraiswamy, were made Heads of the two Organic Chemistry Divisions, which were re-named (see Chapter 13). Sourav Pal, a brilliant theoretical chemist, who was recruited by Doraiswamy, was made the Head of the Physical Chemistry Division. Offers were also made at the middle-level by Mashelkar, Ratnasamy, and Sivaram, and all those who joined were really first-rate scientists. Most of them made contributions that brought worldwide recognition to the NCL and changed the image of the laboratory. In particular, Vivek Ranade made significant contributions in computational fluid dynamics and formed a very effective team in process design equipped with all the modern tools of research, both theoretical and experimental. Murali Sastry did equally well in nanoscience and created an outstanding school in that area.

From these examples starting from the inception of the laboratory, it is clear that the NCL always recognized the primacy of talent in creating excellence, although it did make some erroneous judgments in its recruitment. State-of-the-art facilities, an appreciative and adaptive management, and all the other attributes of a world class laboratory are unquestionably important, but talent is central, the stuff that makes the difference between good and excellent. Good management is also necessary. It makes for a high level of efficiency and staff satisfaction. It fosters good science but does not create originality, and it is here (fostering good science) that management can play its most decisive role. The management of science (or "science of science") is important and much has been written on the subject, but science itself is several-fold more so. The often undocumented clashes between the managers and practitioners of science, particularly in industrial R & D centers, is well known. It has been the NCL's effort to combine the roles of the two and create an environment that de-emphasizes the distinction except at very high levels. Further, most talented entrants to the NCL, then and now, desire an atmosphere in which they can participate in technology development and publish at the same time. The average scientist's desire to publish often exceeds his ability to produce original work, leading to sub-standard publications in some of the ever proliferating number of journals. Keeping this in mind, the NCL made determined efforts to attract scientists to whom original work came more easily. The Impact Factor of its publications has steadily risen over the years: from 0.6 in 1981 to 2.52 in 2009. Although the improvement has been more than three-fold, a much higher number is expected.

THE PROGRESSIVE SOPHISTICATION OF THE NCL

> The world has come a long way since the following statement by one of the greatest polymaths of all time:
>
> *Simplicity is the ultimate sophistication.*
>
> Leonardo da Vinci, c. 1490

What was unquestionably a major feature in the NCL's evolution, almost as significant as the creation and constant renewal of its talent pool, was its progressive sophistication in almost all spheres of its scientific activity: equipment, library and information technology, computerization, creation of digital facilities, and most other features consistent with a Western laboratory born in the mid-20th century and crossing the mythical millennium barrier into the 21st century.[5] Thus, in almost all aspects of its engagement, the NCL has evolved into a state-of-the-art laboratory.

The general quality of research was consistently good, becoming world-class since the mid-1970s. This should not in any way diminish the quality of publications from some of the earlier doyens of the laboratory like M. Damodharan, V. Jagannathan, S. C. Bhattacharya, P. K. Bhattacharyya, H. B. Mathur, J. Gupta, R. C. Shah. S. L. Kapur, C. SivaRaman, K. P. Sinha, M. K. Gharpure, A. B. Biswas, Hira Lal, and others. Their research was largely carried out with instruments commonly available at that time. A fact that in hindsight appears naïve and almost irresponsible is the indirect insistence of the government in those days that, wherever available, only instruments made in India should be purchased. Since the NCL had, on paper, the capability to construct some instruments like the gas chromatograph, and the Central Scientific Instruments Organization at Chandigarh had announced that it had the technology to manufacture a variety of other instruments, the government made it very difficult, if not impossible, to acquire these instruments from abroad unless it could be established that the indigenously available ones were not up to the mark (insistence on the use of indigenous tools of research, as on processes developed by reputed institutions, was not warranted). As a result, tool-driven research was not of the highest standard. The situation would improve with time, but this was certainly an obstacle (albeit not an insurmountable one) to high-quality experimental research at the NCL, except in a few selected areas. Momin, about whom mention was made earlier, and then S. D. Bakre, provided strong leadership to the instrumentation group and were of considerable help to the scientists in repairing their instruments, even those that were imported.

With advances in experimental techniques and the increasing need for more sophisticated instruments for state-of-the-art research, the NCL met the challenge through a four-step strategy:

- Creation of a top class school of research in Mossbauer spectroscopy under H. B. Mathur
- Creation of an NMR facility under A. P. Madhavan Nair by K.Venkataraman (KV) and its subsequent establishment as a separate resource center by Sivaram, as part of his policy of establishing several such state-of-the-art resource centers
- Introduction of computer-aided practices over a period of time starting with the establishment of the computer center in 1975 by Tilak (with the assistance of A. P. B. Sinha and Doraiswamy) in collaboration with the University of Pune
- Creation of a Special Instruments Laboratory (SIL) in 1980 by Doraiswamy and placing it under A. P. B. Sinha (the most coveted instrument being NCL's first electron spectroscopic chemical analysis unit for solid state studies — ESCA).

Then came the era of globalization and with it an urgency accompanied by a huge increase in funds: from the crest of third world modernity to a reasonable level of sophistication by Western standards, and then (with four first-rate resource centers and other modern amenities) to a level that placed the laboratory among the best.

THE COMPUTERIZATION OF THE NCL

How wrong can one be!

> *I think there is a world market for maybe five computers.*
>
> Thomas Watson, chairman of IBM, 1943[6]

> *I have traveled the length and breadth of this country and talked with the best people, and I can assure you that data processing is a fad that won't last out the year.*
>
> Prentice-Hall Business Books Editor, 1957

There were no computers in the NCL before 1980. The first few computers came in the early 1980s, with one in the director's office, another in the Division of Technical Services, and two or three more in the rest of the laboratory. They were all PCs and there was no network system. Then around 1985, a Macintosh was installed in the director's office when I began using the computer, with my former student Ravi Kumar as my teacher, but I still type with two forefingers (often without looking at the keyboard). A computer specialist, a computer science graduate from IIT (Bombay), was appointed to help computerize the NCL. He was found completely incompetent and was soon asked to leave. Then, till the late 1980s, no significant initiative was taken to lead the NCL into the computer age in any meaningful way.

But all this did not mean that the NCL did not have a large enough computer of its own located outside the laboratory. Around 1978, Tilak and LKD started a dialogue with the University of Pune to jointly establish a computer center. After prolonged negotiations involving two Pune University Vice-Chancellors Drs. V. G. Bhide and Ram Takwale and two NCL Directors (Tilak and Doraiswamy), and thanks to a donation of Rs. 7 lakhs from the Khosla Group of Industries, the center was finally inaugurated in 1982. Prof. S. M. Vaidya was appointed Director of the center, which was housed in the Khosla Building (both the university and the NCL resisted strong efforts by the Khosla Group to name it the Khosla Computer Center and Khosla Building was a compromise choice). The main users of this computer in the NCL were scientists of the crystallography group and A. P. B. Sinha was assigned the task of looking after the laboratory's interests at the computer center. The Vice-Chancellor of the university and Director of the NCL were members of the Executive Committee of the center. In addition to this computer, a PDP 11/70 was installed in the Chemical Engineering Division. Neither of these computers had a keyboard or display monitor. Hence data had to be entered using a punch card reader and the output was available only in print format. Thus began, in a very modest way, the computer era at the NCL — in a decade when similar institutions round the world probably boasted of much more modern facilities.

The 1990s saw a leap forward under Mashelkar and Ratnasamy, ably assisted by S. Krishnan, B. D. Kulkarni, Sourav Pal, K. N. Ganesh, and other computer oriented scientists. In fact, it was precisely in 1990 that the NCL entered the modern era of computation by procuring an HP 9000 computer. Following this, thanks to the initiatives of Ratnasamy and Sivaram, a host of modern services were introduced and several new facilities procured. These included the networking of the entire laboratory, introduction of internet with VSNL 64 kbps radio link, e-mail and database server, setting up of an Alpha 4 CPU ES 40 server for high-performance computing across the NCL, replacement of most desktop servers with rack-mount servers, the procurement of Compaq rack mount servers for library databases, installation of Firewalls, implementation of central antivirus server for desktop computers, e-mail communication, etc. These seemingly unimportant details are given to emphasize the speed and thoroughness with which the NCL's computer facilities were modernized. As a result of these steps, by 2009, the NCL has a total of over 900 desktops connected to their LAN, with internet service available for all PCs, and all critical servers could be managed from a remote location.

THE SPECIAL INSTRUMENTS LABORATORY

The development of instrument facilities at the NCL followed what may be described as the convergent-divergent model, applicable to many areas of science and engineering. To begin with, there were a few instruments scattered all over the laboratory. Some divisional heads managed to acquire more instruments and others, who had less use for them, did not make any special plea to the director for them. As a result, divisions which had instruments were often reluctant to share them with divisions that did not. Since laboratory funds were used for the purchase of equipment, this seemed rather unfair, notwithstanding the obvious difference in divisional initiatives. Hence around 1985, several modern instruments were acquired, and all major equipment were pooled together and housed in a new laboratory constructed for the purpose. In other words, there was a convergence of all major instruments from different locations into a single location (the Special Instruments Laboratory, SIL) placed under a single senior scientist. Then there was a planned divergence in the shape of resource centers spawned by the SIL and other parts of the laboratory.

RESOURCE CENTERS

I could trust a fact but I will always cross-examine an assertion.

Michael Faraday, 1791–1867
(the supreme experimental scientist in a letter to Dela Reke, 2 October 1858)

Instruments give numbers, measurements, facts; they do not assert. The Resource Centers are an assembly of instruments that know only facts; they never assert. They are basic to any area of research.

For several years after the formation of the SIL, there was considerable addition of sophisticated equipment in various areas of the NCL during the periods of Mashelkar and Ratnasamy. A step change occurred immediately after Sivaram took over as Director. He reorganized the facilities in terms of resource centers, giving divisional status to many of them. They were encouraged not only to help other divisions but also to grow in their own fields. There was no longer just one instruments' lab but several centers. Thus there was a planned divergence of facilities, in consonance with the convergent-divergent model mentioned earlier. As will be seen later, many of these centers did outstanding work that brought great renown to the laboratory. Some existing facilities were upgraded into centers and some new ones created. As this book is being written, the following seven centers are operational:

- National collection of industrial microorganisms
- Central NMR facility
- Catalyst pilot plant
- Center for materials characterization
- Digital information resource center
- Combi chem-bio resource center
- NCL innovations

Of these, the catalyst pilot plant, NMR and National Collection of Industrial Microorganisms (NCIM) have existed for several years, particularly the NCIM, which was started almost with the laboratory and was modernized considerably over the years. The evolution of these different facilities, or centers, is outlined below.

National Collection of Industrial Microorganisms (NCIM)

One of the pioneering activities of the NCL had its origin in the basement of the laboratory. This was started by M. Damodharan who acquired the Microbial Culture Collection from the Indian Institute of Science along with the group of young and enthusiastic scientists who ran this unit: T. N. Ramachandra Rao, V. S. Govindarajan, and V. S. Krishnamachari. This activity was encouraged by all directors and has acquired a national status, being the country's major center for microbial culture collection. Operating under the name of National Collection of Industrial Microorganisms (NCIM), it was elected a member of World Federation of Microorganisms (WFCC). After Ramachandra Rao and Govindarajan left the NCL to join the Central Food Technology Research Institute in Mysore, the NCIM was looked after for a long time by Krishnamachari. In fact, the two were synonymous for many years in the 1970s and 1980s.

The NCIM offers services to educational centers, research institutes, and industries. It is a unique facility dedicated to the isolation, collection, preservation, and distribution of authentic industrial microorganisms. It also helps the various research programs of the laboratory. It acts as a repository of patent strains, and not just of research strains, indirectly helping to retain important microflora within the country.

While reorganizing the various resource activities of the laboratory, Sivaram reconstituted this as a resource center of the NCL. This should clearly be regarded as the first resource center of the laboratory that has been serving scientists from the NCL as well as from all over India since its initiation by Damodharan. The service it has been providing is truly remarkable. In terms of volume, the number of microbial strains it holds has grown from the initial 400 to 3700 strains of algae, bacteria, fungi, and yeast.

In addition to the services it provides, it has developed its own competencies which are exploited by scientists both from within and outside the NCL and by the industry. Its competencies include: lyophilization of microbial cultures, development of biocatalytic and microbial processes for value added products, isolation and preservation of microbial strains, strain improvement, and long-term preservation of specialized cultures.

An example of the NCIM's role in the development of microbial processes was the use of NCIM 1207 for the conversion of isoamyl alcohol to its acetate, known for its flavor, within 72 hours with a conversion efficiency of 70%. An example of strain improvement was the continuing effort to improve strains for the production of alcohol from biomass.

NMR Resource Center

The history of NMR at the NCL is almost as old as the laboratory itself and has a rich tradition. Since the inception of NMR and related activities in the early 1960s, the journey has been a long and continuing one. The NMR activities at the NCL have always kept pace with developments round the world in the last 50 years. In 2003, it became a centrally accessed and managed resource center with a divisional status.

The seeds of NMR were sown by P. M. Nair, an erstwhile NCL scientist of repute as an organic NMR spectroscopist. The first NMR instrument, a Varian A-60, also the first to come into the country, was installed at the NCL in 1965, thanks to the initiative of KV. This was followed by the addition of a permanent magnet based Varian T-60 in 1971 and the JEOL TMX-60 in 1981. The creation of an NMR group, headed by P. M. Nair, heralded a new era at the NCL. The initiation of NMR activities not only represented an activity of its own within the laboratory but indeed fuelled organic chemical research in many ways.

The NCL did not lag behind when Fourier-Transform (FT) methods were introduced to NMR. FT based NMR spectroscopy for analytical support and liquid state NMR research were initiated in the mid-70s, in tune with the switch over from CW methods to FT methods worldwide. This ushered in a new era of FT-NMR at the NCL, with the induction of two FT-NMR spectrometers, namely Bruker WH-90 and Varian FT-80, in 1978 and 1981, respectively, thanks to the initiatives of Tilak and Doraiswamy. This helped to take NMR activities to the next level and to bring in new structure elucidation tools. With the availability of these two instruments, 13C NMR operations were started for the first time and the use of 1H and 13C not only became prevalent but enabled structure elucidation of more complex organic molecules. Besides acting as a core service group for the organic chemistry divisions, there was also considerable research within the NMR group under the direction of P. M. Nair, resulting in a number of publications and doctoral degrees in NMR.

The NCL also kept abreast of advances in high-field NMR. The first superconducting NMR spectrometer (Bruker MSL-300) arrived in the NCL in 1987 and high-field NMR operations began immediately thereafter, during the regime of Doraiswamy. With the induction of MSL-300, NMR activities at the NCL also entered a new phase. For the first time, solid state NMR research was initiated in 1988 and vigorously pursued. Magic Angle Spinning (MAS) and Cross-Polarization Magic Angle Spinning (CP-MAS) experiments were extensively used by the catalysis and polymer groups of Ratnasamy and Sivaram, respectively, as new tools in the structural characterization of insoluble materials. Significant contributions were made by the NCL NMR group in developing Magic Angle Spinning based experimental techniques for the study of polymeric gels, such as the super absorbing polymer *Jalshakthi*. A second superconducting NMR spectrometer, namely Bruker AC-200, was added in 1991 and at once, 2D NMR tools became available to researchers, especially for the synthetic organic chemists. A micro-imaging system was added to the MSL-300 NMR spectrometer in 1994 and this facilitated the initiation of MRI for the first time at the NCL. Significantly, the MSL-300 instrument, which fuelled solid state NMR research at the laboratory, is fully functional even after 17 years of continuous operation, while in other parts of the world it has ceased to operate due to ageing. This bears true testimony to the excellence in instrument care and maintenance at the NCL in general and within the NMR group in particular.

In the year 2000, a 500 MHz NMR spectrometer was acquired. With the induction of this very high-field instrument, NMR activities were centralized for efficient management and administration. This enabled the group to pool in all the available resources and provide an efficiently managed work environment for the benefit of the laboratory. As a significant development within the laboratory, students were given hands-on training and the 200 MHz NMR instrument was thrown open for student operation at night and during weekends. Facilities for electronic transfer of data over intranet were set up. With the centralization of NMR facilities, new research projects could be initiated and vigorously pursued. These included several industrial projects involving Unilever, Reliance, Ranbaxy, Lupin, Kopran, Eastman Chemicals USA, Sun Pharma and Glenmark Pharmaceuticals. The Central NMR Facility was inaugurated by Professor Richard Ernst, Nobel Laureate, who won the prize in 1991 for the advancement of pulse and Fourier-Transform NMR. As previously mentioned, it was elevated to divisional status and declared a resource center in 2003. A view of the NMR laboratory in 2005 is shown in Figure 5.3.

Figure 5.3: A view of the NMR facility in 2005

The NMR group at the NCL has contributed to the advancement of various solid-state NMR pulse methodologies and in applying them to different materials science areas, such as *smart* gels, zeolite catalysts, polymer blends, polymer nano-composites, metal oxides, soaps and detergents and allied areas. Through interactive in-house research, the solid state NMR activities cut across many disciplines and the research work carried out at the NCL won both national and international acclaim. The NMR group established an international collaboration with the NMR group of Professor Jean-Paul Amoureux at the University of Lille, Lille, France, through a project supported by Indo-French Center for Promotion of Advanced Research, New Delhi.

A measure of the NMR group's reputation is that it is the only instrument-oriented group at the NCL that has hosted national and international symposia: the National Magnetic Resonance Symposium in 1996 and an international seminar sponsored by the Indo-French Center in 2005. The reputation it enjoys today is largely due to the efforts of S. Ganapathy, an internationally renowned NMR specialist who was invited to join the NCL in 1985 by LKD during one of his trips to USA (the due process coming later!).[7]

Catalyst Pilot Plant

This has not been called a center partly because it was called a pilot plant by Ratnasamy who established it in 1995 and largely because it is a mini production unit and not a research center. However, it enjoys the full status of a resource center. Historically, this was almost foreordained, but it took a director in the 1990s to get it done. Catalysis has been a running program at the NCL almost since its inception. It acquired an engineering component in the 1960s, produced a world-class industrial catalyst in the 1980s, became a recognized center of research in homogeneous catalysis in the 1980s, and has been in the forefront in basic and industrial catalysis for over three decades.

The NCL's catalysis group has been responsible for developing many novel catalysts, in particular the *Encilite* series. When *Encilite* 1 was developed for the IPCL's isomerization reactor, the NCL faced the problem of producing the catalyst on a large enough scale for commercial validation. It had to engage the services of the ACC to produce the catalyst. A great deal of manipulation was involved in getting this done, the most important being that the IPCL had to acquire the ACC's CATAD plant to produce the required quantities of the catalyst. To circumvent such problems, Ratnasamy established a catalyst manufacturing unit known as the catalyst pilot plant, and this has proved to be a very useful facility in view of the NCL's continuing involvement in heterogeneous catalysis.

The unit is a multi-purpose one that has the capability to produce a variety of solid catalysts from gram scale to a few hundred kilograms (Figure 5.4). The catalysts it can produce, include such a wide range as zeolites, silica-aluminas, binary oxides and supported metal catalysts used in a variety of industrial processes such as for petroleum,

Figure 5.4: The catalyst pilot plant

petrochemical, organic/fine chemicals, and detergent industries. No other research institution in India has such a complete and state-of-the-art facility for catalyst manufacture on a pilot plant scale. The many competencies of this center (though it is not called that) include:

- Zeolites (ZSM-5 series), TS-1/TS-2 (titanosilicates), Beta (Al, Ti, Sn), (LTL, FAU, BEA)
- SAPOs, oxide/mixed oxide catalysts
- Fly ash-based zeolite catalysts (A, ZSM-5, Beta, etc.)
- Zeolites, mesoporous materials (MSM-41, MSM-48, SBA, carbon) materials, organo-inorgano mesoporous materials and metal oxide
- Catalyst preparation and scale-up to 100 kg powder per batch
- Processing and shaping equipment such as ball mills, extruders with appropriate binders (for shaping into tablets, hollow spheres, balls, etc.), reaction vessels, spray dryer, pug mill/mix truder, granulation equipment, and many more.

Using this pilot plant facility, a number of high-tech catalysts were produced on a scale of 100 kg per batch. An example is a TS-1 catalyst supplied to a multinational company. This high-value catalyst is a unique one, used in the production of (1) catechol and hydroquinone from phenol (see Chapter 11), (2) epoxidation of propylene to propylene oxide, (3) epoxidation of allyl chloride to epichlorohydrin, and (4) production of heterocycles like pyridine and substituted pyridines. Another important example is the preparation of *zeolite beta* from fly ash.

Center for Materials Characterization

As was mentioned previously, a number of modern instruments were procured in the 1980s and housed in the SIL. Although the NMR facility was also considerably enhanced during that period, it was not moved to the SIL but housed in a separate location within the laboratory. The facility was further strengthened in the 1990s and early 2000s and given the status of a division in 2003. A special mention of this is made here because it is the only instrument facility that was given an individual status. At the same time, most other instruments were reorganized and many more added. This was largely the result of the realization that the sporadic efforts on materials research needed to be centralized in view of the importance of the creation of new materials and improving existing ones. It was important to understand the structure, microstructure, morphology, elemental composition (bulk or surface), etc. of the materials for developing new ones. The SIL building was also modernized and given a new name: Center for Materials Characterization (CMC). All the instruments needed to characterize materials were placed in this building. This step was the NCL's first formal recognition (by Sivaram) of the role of materials characterization in modern scientific research.

The facilities of the center include several major instruments which are looked after by experts on different instruments and provide strong support to the laboratory's major R & D programs. Apart from this, the center operates its own research programs, extends technical services to outside research institutes, universities, and industries. It also trains young scientists and students. Historically, the NCL was reluctant to offer training to outsiders till recently. If providing supervision and facilities for students to work for their Ph.Ds is regarded as training, then it was providing training since its inception. But short-term hands-on training on the use of equipment is a new activity started by Sivaram. On the contrary, many other laboratories of the CSIR train young technicians and other aspirants on a regular basis, and have been doing so almost since inception.

On acquiring the status of a separate center, certain goals and missions were defined for it, as for all independent units of the laboratory. The goals and missions of this, the largest, resource center of the laboratory were defined as follows:

- To maintain and continually upgrade the infrastructure facilities for providing high quality results.
- To offer technical expertise in structural characterization and compositional analysis of materials that are important to the major R & D projects of the NCL.
- To extend expertise and consultancy services to universities and industries.
- To take up research projects and contract research in areas of commercial and basic research.
- To train students and young scientists in the use of sophisticated instruments.

About a dozen major instruments constituted the infrastructure of this center. Many available competencies of the laboratory pertinent to materials characterization were consolidated and some new ones created as part of this center. All these competencies, along with the infrastructure, provide an excellent means for the characterization of materials.

Digital Information Resource Center (DIRC)

Starting from 1990, simultaneously with efforts to modernize its computer facilities, the NCL took steps to fully modernize the deployment of information technologies to its scientists. As a major step in this direction, the following specific competencies were developed besides the basic infrastructure including a modern building:

- Biodiversity informatics
- Metadata and clearinghouse techniques development
- Scientific database — data mining and knowledge management
- Web technology implementation

Infrastructure: Developed in 2003, this provides for a centralized support for the information infrastructure. It includes an excellent campus wide local area network (LAN) with about 700+ computers, a range of servers, internet connectivity, access to a range of digital resources including databases like Chemical Abstracts, Current Contents, Chemical Business Newsbase on the intranet, and on-line access to a large number of electronic journals (including back volumes for many) from leading publishers like Elsevier Science, American Chemical Society, Royal Society of Chemistry, and Wiley Interscience. A state-of-the-art building was constructed (Figure 5.5) including the following facilities:

- User room with a range of computers for easy and common access to digital information resources, productivity and other office tools, computer resources, visualization and modeling facility and access to special devices like scanners, CD writers, etc.
- State-of-the-art classroom facility with PCs or workstations at each desk for human resource development and capacity-building training.
- Server room with high-performance servers managing centralized ICT services and information resources.
- Computer laboratory to set up experimental systems and test/evaluation platforms, software, and applications.

Chemical informatics: Known also as chemoinformatics or cheminformatics, chemical informatics is the application of computer technology to chemistry in all of its manifestations. Massive amounts of physical and chemical property data are generated each year for new and existing chemical substances. Such an avalanche of data can bury a chemical research project unless ways can be found to cope with it. Chemical informatics can provide tools to acquire, organize, and evaluate data — tools that yield new insights for further chemical research. A specific project that deserves mention is the QSAR analysis of the National Cancer Institute dataset of thousands of open chemical structures for anti-cancer activity and of an even larger number for anti-AIDS activity using a variety of computational tools such as MOE, OELib, etc. An equally important program is the mining of chemical literature to identify molecules either synthesized or isolated at the NCL or used for chemical research over the last 50 years. In this context, a preliminary study of about 900 selected publications of the NCL resulted in about 12,000 non-commercially available molecules with varying degrees of novelty and complexity.

Figure 5.5: New state-of-the-art building for Digital Information Resource Center

This dataset is expected to be continually analyzed and updated, along with associated information with a unique identifier for building a molecular registration system at the NCL. This is a new and novel program and should place the laboratory alongside the best in the world.

Biodiversity informatics: Although the NCL has had a strong program in biochemistry since its inception and extended it to life sciences in the early 1980s, there was no strong recognition of the importance of biodiversity till the creation of the DIRC. Then it acquired the electonic catalogues of known Indian fauna (IndFauna) and flora (IndFlora). Simultaneously, it took several important initiatives that highlight its commitment to national and international computer-based programs in this area:

- SAMPADA — a multi-taxon biological collections data management system whose aim is to encourage curators and collections managers within India and in neighboring regions to automate the repository data and digitize the specimens. SAMPADA has been included in the list of recommended software by GBIF and CODATA Taxonomic Database Working Group (TDWG).
- ABCDIO — Large numbers of our biological specimens are housed in European and American museums. The center developed a web-based mechanism to provide "Access to Biological Collections Data of Indian Origin (ABCDIO)."
- Sacred Groves Information System — The center also developed ecosystems specific databases. It initiated a collaborative program with the Center for the Development of Advanced Computing (C-DAC), Pune, for developing Web GIS interfaced Sacred Groves Information System (SaGrIS).
- Database on Conservation Sites — a program which collates information on national parks, wildlife sanctuaries, biosphere reserves, Ramsar sites, tiger reserves, botanical and zoological gardens, as well as community conserved areas.
- Database of Indian Taxonomists (DIT) — which collates information about diverse taxonomic expertise available within the country. It also has web-interfaced databases on biological organizations within the country and biological collections in South Asia.
- LISTSERVE — a program to facilitate exchange/sharing of ideas and views and also to provide a platform for implementation of collaborative R & D ideas in the field of biodiversity informatics The program was designed to ensure interoperability amongst datasets being developed in-house and those developed by other agencies within India and abroad.

Common threads: All the programs described above have common threads or technical areas of work. Some of these are document management and workflows, metadata and clearinghouse techniques, digitization methods and standards, standardized terminology and controlled vocabulary database, data mining and knowledge management techniques, web technology, and mobile and wireless computing.

Based on these common threads, the DIRC plans to develop the following facilities in the years ahead:

- Tools for harvesting information spread across the network and building a central depository.
- Search and retrieval methodologies.
- Digital archival and document information management systems.
- Design and implementation of electronic lab notebooks.
- Data analysis and mining tools.
- Visualization and virtual reality applications.

Combi Chem-bio Resource Center

As mentioned in Chapter 4, process development for drugs and pharmaceuticals was always a major program of the NCL. Historically, along with research on the chemistry of natural products, this was a key area of research in organic chemistry since the inception of the laboratory. But, for reasons previously stated, the research was restricted to process development for known drugs ('copy cat research' as most American firms called it). The exorbitant cost of discovering new drugs made it impossible to venture into drug discovery. The Government of India's decision, in operation till 1998, not to recognize the Paris Convention on patent rights for new drugs and produce them in the country, using modified processes, greatly facilitated the production of most drugs in India. In many cases, this led to development of cheaper processes and export of cheaper drugs even to countries where the drugs were discovered. The situation changed radically with India becoming a signatory to the Paris Convention. Today India has to compete with the Western world on their terms by discovering new drugs or paying the stipulated fee for making known ones. This is one reason for shifting the focus of drug research from process development to discovery.

Another reason is that the research climate in the country changed with the increasing privatization of industries. Particularly in the field of drugs, the ability to conduct process development research in the private sector grew enormously. Companies like CIPLA, Ranbaxy, Lupin, and Dr. Reddy's Laboratory created the most modern facilities for development research. It is doubtful, however, if they have (with the possible exception of Ranbaxy and Dr. Reddy's Lab) the wherewithal and broad infrastructure for research in drug discovery.

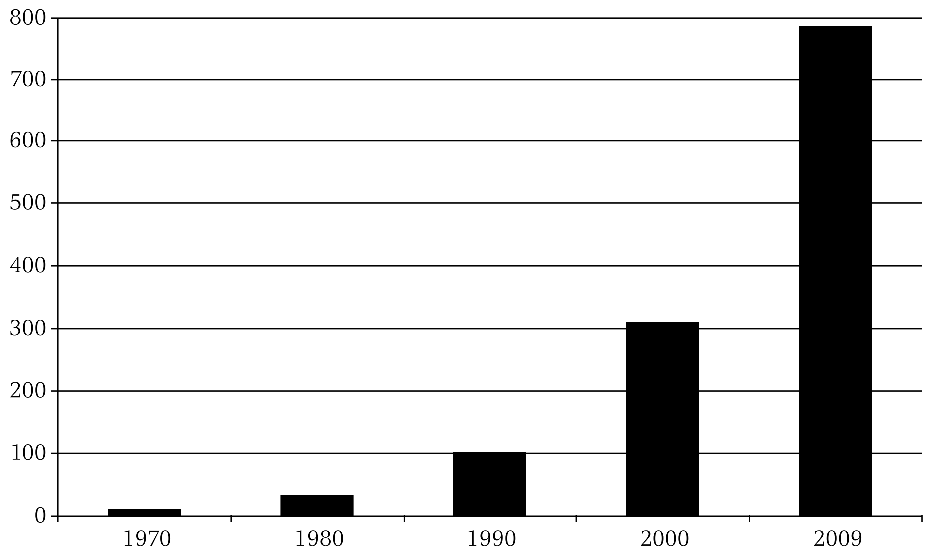
As a result, the onus and necessity of research in drug discovery fell on national laboratories like the NCL and IICT. The NCL recognized this trend some years ago and initiated bold actions to enter the era of drug discovery in India. This required the creation of a high level of competence in what has come to be known as "combinatorial chemistry." The efforts in research in this area are described in Chapter 8. But it required an infrastructure and a set of competencies specific to this kind of research. Sivaram realized this necessity and in 2003, he created the Combi Chem-Bio Resource Center.

It is estimated that over two million molecules must be prepared and tested before a lead molecule can be obtained for a target disease. The time, effort, and money involved in this kind of work can be easily imagined. To minimize these, facilities were needed for quick and parallel synthesis of a variety of molecules, extraction of a liquid mixture into hundreds of fractions within a short time, robotic handling of thousands of compounds per day, continuous separation of compounds at far greater speeds and efficiencies than the conventional batch chromatographic columns, etc. With these facilities, the following competencies were created: chemical syntheses of combinatorial libraries, bio-evaluation of medicinal plants, biological high throughput screening, and chemoinformatics. All these facilities and competencies are presently available for the Organic and Biochemistry Divisions of the laboratory for their various research programs.

MONEY AND EXCELLENCE

Can state-of-the-art be established without money? How is excellence, an almost esoteric tribute to man's quest for the best, related to such a materialistic, down-to-earth quantity as money? I use the word "quantity" because money is exclusively determined by quantity. Given this self-evident truism, can any research institution become truly excellent without recourse to huge sources of money? Nearer home, how did the NCL tackle this enormous problem of funds at a time when government, which was the primary source of funding, held all its ministries in a tight financial squeeze — to impractical budgetary minima in many cases.

Figure 5.6: Laboratory Budget over the years



Year	*1970*	*1980*	*1990*	*2000*	*2009*
Rs. in Millions	8.57	30.95	100.89	310.12	785.1

In the 1950s and 1960s, the annual budget of NCL was less than a crore of rupees (Rs 10 million), of which over 70% went towards staff salaries. After the minimal amounts required for chemicals and other routine purchases, only a couple of lakhs (Rs 200,000) was left for equipment and infrastructure development. This was no more than a pittance even by the rupee value of those days (Rs. 7–10 to the dollar till the 1980s).

The sudden rise in the 1980s was the result of the establishment of the Sophisticated Instruments Lab (SIL), thanks mainly to grants from the CSIR (largely due to the unqualified support of the Chief of Planning, A. R. Rahman), World Bank, UNESCO, and the Department of Science and Technology.[8] Globalization, liberalization, and the involvement of multinational companies since 1990 further added to the list of new, sophisticated equipment in many areas of interest to the NCL, resulting in several new centers. The exponential growth of NCL's budget since 1970 is shown in Figure 5.6.

ZWICKY'S MORPHOLOGICAL THEORY AT WORK AT THE NCL

NCL's claim to excellence is based on many factors, not the least being Zwicky's "private theory of everything" or morphological theory briefly alluded to earlier. Zwicky has been described variously as controversial, brilliant, and a genius. He was no doubt all of that but his theory is certainly not controversial as far as the NCL is concerned, contrary to Freeman Dyson's analysis that the theory fails if you are not Zwicky. I do not wish to imply that anyone in NCL can boast of Zwicky's brilliance but his private theory, as it would apply to any process development effort, has certainly been used many times. Briefly, the theory states that:

> *you write down a list of all conceivable ways of solving a problem before you choose the way that actually solves the problem.*
>
> Dyson, 1988

I recall reading that a similar view was expressed by the fictional detective Sherlock Holmes who once lectured his medical handyman Watson that

> *to solve a murder you write down all conceivable possibilities and by a process of elimination arrive at the one that is left and accept that as the only way the murder must have been committed, however improbable that may appear.*

Nearer home, the Doctor Seuss of chemical engineering, Octave Levenspiel, expressed a similar view in the Danckwerts' Memorial lecture 1988, when he said that to choose the best reactor for a given reaction you write down a list of ALL conceivable reactors, from the ridiculous to the untried, and then by a process of elimination arrive at the best. Thus for the reaction at hand he did not eliminate *a priori* even the ridiculous bathtub as a contender! Finally, he ended up with a reactor that was untried at the time, and that indeed proved to be the best.

Many of the reactors described in Chapters 10 and 11 for a variety of reactions were selected on this basis. The stirred fluidized-bed reactor for chlorosilanes is an outstanding example. This was how the NCL moved from the empirical to the rational over the years and has become state-of-the-art not just in equipment but also in its thinking.

Role of Management in Creating Excellence

> *The test of a first-rate intelligence is the ability to hold two opposite ideas in the mind at the same time, and still retain the ability to function. One should, for example, be able to see that things are hopeless and be determined to make them otherwise.*
>
> Attributed to F. Scott Fitzgerald, 1936

> *Nothing is more common than unsuccessful men with talent.*
>
> Attributed to Calvin Coolidge

INFORMAL *COMMON SENSE* CHANGES

Many of the changes were the result of actions taken to commercialize a technology. In hindsight, they can be regarded as responses to threats to the NCL's continued relevance, although they were not viewed in this specific light when the changes were made. This is largely the story of the NCL: actions taken from a common sense perspective in response to the changing industrial and scientific climate and government policies, and not according to the pedagogic management dicta that now fill books. To the credit of the NCL's management, many of the methods used seem to coincide with the documented tools of management. However, as it is helpful to incorporate formalized management techniques in the interest of overall improvement, a step already taken by the present Director, Sivaram, I attempt to put the NCL's policy shifts in this framework with its own unique phraseology.

A LINEAR MODEL OF INDEPENDENT DOMAINS

In most developing countries of the world, including India, the initial period of growth has followed a common route. This has also been true of developed countries like Australia and Canada in their attempt to establish a strong educational and technology development base in their own countries, rather than rely largely on imported technology. In this process, three distinct domains were explicitly recognized and strengthened.

- Centers of education
- Repositories of technical knowledge
- Agencies for production

Smith, 2000

Clearly, universities are the centers of education. They impart scientific and technical education (I am intentionally avoiding the word "training" for it's not the purpose of the university to "train" but to "educate;" the unfortunate confusion does not often lie only in language but in concept as well). It is their function to supply talent. National laboratories were supposed to be the repositories of expertise and research excellence that could be exploited for the public good. Implicitly, they were expected to function independently of the universities or commercial firms seeking their knowledge. And finally, commercial firms were recognized as the agencies of production, using whatever technology they could get from anywhere in the world. Thus, the three domains operated quite independently of each other, giving rise to the *linear model* of development. In other words, there was not much scope for academic research in the national laboratories and industrial research in universities. The industry did its own research, based usually on short-term goals, and left it largely to the national laboratories to pursue long-term goals. This linear model operated in India for several years after independence and the NCL was no exception. Soon a non-linear model began to emerge in which interaction between the three domains was central. The NCL created for itself the advantage of housing the first two domains and establishing an interactive relationship with the third.

THE GROWTH OF AN INTERACTIVE PARADIGM

Modern science in India came into its own after it had been fully established in the Western world. This maturity of science and industry in the West gave it a kind of stability that is not easily shaken by political and socio-economic convulsions. True, these would have their effect over time if a strong single political persuasion continued long enough, but not in terms of sudden directional shifts. Implanted during the British rule, science and technology in India today are progressing at a much faster pace than in any other developing nation (except China, under a different political philosophy). Indeed, the country seems to be adroitly straddling the gap between the developing and developed worlds (thus suggesting a new definition for a nation in a hurry!). In frogleaping through shifts in political leadership to catch up with the present Western standards, Indian science has had to face challenging situations. Nowhere have these challenges been more acutely felt than in national laboratories largely supported by government funds. The NCL has met these challenges by consolidating them into overall shifts dictated as much by changing government policies as by its own perceptions of future directions. There have been three such major shifts leading to four successive domains in the NCL's history. I shall discuss these in Chapter 6.

Destructive Creativity

To appreciate these management tools more fully, a slight digression into the concept of terms like "destructive creativity" will be helpful in describing the NCL's new paradigm of "simultaneous creation and destruction" (Foster and Kaplan, 2001). The concept of destructive creativity has been in use for some time in the management of industrial corporations. We will rush through it here because its basic principles are relevant to research laboratories including the NCL. The history of a traditional corporation is the same all over the world. The birth, survival, and death of a corporation are the direct result of its continuing over-performance over a reasonable period of time followed inevitably by under-performance in relation to the market average, and eventual collapse in the absence of serious corrective measures. Imaginative corporations have avoided under-performance and death by the simple expedient of diversification, or, more correctly, by introducing sudden discontinuities such as through product pattern changes or targeting of different audiences altogether. This means that some existing activity must be obliterated and fully replaced by a new one. Deeper studies have found, however, that such a course would be far from remedial.

The central problem is not how efficiently existing operating structures are administered but how imaginatively they are destroyed and more relevant ones created in their place. The basic premise for success in today's world — and tomorrow's — is that the assumption of continuity should be abandoned and replaced by one of "sudden" discontinuity.

The implied resort to destructive creativity is not easy. The administrator considering it must be open to divergent thinking including opposite viewpoints, even to accusations of indecision. He must exude optimism with a touch of pessimism and *vice versa*. To borrow a term from Mihalyi Czikszentmihalyi (1990), a leading exponent of creativity, he must show "sunny pessimism," but I would be tempted to say, "nuanced optimism." Although things were never hopeless at any time in the NCL, most directors seem to have been unknowing votaries of this attitude.

Many institutions talk of luring people with experience. One way of looking at experience is Oscar Wilde's (1854 –1900): *It is the name everyone gives to their mistakes.*

More importantly, experience can be a double-edged sword that promotes continuity in a changing world where discontinuity is key. It anchors people to the past and undermines their ability to reset the scenarios to include looming complexities. According to John Sterman of the Systems Dynamics Group of MIT:

> *When the environment is complex, people seem to revert to simple rules that ignore time delays and feedback, leading to lowered performance…Their learning hurts their ability to perform well in* the *complex conditions* [of the future].
>
> Quoted by Foster and Kaplan, 2001

Hence, to be successful it is not sufficient just to initiate discontinuities but it is equally necessary to be able to predict performance under the complexities accompanying such changes. The effects of such action are almost always irreversible and hence a *via media* is required that accommodates failure. The extremes of performance need to be punctuated with shades of each extreme that permit flexibility of action. I describe below how this can be done.

Simultaneous Transformational Creation and Destruction

To overcome this built-in disadvantage of discontinuity, there must be scope for simultaneous creation and destruction. As a common saying goes, *don't burn your boats completely before the new ones are stable!* Thus the concept of transformational creation and destruction was born. The phraseology is new, but the idea itself had found muted expression, and even practiced, at the NCL in some ways in the past, with no academic accreditations, textbook inclusions, or industrial laurels. And yet its codification as a thought process is worthy of note and has opened a window for change with the stamp of formalized authority.

I describe in the next chapter the evolution of management at the NCL, such as it was in the earlier years, with particular reference to the management styles — more correctly, working styles — of different directors. It will be seen how some of these management methods find their equivalents in the modern management tools described above. The most recent Director, Sivaram, is certainly moving the laboratory forward into the more formal methods of management described previously. As of this writing, the laboratory was functioning in an overlapping zone. Whether in time the old will be completely discarded for the new is for a later historian to write. Given the natural wisdom of the past and the synthesized methods of the present (with the present continually becoming the past and the future the present), I hope the combination will always prevail, in varying proportions.

Buggin's Run, Peter Principle, and Blue-eyed Boys[9]

The three items comprising this caption are important in the evolution of an institution, and can accelerate or decelerate excellence, depending on how they are practiced. As defined in endnote 9, Buggin's Run indicates promotion by seniority, Peter Principle refers to a series of promotions till the level is reached where the concerned person is unequal to the task and becomes incompetent, and the cult of Blue-eyed-Boys refers to the tendency to selectively isolate a group of individuals for special consideration. No institution, including the NCL, can claim to be free of these practices. The pertinent question is: to what extent have they influenced the lab's commitment to excellence.

Buggin's Run was fairly rampant in British India. Inescapably, the NCL inherited some of it. Although partiality was not blatant, old friends and confidants of those in power did find their way into the NCL, at all levels. Scientists, quite understandably, came from the Delhi laboratories of the CSIR, and even non-scientific staff, including the so-called peons of infamous memory, was brought from there. The practice quickly changed, however, as the NCL began to cut its strings from the Delhi secretariat. The Peter Principle had its day too, mostly in the 1950s, and in a few cases went far beyond. I recall one particular case, where a scientist, known to be incompetent by all, including the director, was promoted by KV, both due to seniority and other considerations. It took quite an effort by KV and his successor Tilak to undo the damage. Another instance that occurred during my stewardship of the NCL was driven by the scientist's strong commitment to work in spite of his lack of a Ph.D. — but the Peter Principle did have the last say.

The cult of the Blue-eyed Boys (BEBs) began, I suppose, when Finch picked a few scientists for special mention to KV as he handed over office to him (see Chapter 6) and suggested that they should be given every encouragement to develop. KV and Tilak had their own lists of BEBs. S. C. Bhattacharya and Sukh Dev, two of the most outstanding scientists the NCL has had, somehow never made the list, which was most unfortunate for the lab. I cannot complain because I was in both their lists! A. P. B. Sinha and H. B. Mathur were on KV's list, and R. B. Mitra in Tilak's. I had my own BEBs too. The list was headed by R. A. Mashelkar and included Paul Ratnasamy, John Barnabas, and Rama Rao. The later years saw B. D. Kulkarni, S. Sivaram, K. N. Ganesh, R. V. Chaudhari, S. Pal (all of whom became internationally renowned scientists), G. R. Venkitakrishnan, and S. H. Iqbal added to my list as a result of their hefty contributions.[10] As mentioned in an earlier section, their contributions were largely responsible for the NCL's present reputation. Mashelkar, in particular, was multi-dimensional and showed his extra-ordinary talents in many ways. He would soon surpass almost any scientist in India in fame, world recognition, and accomplishment.

The cumulative effect of the actions and some harmless rule-bending by the NCL's directors over the years was to enhance excellence at the NCL. I am not sure if any other institution in India (with the exception of the IISc and TIFR) has enjoyed such continued *effective* commitment to excellence. This is perhaps the single most important reason why the points listed in "Is There Excellence at the NCL," actually happened.

Arthur D. Little and Ravi Mathai Reports

Of all the Directors the NCL has had, Tilak was in many ways the most difficult to understand. Endowed with a strong personality, he often gave the impression that he was the complete master of any situation. He put forward his views with force and a sense of finality that did not easily brook dissent, and yet he was the only pre-globalization era Director to subject the NCL to outside scrutiny and evaluation. Thus came about the appointments of Arthur D. Little Inc. (ADL) of Boston, USA, and Ravi Mathai (RM) of the Indian Institute of Management of Ahmedabad to evaluate the performance of NCL and suggest management changes to effect overall improvement.

Unfortunately, the ADL report was not available. The only comments I can make are those based on my discussion with the ADL expert who spent several days at the NCL. He reported that the laboratory was, in general, being managed well, but that he "picked up some vibes" which suggested considerable staff dissatisfaction with the director. The general feeling was that the director had distanced himself from the working level scientist and depended only on information the divisional heads and other senior scientists chose to give him; and this was usually distorted, giving the impression that the entire staff was fully satisfied with the director. When Tilak came to know about this he was more sad than angry, and tried in his own way to rectify the situation. It is difficult to say to what extent he succeeded.

The RM report, to which I had access, is more general, and in many ways upholds the vibes of the ADL report. After pointing out the dissatisfaction of the staff with the existing methods of evaluation, mainly the confidential report and the lengthier report for five year assessment, RM suggests:

> *If at all, after discussion, the Director and scientists of [the] NCL think it worthwhile to develop a less hierarchical culture, a greater involvement of all the scientists in the development of the organization and so stronger peer relationships and consonance of goals, the evaluation process will be one of the critical factors in determining the effectiveness of such developments.*

The constant refrain that the scientists are not involved in the decision-making process is true to a point, but unfortunately it is also true that there is no organization in any country, other than the academia, where this happens. Hence, I do not personally take this *whipping boy* of criticism very seriously. The NCL is not an academic institution.

For one that is not, there is considerable staff involvement in decision making. It could, of course be better, even much better, but to bring it up as its greatest weakness suggests that it is alone in this conduct. In my view it has done better than almost any other non-academic organization in the country.

The ADL expert also talked of vibes that a large percentage of the staff had nothing to do. They whiled away their time, doing Ph.D. work if so disposed. This is perhaps true, more so in the globalization era than before. Scientists who do not submit projects, or are not assigned to some, stray into inactivity. As this number increases, the laboratory may run into problems of a seriousness it has failed to capture and rectify.

The RM also talks of how the NCL's position in the country can be redefined in so many ways, including its transference to bureaucratic ministries like Chemicals and Fertilizers, an infamous step seriously mulled by the Morarji Desai government of a yesteryear (see Chapter 3). In my personal judgment, this should not be even an option, however remote, for it amounts to breaking up of the CSIR.

Both these reports have been helpful but to what extent they helped the directors re-assess their thinking is open to debate.

In many Indian institutions, the chief's office tends to be an echo chamber, where his own ideas are fed back to him fortified with the overtones of self-seeking colleagues. The NCL has never been a place where its chief has been a prisoner of his own views; neither have the divisional heads. But in a country where, not infrequently, artfully punctuated flattery is substituted for hard work and achievement, this feature should act as a deterrent to shortcuts by errant scientists.

Negative Relevance

This is an interesting term whose meaning is not immediately apparent, and was probably first mentioned by Robert Penn Warren during a speech upon receipt of the 1970 US National Medal for Literature:

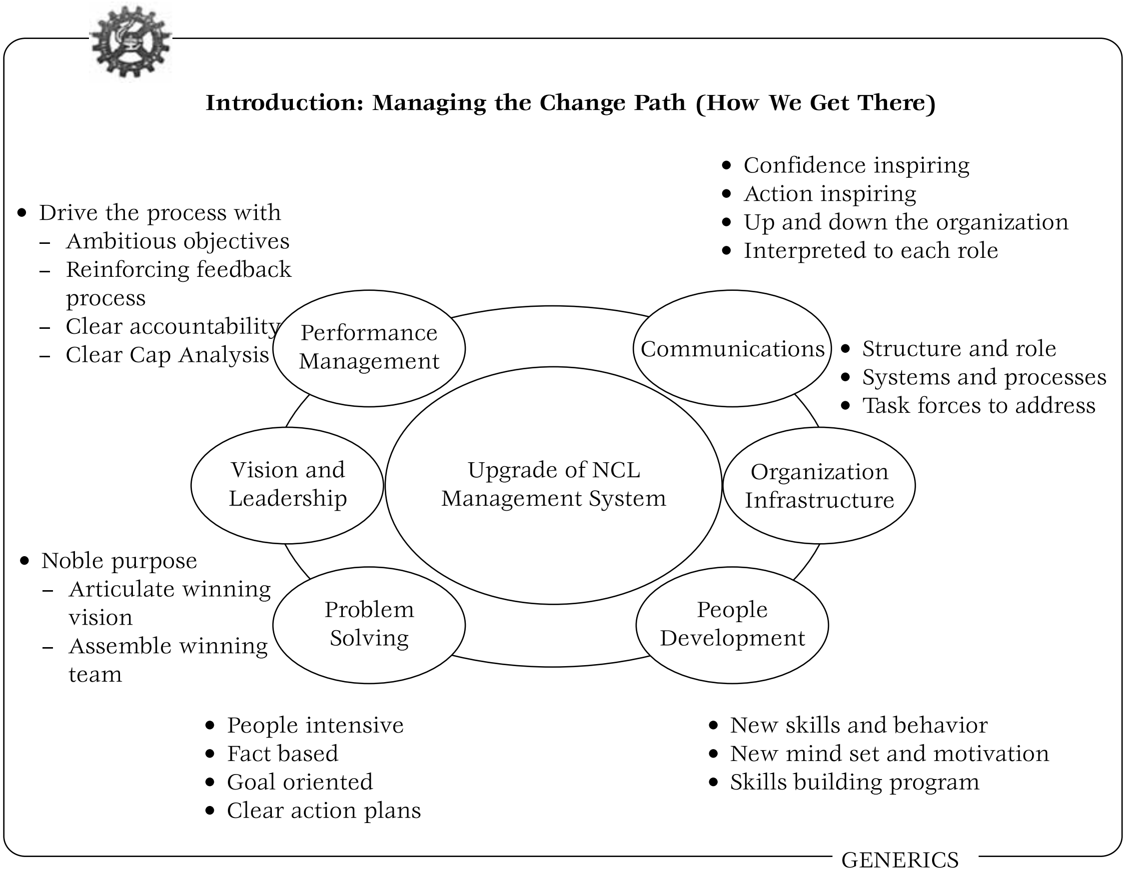
> *If, in the middle of World War II, a general could be writing a poem, then maybe I was not so irrelevant after all. Maybe the general was doing more for victory by writing a poem than he would be by commanding an army. At least he might be doing less harm.*

In addition to the vibes of the ADL mentioned previously, there was also an informal report by A. M. Lele, Head of DTS under Tilak, which noted that an alarming number of scientists were idling away their time, perhaps attending to their own personal chores during laboratory hours. Tilak freely used the word "deadwood" to describe these scientists. When some of them were questioned, their response was even more disconcerting. They claimed that only the BEBs of the director got all the attention and that there would be no reward for them even if they did work hard. Tilak and all subsequent directors thought it best to let deadwood remain deadwood, instead of kindling it to a spreading fire. In a way, these scientists were relevant, if only negatively so, by doing something else, like the poetic general of Robert Warren — thus doing less harm! The NCL handled this situation by ensuring that their influence would not spread.[11]

Management Systems Upgrade

Consequent on its dealings with the World Bank, the NCL was required to commission a report on the upgrading of its management system. Such a report, commissioned from Generics, made some detailed suggestions. In my personal judgment, the report contained nothing new. Well-known common sense stuff was clothed in the language of management and presented very impressively. "Managing the Change Path," as the report grandly calls it, straining under its own weight to be different from the past, is no more than a set of time honored concepts artificially separated into different actions (Figure 5.7). They are all so interconnected that separation can only lead to repetition. And yet such a presentation can serve a useful purpose, if only by helping to refocus on some of the methods and giving them greater clarity.

Figure 5.7: Managing the change path



Is Claim of Continuing Success Suspect?

This is generally against the progression of human events in which, surely, cyclic occurrences are common, like excellence in our case. But then, at first glance, it would appear that the greatest betrayer of natural laws is nature itself. It would even *seem* to defy thermodynamics by creating order out of disorder, complexity out of simplicity. This, however, is not the case, as so poetically expounded by Lewis Thomas:

> *It is thermodynamically inevitable that it (*nature*) must rearrange matter into symmetry. Away from probability, against entropy,* the most pervasive and indestructible of its laws: *Lifting it, so to speak, into a constantly changing condition of rearrangement and molecular ornamentation…*
>
> Lewis Thomas
> in the *Music of This Sphere*, 1971

Order out of disorder, the very basis of the evolution of complexity and of life itself, is a feature of open systems, and only *appears* to defy the law of entropy, which is applicable only to closed systems such as the universe itself.

As far as the NCL is concerned, like for other institutions of repute, these undulations between excellence and rank mediocrity have not been between +1 (as for the most outstanding institutions) and –1 (as for the worst institutions), but between more practical limits, defined by fractional numbers on either side. My own guess would be around +0.6 to 0.7 on the positive side. It has never had a high negative number.

❄

6

DIFFERING APPROACHES, UNBROKEN LEADERSHIP
THE ROLE OF DIRECTORS

> *Some people are so good that nothing*
> *a leader can do will make them better.*
> *Others are so incorrigible that*
> *nothing can be done to improve them.*
> *But the great bulk go along with the tide of the moment.*
> *The leader must help create that tide.*
>
> Attributed to a 19th century
> Japanese philosopher[1]

With the background to the NCL explained in the previous chapters, including an excursion into the establishment and early years of the laboratory, and its emergence as a state-of-the-art laboratory, we will now discuss the various domains of its evolution. Most importantly, no account of the NCL's research structure would be authentic without emphasizing the central role of its directors. Till recently, management was not a crucial tool in the evolution of the NCL. Even so, as already mentioned, certain tools described in the previous chapter were used almost naturally but without the modern nomenclature. This aspect of the laboratory's growth will also be touched upon.

In general, institutions have been built in two ways:

- Pre-determining the areas of research and finding scientists to match requirements.
- Locating top scientists working in the broad areas of interest, attracting them to the laboratory, and providing them with facilities to develop their own specific areas of interest.

Corporate research organizations follow the first route and academic institutions (unfortunately not always) the second. Laboratories like the NCL usually find themselves in an uncomfortable position between the two, seeking both to satisfy their institutional mandate to carry out industrial research in well-identified areas and the scientists' bias towards academic research in subjects of their choice. We shall see how the NCL has been trying over the years to strike a balance between these somewhat disparate demands. The role of the directors in this effort and aspects of their personal styles of management are also discussed at some length. The words of Bhatnagar while announcing the appointment of James McBain as the NCL's first Director, though perhaps somewhat exaggerated in the changed context of the times, continue to be true in their essence nonetheless:

> *The Director, besides his own research work, has obligations to other sections not directly under him. He has to electrify the whole atmosphere of the laboratory. It is his spirit of service and flare for research which will ultimately determine the success of this experiment. The future of chemical research and chemical industry in this country will rest on his shoulders to a large extent. I do hope and pray that he will rise to the occasion and raise this country to great heights in the field of chemical and industrial research.*
>
> National Chemical Laboratory Booklet, 1947

The director continues to play a major role in ensuring the laboratory's undiminished relevance in an increasingly interactive world environment. Photographs of the eight directors the NCL has had from 1950 to 2010 appear in Figure 6.1.

The NCL's evolution over time can be classified under four domains of historical development, (See Chapter 18 for the fifth, future domain as envisaged by me) as indicated in the following, section.

NCL's Domains of Growth/Management

The four domains mentioned above correspond to three discontinuities:

- 1950–65: Stabilizing period under McBain, Finch, and Venkataraman, supplying the underpinnings of a strong research base with an unspoken emphasis on academic research, and accompanied by naïve forays into industrial research; research program largely dictated by scientists' interests and their Ph.D. programs; most work academic in nature, some of which honestly but erroneously believed to be of industrial value; formative stage with dominant divisional structure.
- 1965–78: Emphasis on import substitution and indigenous technology development, and in the later stages a dedication to rural development under Tilak; introduction of industrial research, with formation of project teams; no noticeable interdivisional cooperation; beginnings of the concept of rational scale-up and commercial culture but design and scale-up mostly empirical; main accent on much needed capability building and self-reliance; reduced emphasis on academic/publishable research.
- 1978–90: Shift from import substitution to state-of-the art, internationally competitive technology development, under Doraiswamy; emphasis on all-round excellence, particularly on recruitment of scientists with ability to lead and foster excellence; formation of project teams with scientists drawn from different divisions; emphasis on excellence in every aspect of the laboratory; the beginnings of experimental sophistication.
- 1990–present: Continuation of excellence, with particular emphasis on forward technology development and international collaborations (involving multinational companies) as a consequence of globalization under Mashelkar, Ratnasamy, and Sivaram; adapting to the spreading culture of globalization, privatization and market-driven economy; increased sophistication in experimental techniques and in management, and computerization of all major laboratory functions.

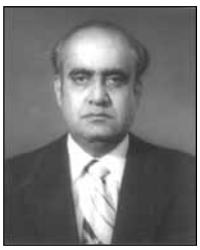
Figure 6.1: Photographs of the NCL's directors 1950 to present

Prof. James McBain
1949–52

Prof. George Finch
1952–55

Prof. K. Venkataraman
1955–68

Dr. B . D. Tilak
1968–79



Dr. L. K. Doraiswamy
1979–89

Dr. R. A. Mashelkar
1989–95

Dr. Paul Ratnasamy
1995–2002

Dr. S. Sivaram
2002–Present

Each transition has added to the overall strength of the laboratory and happened smoothly with no upheavals. The shifts were gradually implemented without unduly disrupting the scientists engaged in any current work or fully dismantling existing domains. In other words, in the language of modern management, this was done by mildly violating the law of "destructive creativity" described in the previous chapter. The four domains are illustrated in Figure 6.2. No single domain is exclusive of the others. A closer look into these domains should provide an integrated picture of the NCL's history.

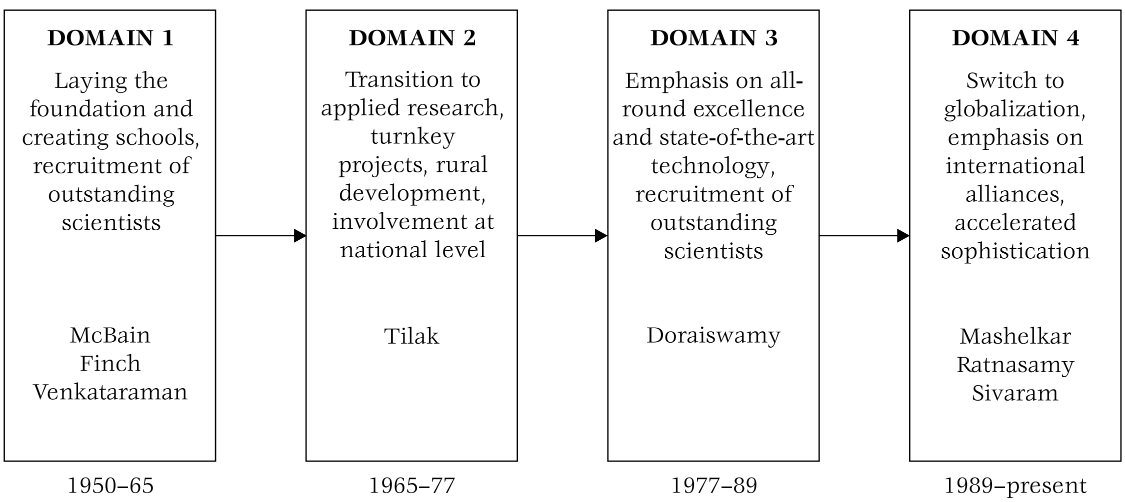
The laboratory has gone from practically no management in the 1950s to a high level of sophisticated management 50 years hence. This progression was as much a reflection of the times as a product of the directors' perceptions. In this section, we will examine the four domains covering this period, each enriched by the personal vision of the directors and marked by an increasing recognition of the role of its management.

One of the principal reasons for the NCL's continued excellence has been the recognition by all its directors of a cardinal fact identified by Pelz and Andrews in an exhaustive study by them:

> ***Effective scientists*** *were not fully in agreement with their organization in terms of their interests; what they personally enjoyed did not necessarily help them advance in the structure.*
>
> Pelz and Andrews, 1975

Till around 1990, when the laboratory largely depended on government funding for its research, the directors set aside a certain amount of money for basic investigations. A fairly large number of scientists did not participate in the applied research programs of the laboratory. They were not punished. On the other hand, reasonable sums of money were made available to them to pursue their own Ph.D. programs. This led to a large

Figure 6.2: The four domains of the NCL's growth



Note: The domains are not mutually exclusive. In fact, there is a great deal of continuity.

number of publications, making the scientists effective in their individual ways, although they did not agree with the goals of the organization. From 1990 onwards, various other means of encouraging basic research, even by scientists who did not see eye-to-eye with the organization, were practiced. Blue sky research or kite flying was encouraged by Mashelkar by offering funding to bright ideas, as determined by a committee of experts. Then came the concept, credited to Ratnasamy, where funding for basic research was offered if the scientists could show publications in prestigious journals, particularly *Nature* and *Science*. Variations of these concepts were then introduced.

Clearly, the NCL was in the forefront of laboratories in encouraging basic research and subscribed in its own way to the effectiveness of non-conforming scientists as observed by Pelz and Andrews, with one difference. The scientists did go up in the organizational structure, particularly the outstanding ones (but the average performers who fully ignored the laboratory's mandate tended to suffer stagnation).

DOMAIN 1: LAYING THE FOUNDATIONS AND CREATING SCHOOLS

If you have built castles in the air, your work need not be lost; that is where they should be. Now put the foundations under them.

Henry David Thoreau, *Walden*, 1854

McBain, Finch, and Venkataraman may or may not have built castles in the air, but they did build strong foundations — which will always remain the springs of the NCL's creativity.

This domain can roughly be divided into approximately two equal periods: the first half when the foundation was laid and strengthened, and the second half during which schools of research in various scientific disciplines of the laboratory were created. They were associated with the tenures of McBain and Finch in the first half, and of K. Venkataraman (KV) in the second. No clear demarcation is of course possible, but from my own personal association with this period (1954 onwards), this seems to me to be a fair representation of what occurred.

McBains's Personalized Style of Management

For the first several years after it started in 1950, the NCL was fully wedded to the concept of monolithic divisions. During the McBain years, each division had projects consisting of one scientific officer and one or two assistants — never more. Divisional heads had a few students in addition to the regular staff working for them. The director conducted the affairs of the laboratory mostly through the divisional heads and occasionally through interaction with other scientists. This direct involvement of the director with the scientists of the laboratory was the central concept of McBain's administration.

Every Monday was earmarked for a meeting between the director and all the scientists, where all the projects of the laboratory were openly discussed. Every scientist was expected to submit a brief outline of the work done by him/her to the director at least a day before the meeting and then elaborate on this to the entire laboratory during the Monday meeting. If there were any delays in a project, these were expected to be pointed out along with reasons for the delays. Since all divisions and support units of the laboratory, like the workshop, glass-blowing section, administration, and finance, were represented at the meeting, the division or section against which any complaint was made would be present to instantly respond. After some questioning and critical evaluation by the director, the concerned people would be instructed to be more cooperative but no blame would be officially apportioned. Whenever a scientific issue was raised this would be thrown open for discussion and sometimes, but not often, scientists from different divisions would be asked to cooperate. McBain made it clear that he would not entertain complaints against anybody in the seclusion of his office. Even if occasionally he felt the need to entertain a complaint in his office, his secretary had instructions to beforehand determine the nature of the complaint and ensure the presence of the concerned individual(s) when it was discussed.

These Monday morning meetings as they were popularly called, became the hallmark of McBain's scientific management and the main talking point of his regime. It is not clear whether they served any scientific purpose, but they did help in removing administrative bottlenecks and hurdles, and delays from the support groups. They had the effect of alerting scientists to possible personal scrutiny by the director. In a country like India where even the possibility of a reprimand by the "big boss" is viewed as a dire event that should be scrupulously avoided, these meetings did serve a disciplinary purpose. Unfortunately, the effect was even greater since the big boss happened to be a Western scientist — however kind and forgiving.

The trouble with this system was that there was really no consequence for continued complaints, partly because McBain was not the punishing type, but mostly because the system itself did not have any quick way of administering punishment. The choice of projects was not only arbitrary but reflected a complete ignorance of what is involved in any project work. I already mentioned in Chapter 4 how a project of the complexity of PVC was selected almost casually. Another such project was transfusion gelatin (used as a blood transfusion substitute), the brainchild of Gurubaksh Singh, a scientist of the Biochemistry Division, that was also multidisciplinary and in which the product purity was of the greatest importance. This was a favorite project of the director but did not go anywhere. Titanium dioxide, a formidable project of tremendous proportions, and chlorination of ilmenite, a highly complicated fluidized-bed technology, were a couple of other projects that were far beyond the competence of the NCL scientists at that time.

One can hardly think of a greater lack of understanding in the choice of projects and of the scope and personnel requirements of the project! But the times were different, perceptions were overly optimistic, and enthusiasm for a project of national importance was stronger than reason. In this climate, abetted by an uninformed scientific bureaucracy, any rational approach to industrial research was almost inconceivable. Any progress from this state of affairs was difficult and needed a sustained effort. And this is precisely what was done in Domain 2, to be discussed later in this chapter.

In retrospect, it appears, rightly or wrongly, that McBain was more interested in creating a culture of research and democratic discourse among scientists than in research *per se*. This is not to devalue his efforts in recruiting good scientists and offering sound scientific advice. Unlike all subsequent directors, he did not personally engage in serious research. Some work was started on colloids and interfacial phenomena, areas in which he had been a dominant presence, but they did not survive as schools. As will be seen later, good work was done in subsequent years on interfacial phenomena.

McBain was what most traditional managers of science were, a first-rate scientist with a common-sense approach to management with none of those flourishes of the modern manager. An example of his down-to-earth approach to leadership, narrated to me by a senior scientist of McBain's time, must have left a scientist embarrassed and a peon smiling. A middle-level scientist went to the stores in the basement (now located in a separate building) to issue a chemical. Having signed for it, he passed on the small bottle of the chemical to a peon whom he had brought along with him. As he was walking back to his laboratory, the peon following him bottle in hand, McBain espied this two-man procession heading to the first floor. He quietly borrowed the bottle from the peon and took his place behind the scientist. Back in his laboratory, the scientist ordered the peon to deposit the bottle on the counter. "Yes, sir," said an obedient American voice! The rest is better imagined than told! Thanks to the constant practice of such an attitude by most of the staff in the formative years of the NCL, the culture of self-help has been deeply rooted in the laboratory. But the Indian culture of Class 4 employees, who can be used as personal bearers, is hard to overcome and continues to this day at the NCL.

Along with his two immediate successors, McBain was also a professor. His attitude to research and his colleagues was therefore hugely professorial. In hindsight, this was not a bad thing, for it helped the NCL gain the manner and prestige of the university, while the more practically oriented approaches of the later directors tended to bring a measure of balance to the laboratory. Too much of either would have been self-defeating. The biggest challenge to all the directors was to keep this from happening. Without getting carried away by the rhetoric of academic and industrial cultures, McBain played his lone hand with a full understanding of its implications. Fortunately his legacy prevailed, and has permanently embellished the style and substance of the laboratory. The traditions and lessons he left behind are:

- A style of management that recognizes the supremacy of the individual scientist
- The dignity of self-help
- Community service
- If one must complain, to do so openly

The Division of Survey and Information was created to assist the director in the scientific management of the laboratory, but there is little evidence to show that it fulfilled these objectives in any significant measure during the early years. The director, either because of his own perception of management or because the S & I Division made no aggressive espousal of its role, did not enlist the help of the division in his Monday morning meetings or other initiatives. The management was highly personalized and did not depend much on existing channels of communication.

Finch's Remote Style of Management

George Ingle Finch was a highly distinguished professor at the Imperial College in London when he was approached by the CSIR to take on the directorship of the NCL. He was still active in the area of diffraction and microscopy, to which he had made significant contributions. In fact, he is regarded as the founder of electron diffraction. It must have been a difficult decision for him, but he accepted the challenge. His own research would continue as he had decided to bring some of his outstanding Indian students, including A. P. B. Sinha, Anil Goswami, and M. K. Gharpure, along with him to the NCL to start a school of electron diffraction, unlike McBain, who brought no one. Like McBain before him, he was a physical chemist, but again unlike the former director he started a school of research of his own. The most notable example of his work at the NCL is his paper with Sinha on the investigation of the iron oxides, hematite, magnetite, and meghemite, which led to the suggestion that a new magnetic phase of ion existed. This work stimulated a number of investigations in various countries into the unusual magnetic properties of hematite.

In view of Finch's personal interest in the research program of the Physical Chemistry Division, the head of the division, A. B. Biswas, was often side-tracked. Biswas was an excellent scientist in his own right, having got his Ph.D. under no less a scientist than Linus Pauling at Caltech. Thus he was always on the lookout for an alternative position. He got one as professor of physical chemistry at IIT, Bombay, and left the NCL in the mid-1960s.

Finch was a very conscientious scientist, as will be clear from the following incident concerning a paper by Lakhbir Singh. In those days, all communications for publication had to be approved by the director. Singh was a physical chemist and although the Physical Chemistry Division had its own head, Finch was not happy with Biswas and wanted to clear the paper personally as it was being submitted to *Nature*. He found it unworthy of the journal and returned it to Singh. Not to be deterred, Singh went back to Finch and argued his case. Finch relented but stipulated that the paper would go with the author's name and residential address and with no NCL communication number (an NCL requirement), with no mention of its affiliation to the laboratory, and no credits to it either. That is how the paper went from NCL — and that is precisely how it appeared a few months later in *Nature*, and earned the compliments of a surprised Finch! The arguments and debate on this strange episode in an isolated neighborhood not averse to such a diversion (gossip?) can well be imagined!

While Finch was unquestionably a very healthy influence on scientific research at the NCL, opinion is divided on his role as an administrator. Unlike McBain, he gave the impression, correctly or incorrectly, that he had strong likes and dislikes among scientists. On the other hand, he had an impersonal style of administration that would not brook emotional links. His distance from the scientists, a cultivated indifference to their personal feelings, would not permit such an attitude on his part. He honestly felt that distance conferred a certain neutrality that was sometimes disliked, coming as it did immediately after the highly personalized administration of his much-liked predecessor. Whenever he had some opinion to convey to a scientist or divisional head, he did not dress it up with sweet language but was quite blunt. He was, by all standards, a straightforward man whose direct manner sometimes invited criticism. But that was Finch's way. The NCL driver, Alexander, had an interesting tale to tell. Often when he and his wife left Poona (Pune) for Bombay (Mumbai) in the NCL car, they would start out on the best of terms.

Somewhere along the road, Finch would say something blunt that irritated Mrs. Finch, and soon they would be sitting at opposite corners of the seat, sulking from each other. It would not be before they reached Bombay that they talked again! That was Finch. And those who did not know this side of him, did not know him at all.

His tendency for abrupt action got him into serious trouble once. It was Republic Day, and it has been the practice ever since the NCL's inception for the director to personally hoist the national flag on the premises. On that particular occasion, Finch was busy with some work and deputed M. Damodharan, Deputy Director, to perform the function, without thinking of consequences. This was reported by a disgruntled scientist to the communist magazine *Blitz*. This magazine published a series of scathing articles demanding an enquiry and his dismissal. To cut a long story short, Finch survived the ordeal and things were back on rail again — almost, for some people never forgave him for this unintended insult, if it was indeed that, to the national flag. It must be remembered that they were the early days of freedom and emotions ran high. Finch should have been better advised by the administrative officer, or should himself have used better judgment, particularly since he was English.

And yet it is an undeniable fact that he had a great admiration for India and Indian scientists. It was said that he had a personal rapport with Prime Minister Nehru, and was delighted when Nehru accepted his invitation to visit the NCL, the Prime Minister's second to the laboratory. This was his first and last visit after the inauguration in 1950, and was particularly noteworthy as he was accompanied by his daughter Indira Gandhi, who became Prime Minister several years later, and his grandson Rajiv Gandhi, who also ascended to that position in 1984. Figure 6.3 shows the three generations of Prime Ministers at NCL.

Some of these incidents notwithstanding, Finch had a robust approach to research and researchers at the NCL. His style of management precluded close friendships with the scientists. And yet, when he left Pune, the occasion did evoke a sense of loss, for he was a great scientist who managed the NCL with an impersonal firmness that brought in a great deal of discipline. He was also admired for his physical prowess, for he was a mountain climber of no mean repute. He had scaled some of the lesser peaks of the Himalayas and also took a shot at Mount Everest a few years before Sir Edmund Hillary and went within a few hundred feet of the peak. As K. Venkataraman (KV) says in his reminiscences (see Chapter 17) Finch used to climb Mont Blanc almost routinely! Even allowing for KV's sense of dry humor, one can assume that Finch had climbed that mountain at least a few times. In those days, the surroundings of the NCL were punctuated with hills unspoiled by the wastes and other intrusions of humans. Finch made full use of this situation to frequently climb those hills and wondered why such an element of rudimentary adventure was lacking in his younger colleagues. Again, as KV regretfully records, Finch was succeeded by a physically weak asthmatic like himself who viewed with awe even Chatursingi, a diminutive hillock, with a famous temple on top, not far from the NCL!

If Finch was a controversial figure in some ways, he also left a lasting imprint on the NCL. He was not happy with the functioning of the radioactive tracer laboratory and invited specialists under the Colombo Plan to reorganize it and lay down a new research program. The Organic Chemistry Division headed by R. C. Shah was engaged in some

Figure 6.3: Three generations of Prime Ministers at the NCL — Jawaharlal Nehru, Indira Gandhi, and Rajiv Gandhi (1950). Morarji Desai, also a future Prime Minister, can be seen behind Indira Gandhi

outstanding work in the field of essential oils under S. C. Bhattacharya. It is to his credit that he encouraged this group, for it soon acquired national eminence and grew under his successor into a separate division, the second organic chemistry division of the laboratory. Similarly, a few other activities started by Finch fully bloomed in (KV's) time. This was probably because his tenure was rather short, 1953 to 1957. An example is the workshop. Housed initially in the basement, he expanded its activities considerably, but it was left to KV to complete the job of moving it to a new location.

It was remarked earlier that Finch was impersonal in his dealings at the NCL. But this was probably a façade, which he thought was the right thing to adopt. My personal experience with him proved this point. I was on a visit to France when I took a few days off to visit England. He was beside himself with delight when I contacted him and insisted that I visit him at Oxford. He and his wife picked me up from the Oxford railway station and took me to their residence, Two Trees House, so named after the two magnificent trees hat adorned the entrance to the house. They treated me with the greatest hospitality and when I left the next day, packed up a lunch of enormous proportions that was good for two full days!

Venkataraman's Dedication to Research and Creation of Schools

KV, as he was commonly known, was nothing if not polished, suave, totally dedicated to research, and magnificently articulate when he chose to be — always with a sense of dry humor. He was Director for seven years and stayed on for 15 more to complete a multi-volume treatise on dyes. His post-directorial stay was made possible through a hefty PL-480 project on lac dyes by the US government. KV made his debut in the NCL with his characteristic dry humor when, in his opening address to the staff, he declared in a subdued tone that he had known all along that Pune was a good place for retired old scientists but on coming to the NCL, he realized that it was also a good place for retired young scientists! This reputation for cutting humor never left him. In another remark soon after joining the laboratory, he indirectly chastised a senior scientist for his too frequent travels outside Pune. All travels outside the city required director's approval, a practice that was later discontinued by me. When this senior scientist sent a note to the director seeking his permission to travel to Delhi and other places in 5–6 separate trips, the file was returned to the scientist with the following comment:

> *It would be easier and save much paper if in future you just indicated to me the dates on which I could find you at the NCL*!

Like his two predecessors, his only previous engagement was with a university. But so was Bhatnagar's. On the other hand, he was very much unlike Bhatnagar or any other professor of those years. He was instrumental in the establishment of the dyestuff industry in India, when the Indian Dyestuff Industries Ltd. was started based largely on the work done by him and his group at the Bombay University Department of Chemical Technology. In the absence of any industrially oriented laboratories till the advent of the CSIR, it was the general practice in the formative years of the CSIR to appoint university professors as its directors — a fitting and fortunate circumstance. This practice largely continues to this day whenever a director is selected from outside the system.

KV was a workaholic. His only interests were his own personal research and the laboratory. Unlike in the days of McBain when social work was considered a qualification, in KV's time it mattered little. In fact, an overzealous dedication to social causes or time taken off to attend to some important family chores never failed to invite a dry comment. He was not unlike the Nobel Prize winning German biochemist Otto Warburg, who had a penchant for work and hated holidays.[2]

The genesis of this attitude was perhaps the fact that he had surrendered all his responsibilities besides the laboratory to his wife and his unspoken desire — requirement, if you will — that others do likewise and spend most of their time on laboratory work. Mrs. KV was a remarkable person and was perhaps the most admired *first lady* of the NCL. She took interest in a wide variety of issues including the use of birth control among the Class 4 employees. KV heartily encouraged those activities as long as his own time and that of his scientists were minimally involved.

This single-minded devotion to research and laboratory affairs was clearly reflected in KV's management style. He wanted every staff member to be equally involved in the decision-making processes of the laboratory. To accomplish this, and also as a consequence of his academic background in England, he started the collegiate style of management in the NCL. If McBain had his Monday mornings, KV would have his Senior Common Room (SCR), at which all divisional heads met periodically to discuss all matters pertaining to the laboratory. But KV being KV, the greatest importance was given to the research programs. The SCR soon became an institution as the directors immediately following him, Tilak and Doraiswamy, continued this practice. Due to various reasons, not the least being the increasing number of senior scientists and the creation of new independent units, this practice was discontinued by subsequent directors. Meetings were held, but not necessarily of all divisional heads, other senior scientists and unit heads together.

His style was marked by precision and a total dedication to English grammar. He operated on a zero tolerance for lapses in these. This even extended to his supervisory role as a Ph.D. guide. It was the habit of students then to calibrate supervisors in terms of the length of time they took to complete a Ph.D. program. Thus the supervisors were graded as three year guides, four year guides, and so on. KV was a seven year guide. Actually, his reputation for length of his Ph. D. program went beyond that. He drew the following comment: *If you work for your Ph.D. with KV, you normally get the degree posthumously!* And yet he produced about 85 Ph.Ds.

Management of science was not a major priority for KV — although he had no illusions about its importance. When told about some books written by CSIR's scientists on the science of science, his immediate reaction was: *Let us first do good science and then talk of the science of science.* He was not a great believer in formal management styles. What came naturally from experience and common sense and suited a vision was the right thing to do. If he was indifferent to management as a science, he was no different from many other top scientists of his time.

It was during his time that some major changes were made in the publication procedures of the Division of Technical Services (DTS). This division was responsible for the publication of all reports of the laboratory, including quarterly reports. Till 1962, all annual reports were published only in cyclostyled form. Then, for the first time, a report for a full decade, 1950–60, was printed in 1962. KV was keen that this report should be made available to as large a section of the scientific community as possible. Publication of printed annual reports then became a regular feature of the laboratory. He encouraged the DTS to go about its normal business: development of business interests by providing research and technical information to likely clients, carrying out the functions of scientific and industrial liaison, and disseminating technical information through publications and publicity as communication tools. There is little evidence that he evinced personal interest in these activities, but liked to be kept informed.

His many other contributions to the laboratory notwithstanding, KV's single most important contribution was the creation of several schools of research, nourishing them, and attracting some highly talented scientists to the laboratory, particularly in the field of organic chemistry, to sustain these schools. He encouraged research of a high order by personal example. Of the scientists he attracted to the NCL, the most outstanding was Sukh Dev from the Indian Institute of Science. He offered him excellent facilities and, on the retirement of R. C. Shah, made him the head of the Organic Chemistry Division.

He did not seem to mind the fact that Sukh Dev, like S. C. Bhattacharya (SCB), was also a natural products chemist. For that matter, so was he. It was mentioned at the beginning of this chapter that institutions can grow in two ways, one by attracting talented scientists irrespective of their particular field of expertise as long as it was in the general field of the institution, and the other by planned recruitment. KV believed in the first mode of growth. He also encouraged talented scientists within the laboratory to grow. This paid rich dividends, for SCB became the first NCL scientist to receive the prestigious Bhatnagar Prize, the hallmark of excellence in India, for outstanding work by a scientist under the age of 45. It was a joyous moment. SCB started this tradition of excellence in 1962 which was followed by 13 more scientists, the highest number in any institution in chemistry in the country.

KV also attracted from the UDCT, another distinguished organic chemist and the 1963 Bhatnagar prize winner in chemistry, B. D. Tilak, who was later to succeed him as Director. Tilak was brought as Additional Director with the full blessing of the then Director-General, Husain Zaheer, to succeed KV as Director. This had unfortunate and unforeseen consequences. SCB was greatly disturbed and soon left the NCL to take up a professorship at IIT, Bombay. In retrospect, although SCB was an outstanding chemist, had his genuine reasons for disliking the director, and won the sympathy of many chemists, as will be obvious from many chapters of this book, Tilak's appointment was one of the finest things that happened to the NCL. His detractors accused him of killing organic chemistry at the NCL, as they did me a few years later when I became Director, but it is for the reader to judge from the facts given in this book.

Although KV was fully involved in many of the activities of the laboratory, he was always unobtrusive, with his gentle manner and low-profile. There was more building activity during his regime than at any time in the NCL's history. He completed the job started by Finch and had the workshop and glass-blowing sections housed in separate new buildings. These are two of the most important support groups of the laboratory. The Essential Oils Division also had a new extension during his period, and so did the radioactive tracer lab. The beginnings of these two activities could also be traced to the Finch period. A huge well-designed pilot plant building was conceived and constructed by him. Considering his perceived indifference to affairs other than scientific, it is noteworthy that the following new facilities were added during his tenure: a canteen, extension to the cooperative store, the NCL housing colony, a new building for the NCL post office, a new hostel, and many other sundry facilities.

Both in terms of technological achievement and management, his most impressive contribution was the creation of a chemical engineering equivalent to his pet subject: the chemistry of synthetic dyes, on which he wrote the first ever book, which remained, for a long time, the bible in the teaching and production of dyes. His concept of chemical engineering was based on the old German concept of unit processes, such as nitration, sulfonation, hydrogenation, halogenation, hydrolysis, alkali fusion, etc. He wanted me to prepare a scheme in which equipment for all these unit processes could be housed and used as desired. I tried to tell him that chemical engineering had come a long way from this concept but he was insistent. Soon he went to the Executive Committee to establish a new Division of Organic Intermediates and Dyes (OID) (see Chapter 17, KV's reminiscences). This was one more instance of his style of management: encouraging scientists who, he felt, were assets to the laboratory. KV was a powerful voice in the affairs of science those days. In the popular language of today, what KV wanted KV got. Thus very quickly the new division was established and I was installed as the Assistant Director in charge of it.

Another major initiative of KV was the establishment of a Fine Chemicals Project to supply much-needed fine chemicals to the organic chemists of the laboratory. This project, run as a manufacturing unit in a research environment, was foredoomed to fail, and it did. Details of this are given in Chapter 10. But it is to the credit of KV that he created the only mechanism for supplying fine chemicals of great purity for research those days. He had enough knowledge of the industrial culture to know that this would not succeed, but was satisfied with the short time relief it would provide.

KV was also a very sensitive man, something which most of us knew but did not quite expect him to reveal in the startling manner that he did. In one of the meetings of the SCR, there was a severe difference of opinion between SCB and himself. This was brewing for a long time and erupted at this meeting. Some members of the SCR tried to ask SCB to drop the matter but he was adamant. We could see the tension building up and soon, with no warning, KV threw his papers down and walked out of the meeting. Many accusing faces were quickly turned towards SCB, but he appeared unmoved. Soon, quietly, everyone left the meeting. After about an hour, I walked into KV's office (since he always liked me) and stood there. He asked me to sit down. After a while, he asked me: *LKD, did I behave foolishly?* I said no, and soon he fully recovered. This was a moment I never forgot, for the great man's façade had slipped and he had shown himself to be all too human. When after a couple of years, Tilak was appointed as Additional Director to succeed KV, SCB left in frustration. From what I can gather, SCB never forgave him for this "treachery."

The personal side of KV showed up at its best when Pune almost went under due to the floods caused by the breakage of the Khadakvasala dam. Situated at a height, the NCL was not affected, but large parts of the city were literally swallowed up by the raging rivers, Mullah and Mutha. As a number of the NCL's local staff lived in the city, theirs was really a sorry plight. R. V. Kulkarni, the engineer in charge of the workshop and one of Finch's outstanding recruits, lived in a part of the city that was badly affected. KV offered him and many others the hospitality of his huge flat on top of the NCL. He also made use of this opportunity to formulate a plan with Kulkarni for the quick construction of a number of quarters of various categories in the NCL colony, so that those who were deprived of decent housing could move in as quickly as possible.

For one who hailed from a South Indian Brahmin family, he and his wife were marvelously unorthodox and devoid of any caste feelings. In fact, Mrs. KV's *puja* room was left fully to the care of two of their Christian servants, Anthony and John. Whenever Mrs. KV performed *pujas*, it was Anthony or John who broke coconuts and brought in all other paraphernalia for the *aarathi*. Although she was very well informed on all general matters and could hold her own in conversations with the many outstanding scientists who visited with her husband, she was often naïve beyond belief. My wife (who was to undergo stomach surgery) and I paid a visit to the KVs a couple of days before our departure for Madras for the operation. Mrs. KV, quietly and very encouragingly, told my wife that just two days previously one of her friends underwent a similar operation but the poor woman died on the table. An outraged KV did his best, in his own gentle way, to make up for this faux pas. Another interesting aspect of the KV family, this time involving KV: Indian families do not dress for dinner. KV always did, mostly in a full suit and a tie. He seldom ate with his hand and used cutlery specifically chosen for different dishes, gently wiping his mouth to make sure it was always clean. My young daughter always referred to him as "that cute man."

KV was also not beyond the failings of many a retired director who continued in the same laboratory after retirement but with no powers. Although I followed him after Tilak, he perhaps felt he could take some liberties with me. Soon after I was named Director, he called me to his office and without preamble put forward a proposal. I was to allocate ten scientists to him with no questions asked about their performance or their promotion. They were to be handled based entirely on his report and without any comparative assessment with other scientists. I was completely taken aback and as I sat thinking, he repeated the proposal. My weak, almost inaudible, reply that I would like to think about it, drew his ire. He told me that I might consider the proposal withdrawn and changed the subject. He never fully forgave me for this disloyalty and I, for my part, never saw any reason to subject ten scientists to a different system of appraisal, even if the lab could spare their services — which it could not.

This entire discussion in this chapter has been in terms of domains of operation in the NCL. We are just at the end of Domain 1. Before we move on to Domain 2, it is interesting to recall the definition of destructive creation, although it was not called exactly that by the last director of Domain 1. It provides an unvarnished, if somewhat cynical, perspective of what a highly respected scientist of an earlier time thought about destructive creation. Wrote KV, an uncharacteristically undiplomatic KV (see Chapter 17, KV's reminiscences):

> *A common phenomenon in our country, when a new person takes charge of an institution as Vice-Chancellor, Director, etc., is that he quickly proceeds to demonstrate that his predecessor was an unusual combination of congenital idiot and crook; and to turn things upside down. Fortunately, the NCL has been undergoing a natural and healthy process of evolution based on tradition, an understanding of earlier problems and difficulties, and a pride in past achievements.*

In closing this description of Domain I, KV should be remembered as an unusual man, an outstanding chemist and in the league of the best in the country. It was fortunate that when the NCL's leadership was passed on to Indian scientists, the transition occurred through a scientist of his caliber and insight. On the other hand, if the NCL deserved no less, KV deserved no less either.

DOMAIN 2: THE TRANSITION TO APPLIED RESEARCH UNDER TILAK

> *I have been impressed with the urgency of doing. Knowing is not enough; we must apply. Being willing is not enough; we must do.*
>
> Leonardo da Vinci, c. 1490

Tilak gave the NCL the advantage of learning from practical experience. This section recaptures the flying start he gave to the laboratory in a field the whole country lacked experience in. His successors added shades of excellence to this much-needed early initiative.

The underpinnings of change in the NCL

The changes in the CSIR's rules and procedures mentioned previously augured well for the individual laboratories to pursue their own lines of growth. Meanwhile, the NCL was gaining increasing strength and visibility, with its leadership acting to exploit these within the broad ambit of the CSIR's policies, but without being unduly stifled by imposed systems and procedures (for which it had to absorb some jibes from the CSIR — not much more, fortunately). In the absence of the wisdom of hindsight and the advantages of modern phraseology, natural leadership over the years led to a series of changes consistent with the basic tenets of destructive creativity, but differing from it in one major aspect — there were no sudden sweeps. The first major equivalent of destructive creativity occurred around 1965 when Tilak took over the reins of office as Director of the NCL. There were changes when Finch succeeded McBain and Venkataraman succeeded Finch, but these were largely changes in style and not in philosophy. In a sense, they were intra-philosophic changes that did not seek to destroy an existing emphasis and replace it by a new one.

When Tilak succeeded KV, there was a philosophical change. This era was heralded by the actions of Tilak, even when he was the presumptive or *de facto* Director and KV had practically relinquished all major responsibilities to him. Even so, when he took over the *de jure* leadership of the laboratory, he made his intentions clear in his own direct, forthright way, giving a message to all scientists that he expected them to do project work and that academic work would not be as valued. However, he did not cut down basic research, though, to a large extent, the message had that effect. Thus began a new era at the NCL, with the kind of work the founding fathers had in mind, almost 20 years after the laboratory was established. Tilak introduced a number of changes in the functioning of the laboratory. We shall now describe these changes and examine how they affected the performance and image of the laboratory. The directors of the NCL were different from other directors in that they had personalities of their own, and while dealing with New Delhi, did not allow the DG to dictate terms. This mutual sparring was most apparent during the Nayudama-Tilak era (Nayudama was the DG during most of Tilak's directorship at the NCL), and led to some unnecessary jibes from Nayudama, which Tilak ignored. Tilak did not help matters by going directly to the highest echelons of power in Delhi, bypassing Nayudama, during some of the most intricate technology transfer negotiations.

Within days of taking charge as Director, Tilak sent for me and told me how important he considered chemical engineering to be in the plan he had for the future of the NCL, starting right then. Although I was not officially in the chemical engineering division, being the Assistant Director in charge of the Organic Intermediates and Dyes Division, he made no secret of his lack of confidence in M. U. Pai, the head of the Chemical Engineering Division. Tilak was not one for convoluted ways of saying and doing things. Even so, the way he handled the acetanilide project showed that he could be diplomatic. He also realized that he had just taken over as Director, succeeding a man of great diplomatic skill and finesse. While he did not wish to dilute his message of the imperative need for a quick change in policy, he did not wish to upset the senior staff any more than he had to in implementing changes. The acetanilide project, the full story of which will be told in Chapter 10, was just gathering momentum at the NCL. Tilak had made up his mind to make a turn-key bid to HOC, even before he had the outlines of a process! Warnings and calls for caution from KV and others had little effect on him. It was then that he played his hand. He sent identical notes to Pai and me asking us what would be involved in developing a process on a pilot plant scale in six months. Pai's was a huge proposal involving an entire division and an unconscionable budget. What was more, he divested himself of all responsibility and said that, given all he asked for, he would make an honest attempt. My note had a different tone altogether. In principle, I agreed with Pai, but I was young and full of the recklessness of youth. I also knew that the process was simple and that I could assemble a strong and dedicated team of chemical engineers. The proposal I gave Tilak, besides having a strong technical base, implied all this in no small measure. This gave him the reason he was looking for to take the project completely out of Pai's hands and place it in mine. Pai was happy that he did not have to undertake such a huge responsibility, I was happy that I was given it, and Tilak was happy that he had found a kindred spirit in me. All this made for a good beginning for the first major industrial project of the NCL. Tilak was particularly happy that Pai had written and talked himself out of the project, the way he had hoped he would, without forcing the issue.

Tilak did not have any idea of a structured kind of leadership. In other words, management was not something that had to be viewed as a distinct entity, catering to the present as well as the future. Actions were taken as were needed to meet a situation. He lived in the present and did not overly bother about the future. He was not even concerned with the implications of his actions. He was always a single-minded individual in pursuit of a goal. If other things received minimal attention, he did not even bother to notice that. He was such a strong individual that his colleagues mistakenly assumed that he was indifferent to their views, which he was not. It was just that he was much more concerned with getting things done than in giving them fancy names. There was too much going on in the present and the future, he assumed, would naturally grow out of it. Viewed in this context, he did not manage the NCL. He ran it.

One of the things he did was to form a sub-committee of the laboratory's apex body, the Executive Council (E. C.) that would look into the release of the NCL's processes to the industry: The Process Release Committee. As this committee had a few industrialists as its members, it was ensured that all processes submitted for release were thoroughly discussed and their terms of release properly settled before they were deemed ready. To prepare for each E. C. meeting, he held meetings of each division, where the project leaders were required to present details of their projects with time-frames, staff and budgetary requirements, and all other aspects of the projects as perceived by them. These were free-for-all meetings where even the junior most members of the projects were free to express their views. Tilak showed an amazing understanding of projects unconnected with his own area of specialization (organic chemistry: chemistry of dyes), and often asked searching questions, and had some excellent suggestions. Based on these discussions, the reports of the divisions were modified for presentation to the E.C.

These meetings did not reflect his own vision of the NCL's future but were a collection of ideas from the laboratory's scientists regarding what they would do in the next few years and which he approved. There was no connected policy of growth. As far as he was concerned, he would identify a few projects and push them with all his vigor and enthusiasm. These became his passion and the short-term definition of the laboratory's purpose. If he appeared to sympathize with chemical engineering or any other division, it was because they would help him in his pursuit of certain projects. Any scientist, division or activity that helped him got all they wanted. Others had to manage with what they had. Thus, an area like theoretical chemistry received little attention from him, as did tissue culture, till he realized that some of its projects could be of enormous value to his new passion: rural development. Before this happened there was talk that he would terminate work in this area at the NCL and transfer it to the National Botanical Research Institute in Lucknow. This might not have happened but it certainly was a measure of his indifference to tissue culture at that point in the NCL's history.

His consuming interest in an area like rural development in later years seemed to belie the earlier statements that he was not interested in the future. But then this was a transformed Tilak, a Tilak traveling from village to village to understand local problems. He "adopted" the village of Chandrapur for taking the benefits of science and technology, wrote massive reports, identified projects where the NCL could help and drew up plans for implementing them. There was no high science involved (he stoutly refuted this). It served a purpose, even as acetanilide had served an earlier purpose with no high science involved. We will have more to say about rural development in Chapter 10.

In many ways he had grown beyond the NCL. His project-oriented style of management and relentless pursuit of an objective were known throughout the country. As a result, he was appointed chairman of HOC. In this position, he ensured that HOC undertook several projects and implemented them. He was also made chairman of the chemicals group of the National Committee on Science and Technology (NCST), where he formed scores of committees in different areas of chemistry, instructed them to break up recommendations in terms of projects, and come forward with time-frames, budgets, and staff and equipment requirements for each project. The time-frames and budgets were bound to be unrealistic, but he was more interested in identifying projects and giving a broad idea of what was involved. That was the Tilak of the NCL, that was the way he managed the laboratory and identified projects, their importance and how they could be implemented entirely through indigenous effort, mostly through use of existing technology. Projects again!

In his pursuit of projects, there were many scientists who were not involved and were being progressively side-lined. His style of management did not recognize this. The result was that they were forced to continue with their own academic research on which he did not set any premium. They soon became "deadwood" during his own regime. He was aware of this happening, and in a move that marked him out as a more perceptive manager than the votaries of management, called on the services of Arthur D. Little Inc. of Boston, USA, to submit a report to him on the involvement of scientists in the working of the NCL. Tilak was nothing if not forthright, even if it meant exposing himself to criticism. The report was mildly critical of the director, but Tilak had no hesitation in making it available to the entire staff and seeking their views. From his intense commitment to projects to his apparent disregard of scientists' views and aspirations, to his concern about their thinking when informed of their plight (that many of them were being relegated to the background as deadwood), Tilak was a man of contradictions. I attribute this to his philosophy of management marked by no philosophy, of not regarding management as a tool and doing what he considered as best even if it meant contradicting himself in the eyes of management *gurus*. In this sense, but more forcefully and with the added trait of inconsistency, he was his teacher's student, his *sishia*, Venkataraman's gift to the NCL.

Tilak also called on the services of Ravi Mathai of the Indian Institute of Management at Ahmedabad to study the functioning of the NCL and submit a report to him. This report will be briefly discussed in a later chapter.

The NCL of the 1950s and 60s was regarded by the good scientists of those days as a laboratory for the chemist, to be run by the chemist, with intrusion by none other, particularly that intrusive species, the chemical engineer (for the few who knew of his existence) who thrived on confusion, passing for an engineer in the presence of chemists and for a chemist in the presence of engineers. Tilak had a different view, being a product of the Bombay University Department of Chemical Technology, which boasts of one of oldest chemical engineering departments in the country. He was also exposed to the growing chemical industry in Bombay, particularly the dyestuffs industry, and knew what was involved in developing a process. He carried his knowledge to the NCL and made chemical engineering a central activity there. I use the word activity advisedly here, for chemical engineering was being done in two divisions, Chemical Engineering and Organic Intermediates and Dyes (OID). Tilak ignored the Chemical Engineering Division and placed his faith in OID, which was ridiculed by KV's detractors as neither organic, dyestuff, nor engineering, but hailed by many as a top-ranking chemical engineering department. A few years later, in 1967, he consolidated the two divisions into a single division of Chemical Engineering and Process Development and placed it under the charge of L. K. Doraiswamy (LKD). Tilak did what no other chemist had the imagination to conceive in India and no chemical engineer would have dared to do. He lifted chemical engineering from an *also ran* status in the beginning to a central status in the NCL of the 1960s and after. This was one of the most far reaching decisions taken by him. He also promoted LKD in circles that mattered to ensure that the NCL had a chemical engineer as director. Once he did that, he knew that with his credentials, LKD would be the *automatic choice*. Although in later years he was occasionally, and on some major issues, critical of LKD, chemical engineering owes much to this remarkably broad-minded chemist for its present pre-eminent position in the country. Another major event that happened about a decade previously was the direct appointment of the 27 years old M. M. Sharma as one of the youngest professors of chemical engineering in the history of chemical engineering across the world. Sharma, whose association with the NCL began with his personal association with me in the mid-1960s, when writing our book, *Heterogeneous Reactions: Analysis,* *Examples and Reactor Design*, went on to become the first Indian chemical engineer to be elected to the Royal Society of London. Tilak consulted him on many issues and his association with the NCL continues to this day.

Tilak continued with the collegiate system of management and the SCR remained a major forum of discussion during his entire regime. He did not re-organize the Survey and Information Division but gave it a new name: the Division of Technical Services (DTS), with almost the same functions as before. Following the departure of S. K. Subramaniam, who accepted a position as deputy secretary in the Department of Science and Technology in New Delhi, A. M. Lele was appointed head of that division. Lele had no particular training or background in management or research, but he proved to be an effective spokesman for Tilak. He also became conversant with the language and jargons of management, and functioned as well as he could under the limitations of Tilak's domineering presence. He became an ardent supporter of the rural development program. As that program grew, he became increasingly divorced from the NCL's main activities. So did Tilak, but to a lesser extent.

An incident occurred during Tilak's regime in which he was not involved but deserves mention, if only because I fear to speculate on what might have happened if he were present! It is included in Chapter 16 as *How a minister announced he was "boss" and Gupta was silenced.*

Tilak organized many national and international symposia. Many famous scientists and other personalities also visited the laboratory during his tenure. It was during his time that the Silver Jubilee of the laboratory was celebrated. This occasion was marked by the fact that it was inaugurated by Prime Minister Indira Gandhi. Tilak was particularly proud of this occasion because Mrs. Gandhi had tea with him and his wife at his flat. Some senior scientists (including me) were invited. Every drink and snack was tasted by the police before being taken to the reception hall. Some of the police officers standing at the steps were enjoying themselves with unreasonable quantities of the "test samples" specially brought for the occasion.

Being what he was, Tilak did not have the best of relationships with the Director-General, Y. Nayudama, himself an upright and strong individual. Both had strong connections in Delhi, Nayudama with the Prime Minister herself. The fact that Tilak was made chairman of the NCST without consultation with the CSIR did not sit well with the DG. Both were broad-minded men, but this thing rankled them. Once when Nayudama visited the NCL and held a meeting of senior scientists, he asked Tilak to talk about the NCST. Tilak had just then prepared an overview of a Science and Technology Plan for the Fifth 5-year plan. In an uncharacteristic aside, Nayudama aimed a jab at Tilak:

Tell me about the overview — and don't forget the underview!

With a great deal of effort, Tilak controlled himself and the incident passed.

After his intense involvement with three major turn-key projects, all of which he pursued with single-minded devotion, Tilak's interest in commercial projects seemed to wane. He had found a new interest: rural development, which he now pursued with the same devotion, almost like a new found joy. Tilak gave of his best to any task he undertook. This is another way of saying that the other tasks of the laboratory received scant attention from him. He kept himself informed and aware, and being very bright, would make some useful suggestions. Absent were those trips to Delhi to meet top government officials and to Bombay to meet the captains of industry. Instead, his trips to villages increased, resulting in a massive plan for bringing the benefits of science and technology to the Chandrapur district in Maharashtra, with particular attention to the village of Chandrapur (see chapter 10). This was a scaled down version of what Nayudama had done for the district of Karimnagar, with the involvement of all the relevant laboratories of the CSIR. Rural development, a priority in India, was particularly popular among scientists in the 60s and 70s, and most laboratories felt that they should be part of it.

The rural development program went on full throttle at the NCL after Tilak's retirement, when he established an independent unit at the NCL under the aegis of the Department of Science and Technology. I was the Director then and extended full support to the program, with Tilak retaining the office he had moved to as Director. Tissue culture and water evaporation control were not his favorite projects in the early years of his stewardship of the NCL, but in view of their importance in rural development, quite understandably, they became very important to him in later years, particularly after his retirement. This led to some unfortunate situations but ended well when his cherished goal of having this activity declared as a Center under the name Center for the Application of Science and Technology for Rural Development (CASTFORD) was realized, and the Center was moved to a new building in Pune.

DOMAIN 3: PURSUIT OF EXCELLENCE UNDER DORAISWAMY

The immeasurable of today may be the measurable of tomorrow…It is dangerous to base a philosophy on the assumption that what I know not can never be knowledge.

Sir J. J. Thomson, quoted in Lord Rayleigh,
The Life of Sir J. J. Thomson, 1942

LKD's appointment as Director needs to be mentioned in some detail as there were two firsts about this. He was the first scientist from the NCL to be elevated to this position, and the first chemical engineer. Tilak promoted his case, and Venkataraman hoped he would be selected, but his selection was by no means certain by the independent selection committee appointed by A. Ramachandaran, Director-General of the CSIR. Two outstanding scientists from the NCL also presented themselves as candidates. When KV and Tilak were appointed, they were invited and did not have to appear for an interview. Over the years, things had been more formalized, indeed more bureaucratized, in the CSIR. Gone were the days when an eminent scientist was invited to be director. The post was advertised, as for any other scientist, candidates were short-listed and called for interview. The recommendations of the selection committee were approved by the Director-General, then by the Minister for Science and Technology, and finally by the Prime Minister. This procedure was fully followed, and three candidates were called for interview: Sukh Dev, perhaps the most outstanding chemist of India at that time,

A. P. B. Sinha, an outstanding physical chemist, and LKD, a chemical engineer. The selection committee met on the appointed day and made its recommendation. It is understood that the committee recommended LKD's name and also suggested that every effort should be made to retain Sukh Dev by offering him a position equivalent to that of the director but without that designation and authority. Sukh Dev was a consultant to an emerging company, Maltichem, and had established a modern laboratory for the firm in Baroda. He was acting as its *de facto* Director by paying frequent visits from the NCL. Thus, when he was not offered the directorship of NCL, he turned down the next best offer from the CSIR.

About LKD's appointment, there is an interesting story to recount, which tells us much about the grapewine in India. When LKD was in Delhi for the interview he stayed in the guest house at the National Physical Laboratory. He returned to the guest house after the interview, ordered a meal in the room, and retired, soon after finishing it. Within an hour there was a knock at the door. On opening it, LKD saw the smiling figure of one of the CSIR drivers (he knew all of them). The smile deepened and a twinkle developed in his eyes. Some drivers were in the habit of paying such visits to the directors whom they liked, to collect their usual quota of tips, even when they were not on duty on a particular trip. LKD thought that was one of those occasions and hurried to take out some money. Then he heard him: *Saab, it's all over*!

Fully in the dark, LKD asked: *What's over*?

His tantalizing reply was:

Yes, saab, it's all over, I got it first hand!

A little annoyed, LKD asked him to come clean. He did: *You are the new director of the NCL, Saab. I heard it from their own mouths. I was taking some of them home and they were saying they got the best man for the job — you, Saab.*

He lingered. LKD made the tip heftier. He left, happy that he had unburdened himself of the great news, happy with the huge tip in his pocket. Such did the grapevine work in New Delhi, where it was not just the ministers who were politicians. Drivers were too!

Thus did LKD get the first news of his appointment as Director. Soon after Tilak told him and it took a few more weeks for the formal letter to arrive. Then began the 11 year tenure of LKD as Director. The appointment of the director this time was different. As far as the staff was concerned, for the first time in the NCL's history, one of their own had been elevated. As a result, even some chemists who did not particularly care for LKD showed a certain measure of enthusiasm. On a certain Saturday when LKD arrived in the ante room to the director's office, Pratibha Khare, who was secretary to the Director, next in rank to the Personal Assistant (B. R. Narayanan) in Tilak's office, and continued to be in LKD's, had drawn a beautiful *rangoli* at the door to the office. They had informed LKD's wife and got her there on some pretext without his knowledge. When LKD arrived, an *aarathi* was performed at the door, a coconut was broken, and LKD and his wife were ushered into the office. This was a moving welcome to the new chief by his office staff to be, seldom seen in any office. Also, there seems to have been high expectation all round. With such a welcome LKD was afraid that one could only do worse!

As KV and Tilak had done before him, LKD addressed the entire staff of the laboratory soon after taking office. After acknowledging the great accomplishments of his predecessors, he went on to say that as time moves on, some changes become necessary. He then proceeded to outline the major changes he had in mind. Most of all, he repeatedly emphasized the need for all-round excellence. No longer would old technologies be repackaged, any NCL technology must stand on its own legs and be competitive with the best anywhere in the world, basic research of a high order must be pursued, every major area of the NCL would have a science and an engineering component, and talent will be attracted and encouraged in every way possible. Certainly these objects were also on the lists of his predecessors, but they would have the highest priority in his. Encouragement would only be given for performance based on these tenets. He gave no indication of the style of his management, but that will become evident as we delve further into his regime. Tilak had succeeded in much of what he had set out to do. Had LKD? This also will be clear from the following retrospective glance.

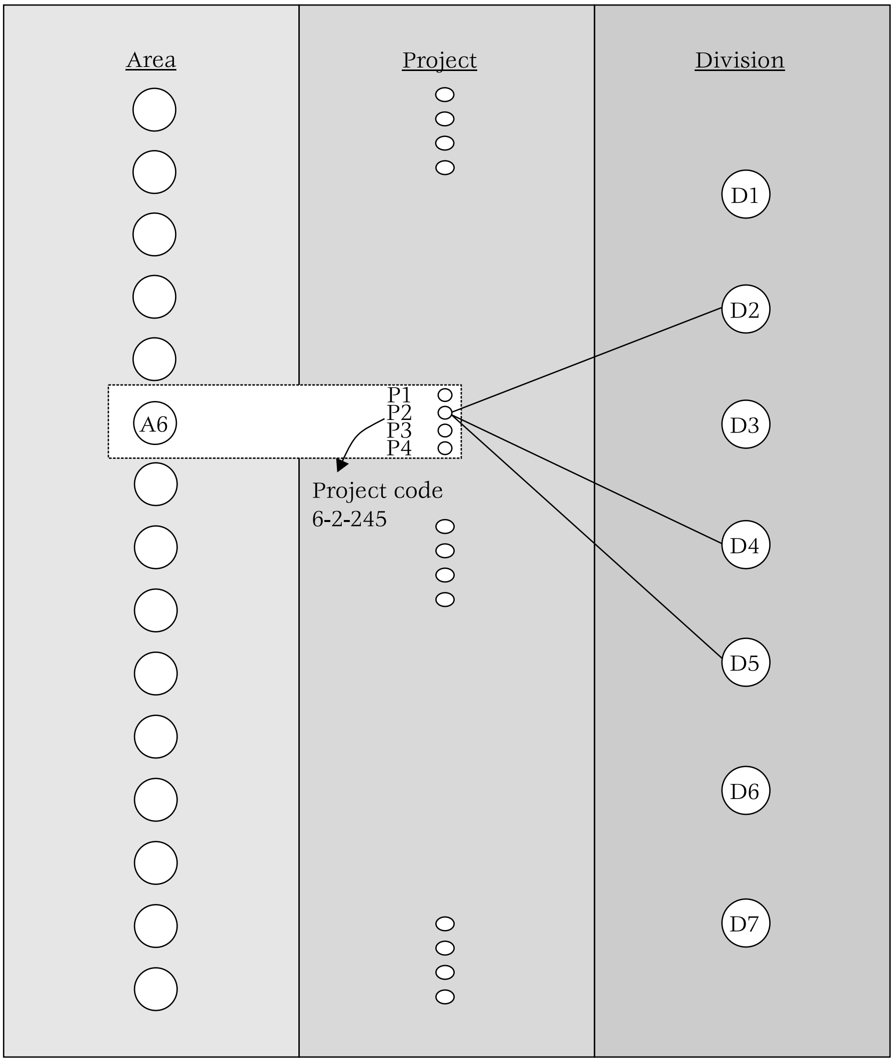
LKD's first management action was to identify himself with the entire staff in private life but to stay aloof in official life. His wife's refusal to move into the director's flat on the third floor of the NCL (with an area of about 7000 square feet) fitted well with his idea of a more accessible private life. His wife did not like the idea of visitors to her house having to pass through two security levels, one at the main gate and the other at the entrance to the laboratory. Thus LKD continued to stay on in his bungalow and later upgraded it to the level permitted by the CSIR (still much smaller than the NCL flat). Successive directors after him further improved it — quite considerably (including the addition of a security guard at the gate!) This was a good move for it made it much easier for the staff to approach the director, although people being what they are in India, it often led to an overdose of visitors and complaints! Some examples given at the end of this section will attest to this statement.

The need for the first major official decision was soon upon LKD. Lele did not wish to serve any more, partly because Tilak had retired and he did not wish to serve under any other director. Whatever the reasons (ill health, too, must have been one), he retired and his position as the head of DTS had to be quickly filled. LKD picked S. H. Iqbal, who readily agreed. Iqbal served with distinction for almost 15 years, although in his later years, under Mashelkar, the division was re-organized and his powers and responsibilities were distributed. He was unhappy with this situation and moved to the National Center for Cell Science (NCCS), located adjacent to the NCL, when he retired and was appointed emeritus scientist.

We now come to the scientific management of the NCL under LKD. This was dominated by the following features:

- Work was organized in terms of divisions, areas, and projects. Scientists would be drawn from different divisions for a project and would return to their parent divisions after completion of the project. Figure 6.4 shows how a project was identified.
- Scientists associated with projects were free to carry out basic research as spin-offs from the projects, using research fellows or junior staff.
- Scientists who were not assigned to any projects were encouraged to join support groups to help the specialists in those groups.

Figure 6.4: Project identification in L. K. Doraiswamy's regime, based on the area to which it belonged and the divisions involved



- Decentralization was encouraged in all aspects of management, including publication of papers, undertaking trips within India, issue of chemicals.
- International collaboration, and funding from the DST, UNDP and other agencies was actively sought to supplement the limited budget from the CSIR.

All of these worked well, up to a point. For when the management changed, the new director had his own ways. However, certain decentralized features and the concept of units took root and continued. Most of all, the emphasis on excellence remained as the guiding principle of the NCL.

LKD strongly believed in the disciplinary structure of the NCL, as manifested by the divisions. Correctly or incorrectly, he was wedded to the divisions that were in existence since the beginning. Any new major activity was pursued as an area, with scientists drawn from one or more divisions. Catalysis and plant tissue culture are outstanding examples of this concept. Both flourished in his regime and attained national/international eminence, and yet, they were not declared as divisions. LKD firmly believed that catalysis was basically an activity of the Physical Chemistry Division and should grow as part of that division. Similarly, plant tissue culture was part of the newly named Division of Biological Sciences and there was no need for it to acquire a separate status. This philosophy was in keeping with the practice in many other countries, including USA, where a new department was never created to accommodate a growing area. Instead, centers were established as part of the department but with an autonomous status. As we shall see later, Mashelkar, Ratnasamy, and Sivaram moved away from this concept and created new divisions. But the number of divisions was not steady and changed with the perceptions of the director (see Chapter 13).

The NCL's transformation into a state-of-the-art laboratory began in LKD's time, with the conversion of the radio tracer laboratory into a Sophisticated Instruments Laboratory (SIL). The building was completely renovated and new equipment were acquired. It was placed under the charge of a senior scientist with considerable autonomy but continued as part of the Physical Chemistry Division under the overall charge of A. P. B. Sinha. R. A. Rahman, the head of planning in the CSIR, recognized the NCL as the front runner among all the laboratories of the agency. He also had a special relationship with LKD and had complete confidence in his ability to lead the NCL into a new era of sophistication and world-class status. The result was that he agreed to sanction over Rs. 1 crore (a huge amount in those days when the entire budget of the NCL was of that order). Out of the new equipment that was procured under this grant, special mention may be made of the electron spectroscopic chemical analysis (ESCA) unit, one of the first such units procured in the country.

Several events that shaped the future of the NCL happened during LKD's regime: the establishment of the polymer science and engineering unit under Mashelkar, appointment of Ratnasamy and creation of the catalysis group under him, a step rise in the strength of the NMR group by the appointment of Ganapathi, appointment of Barnabas (an evolutionary biologist) as the head of the Biochemistry Division against the advice of many who felt that evolutionary biology had no place in the NCL's program, and the appointment of Sivaram to strengthen and give a new direction to polymer chemistry. Several other exciting developments too occurred in the regimes of Mashelkar, Ratnasamy, and Sivaram, and they will be chronicled later in this chapter.

Of each of the appointments mentioned above, there is a story to tell. These stories, and the creation of new sections, comprise the essence of LKD's style of recruitment and management. As mentioned previously in this chapter, Mashelkar was officially appointed during Tilak's time. As Mashelkar was a chemical engineer, Tilak left the matter entirely in the hands of LKD. Mashelkar was a student of M. M. Sharma and was highly recommended by him. LKD carried on a long correspondence with the highly demanding

Mashelkar, when such minute details as the journals in PSE to be procured by the NCL were discussed. Meanwhile, Nayudama, Director-General of the CSIR, met Mashelkar in London and was greatly impressed by him. His telegraphic comment "grab him" told its own story. An offer was quickly made by the NCL and he joined the laboratory (November 1976). In the years immediately following his appointment, Mashelkar established himself as an effective consultant and a good leader. Then, in LKD's time, adequate funds were obtained and the first PSE group in India was established at the NCL, and a new extension was added to the chemical engineering building. It has since grown into an outstanding group with an international reputation and Mashelkar went on to become the Director of the NCL and then the longest serving Director-General of the CSIR.

M. K. Gharpure, a senior scientist of the NCL, had moved on to the ACC in Bombay to join the emerging catalysis group of that company. One morning in 1980, as LKD was traveling from Pune to Bombay in the Deccan Queen, he met Gharpure in the dining compartment. During an informal conversation on catalysis, Gharpure suggested that if the NCL was looking for a good man in catalysis, they could not find anybody better than Paul Ratnasamy, who was then Assistant Director at the Indian Institute of Petroleum in Dehra Dun. LKD, who was looking for an outstanding catalyst chemist to lead the NCL's weak program on catalysis and raise it to a national level, was enthused with the idea and took the earliest opportunity to meet Ratnasamy. This happened at the next meeting of the Catalysis Society of India at IIT, Bombay. LKD was so impressed with Ratnasamy, and Ratnasamy with LKD's enthusiasm that it only remained for details to be worked out before Ratnasamy moved from Dehra Dun to Pune. This turned out to be more complicated than anticipated, with the IIP and the CSIR creating many obstacles. But all the hurdles were overcome and Ratnasamy joined the NCL in 1979. This was the first, and the most important, step in the NCL's rise to prominence in the field of catalysis. In less than 15 years, Paul was to become the 7th Director of the NCL. Paul soon wanted two other scientists from the IIP, A. V. Ramaswamy and S. Sivashankar to be also transferred to the NCL. This was arranged and the contours of a strong catalysis group soon began to appear in the NCL.

At this point, two major happenings speeded up the rise of this group. One was LKD's decision to move the entire Biochemistry Division from the main building to the new building built essentially for tissue culture and settle the entire catalysis group in the vacated wing of the main laboratory. This raised some angry protests from the biochemists, who complained that in moving them out of the main building the director had shown a lack of appreciation of their subject. Soon, when they realized that they had a new building to themselves, the criticism waned and there were even signs of muted appreciation. For Paul's part, he was happy that the promise of a separate group with a contiguous laboratory had been kept.

One more item remained for LKD's promise to be fully kept: equipment. It is here that the NCL as a laboratory rose to the occasion. As per the practice at the time, the budget of the laboratory had been distributed between its divisions (after which the director never interfered) and there was no way by which additional funding could be found for Paul. LKD wrote a note to all the divisional heads in which he talked about Paul, the importance of catalysis, and what Paul and his group were likely to do to help them all lift the image of the laboratory. But to enable this, immediate additional funding was needed, to the tune of about Rs. 12 lakhs, which could only be provided by surrenders from other divisions. He would greatly appreciate it if each division would consider surrendering about Rs. 1.5 lakhs to the director, which he would collectively pass on to Paul. It was a mammoth moment for LKD when within a week the entire amount was collected and a happy Paul was pushing the final buttons on the purchase of some important equipment.

Another incident in building the NCL's talent pool occurred in the mid-1980s when LKD was looking for a renowned biochemist to head the Biochemistry Division. He had heard of John Barnabas, a professor at the little known missionary college at Ahmednagar, not far from Pune. He was a brilliant evolutionary biologist, who had worked at Yale for a few years and had publications in *Nature*. LKD invited him for a discussion at the NCL and was so impressed with him that he made up his mind then and there to bring him to the NCL as head of the Biochemistry Division. Although he was already holding the prestigious Jawaharlal Nehru Fellowship at the Ahmednagar College, he was keen on moving to the NCL if the fellowship could be moved there and if he was offered some additional facilities. LKD immediately agreed to these and offered one more attraction. He would act as *de facto* head of the Biochemistry Division but would soon be appointed to that position. John was quite thrilled and agreed straightaway to come to the NCL. But LKD faced opposition from the most unexpected quarters: senior scientists of the NCL as well as the biochemical community of the country. Why was the director of the NCL going in for an evolutionary biologist, they wondered, when the NCL had nothing to do with evolutionary biology? But LKD pressed forward, based on the second model of growth mentioned earlier: find an outstanding scientist in the general, if not any specific, area of interest to the laboratory and give him all the encouragement to grow. He went ahead and brought John to the NCL. And what John did for the Biochemistry Division is there for all to see.

Another appointment of note was that of S. Ganapathy, a renowned NMR spectroscopist. LKD was in USA for a conference. He suggested to Ganapathy that they might have lunch together in Newark, Delaware (where his son was studying at the university). At the meeting, Ganapathy's expertise came through in no uncertain terms and LKD made up his mind to make an offer. Ganapathy had a couple of confirmed offers in his pocket and hence was hesitant to accept the NCL's offer, which could only be formalized after due process. To overcome this problem, LKD made a written intent-to-appoint offer to Ganapathy, which the latter accepted. When, on his return to Pune, LKD informed the AO of the offer, an astonished chief of administration informed the Director that he had no authority to make such an offer. An impatient LKD told the AO: *As if I do not know that! Your job is to make sure that he gets the job.* In any case, the due process was gone through very quickly, and Ganapathy was firmly installed in the NCL.

The last important appointment during LKD's time was that of S. Sivaram, the present Director. LKD had known Sivaram since his appointment as a scientist in the IPCL's R & D. He had come to admire him during his many visits to the IPCL as a consultant, when he was requested by the CMD to look after the R & D department. He also had occasion to interact with Sivaram during many of the latter's visits to the NCL to monitor the projects sponsored by the IPCL. Within a few years after LKD's becoming Director and soon after the retirement of N. D. Ghatge as head of the Polymer Chemistry Division, LKD desired to bring Sivaram to the NCL to head that division. The situation was quite delicate as LKD was also on the Board of Directors of the IPCL. After several meetings with Sivaram, he had a final meeting with him at the IPCL's guest house, where Mrs. Sivaram was also present. After a detailed discussion, LKD came away with the certainty that Sivaram would come to the NCL if Subruto Ganguly, the IPCL chairman, would agree to it. Sivaram continuing at the IPCL with an unhappy Ganguly would be the last thing anybody wanted. But things were worked out smoothly enough and Sivaram joined the NCL in 1988. This was yet another great day for the laboratory for in just about 15 years, he was to become the 8th Director of the NCL.

It is noteworthy that three outstanding scientists of the NCL, Mashelkar, Ratnasamy and Sivaram, all became Directors, each in about 15 years after joining the laboratory. Three others, A. V. Rama Rao, J. S. Yadav, and Sukumar Devotta, all appointed by LKD, became directors of other CSIR laboratories. LKD met Yadav at Wisconsin and interacted with Devotta at Salford and offered them appointments at the NCL. The appointment of Rama Rao deserves special mention. A replacement for Sukh Dev had to be found. There was no one in sight of that caliber. As the laboratory was pondering over this matter, Rama Rao met LKD at what was supposed to be a casual encounter in front of the NCL canteen. He was not well treated at the NCL. After being promoted to the level of scientist E (equivalent to assistant-director) on a project under KV and having done brilliantly in that capacity, he was demoted by Tilak to scientist C at the termination of the project, because that was the substantive position he held. This was strictly according to rules. But many were surprised that Tilak, no lover of rules, should apply them, of all cases, to this particular one. Rama Rao mentioned this to LKD and put the question bluntly, *Why not me for the position to replace Sukh Dev?* This was a daring proposition. Here was a scientist, just demoted from Scientist E to C, aspiring to replace Sukh Dev at level F (equivalent to deputy director)! This, notwithstanding the fact that there were many scientists in the same division with a more senior rank! The abruptness and audacity of the proposal stunned the director. He told Rama Rao that he would consider it and beat a hasty retreat! The one thought that kept constantly coming to his mind was that there was nobody in the NCL or outside in the country to match Sukh Dev, so why not take a risk on a young scientist with tremendous potential, one who had shown an equal aptitude for basic and applied research. Correctly or not, LKD's mind was made up and he pushed Rama Rao's appointment through a surprised and reluctant selection committee, which fully expected him to support their strong opposition to him. The general refrain was "Organic chemistry is already at a low level at the NCL. If you wish to totally destroy it, go ahead, we will not stop you." What Rama Rao did to organic chemistry in the NCL is today well known. Sukh Dev, who was solidly opposed to the appointment, remarked on several later occasions that the best thing that happened to organic chemistry in the NCL was Rama Rao's appointment and he was glad that LKD had stood his ground.

For the first time in its history, the NCL established collaborations with two well-known overseas universities, Salford University in England and University of Erlangen in Germany. Efforts to establish collaboration with the University of Edinburgh did not succeed. The Salford collaboration was in the field of energy saving through heat pumps and was made possible through hefty funding of about $5,00,000 by the British Council. LKD was appointed visiting professor at Salford University and visited Salford every year for eight years. S. Devotta was a research assistant with Prof. F. A. Holland at that university at that time and LKD was able to bring him to the NCL after a few years. A few years later, Mashelkar was also appointed visiting professor. The NCL also established a collaborative program on homogeneous catalysis with the University of Erlangen in Germany. This involved Prof. Hans Hoffman, one of the most distinguished chemical engineers of Europe, and R. V. Chaudhari from the NCL.

Apart from winning funding from the Britain's Overseas Development Agency (ODA), contacts were established with several other overseas organizations: Imperial Chemical Industries (ICI), the Catalyst Corporation of America, Akzo Chem, Scientific Design, and Englehard. Negotiations to commercialize processes based on the Encilite series of catalysts with these firms were not successful, but they exposed the NCL to the issues involved in commercializing a catalyst and were helpful in its future negotiations. It was during LKD's regime that a massive funding of Rs. 9 crores from the World Bank, Rs. 75 lakhs from the United Nations Development Program (UNDP), Rs. 2 crores from the National Bank for Agricultural Research and Development (NABARD), and Rs. 2.5 crores from the Department of Science and Technology were obtained. These amounts were used to purchase sophisticated equipment and to construct the new building for biochemical sciences and tissue culture. Mashelkar, Ratnasamy and Sivaram built on this beginning by raising huge sums of money from multinational companies as well as other major companies in India.

LKD's management style was clearly reflected in the manner in which he and the Administrative Officer, M. M. Sharma, handled a delicate issue. The CSIR had a union of scientific works called The Scientific Workers' Association (SWA), a union formed and encouraged by a former Director-General, Hussain Zaheer. While all laboratories had branches of the SWA, the NCL did not — a clear measure of the excellent relationship between scientists and administrators in the laboratory. Some scientists made up their minds to start a branch at the NCL, and for the first time in the laboratory's history, held a gate meeting. It was timed to coincide with the director's homeward walk through the gate, thus providing an opportunity for some booing! It was again a measure of the scientists' conduct that, in spite of prodding by the meeting leaders, they did not shout and behaved very respectfully when the director walked through the gate as the meeting was in progress, ignoring administration's advice to go home early. The next morning, LKD sent for the meeting leaders for a frank discussion. He told them that they should give him a list of their genuine complaints. He would settle whatever fell within his own jurisdiction. What was outside his jurisdiction, he would study carefully and send his recommendations to the CSIR. This had a dramatic effect and all union activities ceased.

G. S. Sidhu was a particularly helpful and decent Director-General. He always espoused the cause of Indian technology and the Indian scientist/technologist. The NCL had undertaken the challenging project of developing a process for silicon. This project was not going well and had eventually to be given up. In the meantime, Sinha (leader of the silicon project) and LKD had not given up on it. In one of his visits to the NCL during this period, Sidhu had a detailed discussion with LKD in his office, when LKD informed him that no substantial progress was possible without a further input of Rs. 1crore. Sidhu looked at LKD and asked for a sheet of paper. On it he wrote a crisp note to the Controller of Finance at the CSIR instructing him to make the money immediately available to LKD for use on the silicon project. Not the least surprised, LKD and Sinha were of course thrilled. When after a week LKD presented this note to the Controller of Finance in Delhi, that officer's smile was seraphic. *Doctor*, he said, *do you really expect me to act on this note? If you do, you are even more naïve than the person who wrote it. This kind of expenditure requires approvals at various levels and is outside the DG's authority! I am sure you know that and are taking a chance on some mad action on my part!*

There were several visits by the Minister for Science and Technology during LKD's regime. Both Shivraj Patil and K. R. Narayanan (who later became President of India) visited LKD's home and had dinner with him and his wife; a few senior scientists were also invited. These were informal occasions when the minister opened up a little.[3]

DOMAIN 4: THE NCL IN THE GLOBALIZATION ERA UNDER MASHELKAR, RATNASAMY, AND SIVARAM

It is often argued that globalization is a new folly. Is that a plausible diagnosis? I would argue that globalization, in its basic form, is neither particularly new, nor, in general, a folly…The direction of interregional movements has varied over history, and these directional variations are important to recognize, since the global movement of ideas is sometimes seen just as ideological imperialism of the West — as a one-sided movement that simply reflects an asymmetry of power that needs to be resisted.

Amartya Sen, Nobel Laureate, *The Argumentative Indian*

A new era began in India's economic policy in the late 1980s. The days of controls and licenses would be a thing of the past. The open market economy had come, as it had in most parts of the world, and with it, a completely different industrial philosophy. This influenced all state owned enterprises including public sector companies and laboratories, like those of the CSIR. With the removal of constraints, the NCL's *raison d'etre* changed. It had to adapt itself to a completely new philosophy. How Mashelkar did this and the subsequent directors followed form the story of this section. But as this was a paradigm shift in policy and the working principles of the laboratory, a general account of what this shift meant to the chemical industry and R & D at large would be a useful introduction to a description of how the laboratory coped with it. The NCL's solution to this problem was by no means easy. Quite unknowingly, Mashelkar and company seem to have taken note of H. L. Mencken's characteristically sarcastic comment that *There is always an easy solution to every human problem — neat, plausible, and wrong*, and studied the problem in depth to evolve a difficult solution that was right.

The Effects of Globalization

The major features of the economic reform announced by government were summarized in Chapter 4. These and many more formulations are contained in several acts and statements of government such as: The Industrial Policy Resolution 1991 (IPR 1991), Technology Policy Statement 1993 (TPS 1993), Trade Related Investment Measures (TRIMs), GATT agreement, and Trade Related Intellectual Property Rights (TRIPs). The FERA (Foreign Exchange Regulations Act) measures were also considerably relaxed. Our concern here will be mainly with the effects of these on research and development in the field of chemicals and how they transformed the functioning of the NCL.

The various reforms notwithstanding, the performance of the chemical industry showed a strong downward trend. From a robust annual increase of 12% it plummeted to as low as 3% in the early years of this century. This is probably because the much needed secondary reforms were not fully formulated. The industry's actions that included research and development, knowledge engineering, and mathematical modeling were no match to the negative effects of the government's inability to come forward with a host of secondary reforms without which the primary reforms would be meaningless. Thus the basic inputs to the chemical industry such as power, energy, finance, labor, and logistics were all continued to be priced at levels that made them highly uncompetitive. As a result, in spite of the conditions being ripe for foreign investments, the industry was not able to exploit this situation and foreign investment remained disappointingly low compared to countries like, say, China, Singapore, and Thailand.

But it would be unfair to lay the entire blame at the government's doorstep. The industry must take the blame for outmoded technologies, inefficient operation, and low R & D engagement. The global outlook that was lacking demanded shedding of both internal and external insularity. Consequently, as the new policies unfolded and the industry was exposed to global markets with no protection, it found itself unequal to the challenge in many ways, most particularly in two: the economics of scale, and shift in emphasis from traditional to non-traditional competencies.

- The scales of production in the country were far too small to challenge imports. Research and development to enable rational scale-up became a far greater necessity than in the past characterized by smaller scales of production. It was one thing to set up plants of a few thousand tons capacity but quite a different matter when the plant capacities had to be raised by an order of magnitude or more. This required collaboration between research laboratories or research wings of industrial establishments with large overseas companies (usually multinationals).
- Where traditional chemicals, including petrochemicals, were concerned, it was a matter of debate whether any attempts were warranted to continue the practice of establishing entire plants based on indigenous technology. On the other hand, entirely new fields were emerging and it appeared appropriate to enter these fields and make contributions that would match any from other parts of the world. Some would say that even in these areas we were at least a decade behind but this would not be an insurmountable gap. In other words, there was a need for creating *core competencies*

> (Harmel and Prahalad, 1994) and hence "focused competition" (Roy, 2002). Safety, health and environmental (SHE) regulations would make the search for newer technologies (using the core competencies) even more difficult.

The core competencies needed to be supplemented by strengthening traditional competencies by infusing modern methods into them, such as in the field of process design. Nanotechnology emerged as one of the most important areas of science, but the methods of scale-up for such technologies still remained to be addressed rationally.

In its desire to encourage indigenous R & D effort, government proposed to raise the investment in this from 0.9% to 2.0%. The same acts and provisions that engendered this rise also rendered it much easier to buy proven technology from abroad. Quite naturally, the industry opted for the second alternative. Even here there was no foreign capital to any significant extent. Pressures of global competition were hardly adequate to induce the industry to invest more in R & D. In fact, a study by the Center for Technology Studies clearly concluded that the degree of competition had no pronounced effect on industrial R & D in India (Financial Express, 1993).

There are exceptions to the conclusions presented above: the drugs and pharmaceutical and specialty chemicals industries. Ranbaxy's, Dr. Reddy's Laboratories, and Lupin Laboratories are excellent examples of what the drugs and pharmaceuticals industry accomplished in the globalization era. Let us now see how the NCL, historically attuned to planned development, dealt with the changed scenario in the chemical industry as a whole.

Mashelkar's Response: International Collaborations/Consultancies the Answer

The NCL had gone through two paradigm shifts in the past, one around 1965 and the other around 1978, but they were both within the same economic philosophy of the government. Now there was a change in economic philosophy, from license and control to free market. This demanded a change in the way the NCL operated. The laboratory rose to the challenge under the leadership of Mashelkar. In tune with the reigning business philosophy of the country, he brought in a similar philosophy to the laboratory by creating a Business Development Group, making NCL increasingly business-oriented. Good research papers continued to flow but there was a greater patent consciousness. The way the NCL operated before Mashelkar, several potentially money-making ideas might have been published without a prior patent protection exercise. Publication in an international journal was far more important than taking out a patent, for the former earned recognition among peers. An outstanding example of this is a research study by N. R. Ayyangar, which was published with undue haste, without examining its commercial possibilities. I cannot help using some technical jargon here. A novel synthesis of unsymmerical ketoprofen (of the well known pain-relieving iboprofen family) by diazo-coupling was developed. It involved reaction between nitroaromatic compounds with acetanilide and analogues in presence of phase transfer catalysts. A similar reaction was done in dimethyl sulfoxide when, to Ayyangar's great surprise, 4-nitrosodiphenylamine resulted as a product. Further reduction resulted in 4-aminodiphenylamine, a very valuable antioxidant for polymers and rubber. Instead of patenting this important discovery (which was another case of serendipity in the NCL), Ayyangar decided to publish it, thus missing out on a chance for making money for the laboratory and for himself and his group.

I am not aware of a single industrial laboratory that would permit such a publication. However, the CSIR labs are under no such obligation. If patents were not taken, it was no more than a compelling desire on the part of the scientists to publish, in keeping with the adage "publish or perish," the driving force in the academia to satisfy one of the major criteria for performance evaluation — a criterion that also crept into the CSIR from its early days. Mashelkar brought about the transformation adroitly by encouraging both publication and patents, by supplementing the term "publish or perish" with "patent, publish or perish."[4] That was the first major change he introduced in the NCL to enable global competition in the emerging free market era in the country. As a result, thanks to the innovativeness of its scientists, the proportion of foreign to Indian patents increased substantially over the years, particularly in the time of his successors Ratnasamy and Sivaram (see next section). At the CSIR level, an earlier Director-General, S. Varadarajan, had also attempted to inculcate patent consciousness among the CSIR scientists, and talked about it enthusiastically at the NCL on one occasion, but he was not successful.

Mashelkar made excellent use of the environment in which he inherited the stewardship of the NCL. With his outgoing personality and assiduously cultivated powers of articulation, he was the right man at the right time for the job. Any environment is often best exploited when it is new. Mashelkar seized the opportunity presented to him and decided to forge international collaborations with single-minded purpose. He made that the most important feature of the NCL and thus was able to greatly strengthen a culture started at an earlier time in an environment clearly inimical to any foreign involvement. This started a chain reaction and soon almost a dozen collaborations were forged. As will be seen later, his successors then built on the strengths passed on by him, even as he had built on the strengths he inherited, and together they made foreign collaboration the central piece of the NCL's program in the free market era.

In order to promote its many competencies that could be used by industry, the NCL came as close to publicly advertising its strengths as made no difference. I say this in a roundabout way because the NCL had never openly advertised its ware before. It was made clear that the laboratory could offer expert consultancies to industries in several areas. In spite of entering the consultancy field later than most existing consultancy firms, it created a niche for itself. It was soon realized that the NCL's offer was backed by strengths in diverse disciplines, all under one roof:

- Process Simulation, Optimization and Energy Conservation
- Process Improvements and Modernization Studies
- Process Design and Engineering
- Research and Technology Management
- Environmental Studies

- Product Application and Market Development
- Techno-Commercial study of Markets
- Technology Search, Evaluation, and Selection

The following were some of the more visible relationships established during Mashelkar's regime:

- GE Corporate Research & Development
- Swiss Agency for Development & Cooperation
- German Development Cooperation
- Unilever Research Port Sunlight Laboratory
- Thai Chemicals Company
- National Research Council of Canada
- Du Pont Textiles and Interiors (UK) Ltd.
- Schenectady Specialties Asia Ltd.
- Invista Textiles (UK)
- Several Indian Companies, including Reliance Industries

The Jiangsu Petroleum and Chemical Industry Department (JPCID) of China had invited proposals from many leading organizations of the world to provide consultancy services to improve two of their research establishments, the Suzhou Research Institute of Chemical Industry (SRICI) and the Nantong New Chemical Materials Technology Development Center (NNCMC). The NCL sent in its proposal along with many other reputed organizations such as Arthur D. Little Inc. The JPCID selected the NCL, a first in the history of India when a Chinese government selected an Indian organization to improve their research facilities. The NCL collected data in a desk-study as well as during field-work and discussions with officials of the Jiangsu provincial government and senior management of both the institutes. After a detailed analysis of the information, it made a number of recommendations to improve the R & D facilities, support systems and management at the SRICI and NNCMC as well as for creating an enabling environment for industrial R & D in the Jiangsu province.

Mashelkar's style of management was very useful to the laboratory. He was a master of timeliness. Our enthusiastic interest in cricket found its expression in many discussions and agreements. We agreed, for example, that a really good batsman would take all the time in the world to play his shots without shuffling across at the last moment to stop the ball from hitting the stumps. He was such a player at the management level, and proved, if proof were needed, the truth of Wolfgang von Goethe's famous lines:

One always has time enough, if one will apply it well.

Oxenford, 1974

He had a clipped, impressive way of speaking that compelled attention, and had something useful and exciting to say for every occasion. He was personally involved in most committees, and was a member or chairman of choice of many committees of the Delhi bureaucracy. For instance, he was chairman of the committees investigating two of the deadliest accidents that occurred in the 1980s and early 90s: the Bhopal gas leak (BGL) and the explosion at the IPCL's MGCC complex at Nagothane. The BGL occurred during LKD's time and much of the NCL's involvement happened during that period. The NCL's involvement during Mashelkar's time was through him personally and of greater significance. It resulted in a report that was accepted by the government (see Chapter 13).

The NCL's most powerful asset has always been its scientific staff. Mashelkar made some very good new appointments at the middle-level, for instance, in the polymer science and engineering group (Ashish Lele) and in the process design group (V. R. Ranade). He promoted some middle-level scientists recruited by his predecessor to senior levels, which was a very good move, for they all did exceptionally well. He also continued to give them and other senior scientists encouragement in many ways. For instance, when Tony Mascarenhas and Rajani Nadgauda published their spectacular findings on bamboo in *Nature* a few months after he took office, he made sure that the work received the maximum publicity and very soon declared plant tissue culture a separate division headed by Tony Mascarenhas.

Traditionally, most CSIR laboratories celebrate Foundation Day to commemorate the laboratory's founding. For some reason, the NCL did not have a Foundation Day till 1990 when Mashelkar became Director. None of the previous directors, for some inexplicable reason, gave much thought to this issue. Not that they were opposed to it, but it just didn't appear to catch their attention. Mashelkar not only thought of it but also made it a really great occasion for the laboratory. He did this by creating a number of awards to be given on that day in recognition of the various accomplishments of all categories of staff. This immediately sent a message to the laboratory that it was not just the scientists who were important but all other categories of staff as well. This was indeed a fine move and created a sense of healthy competition and all-round involvement within the laboratory.

Mashelkar took personal interest in creating lectureships in the names of two out of seven former directors with appropriate endowments. He created lectureships in the names of McBain and Venkataraman. In 2002, through other endownments, lectureships in the name of Tilak, Ratnasamy and Mashelkar were established by Sivaram. A host of distinguished scientists from all over the world were invited to deliver these lectures (see Chapter 13).

One of the most important contributions made by Mashelkar was to sustain excellence in basic research. He did this imaginatively by dangling a carrot in front of the scientists — those who wanted to claim it must do so by coming forward with brilliant proposals (called 'kite flying') which would be evaluated by experts and all encouragement given to the selected scientists by way of funds, staff, etc. This resulted in some outstanding publications in the most reputed journals of the world. The NCL was confronted with a grim economic environment in the early nineties. To augument the resources and quickly inject capital to modernize its ageing infrastructure, Mashelkar took a bold and unconventional step in borrowing money from the World Bank for this purpose. The principle and interest were to be repaid by the laboratory out of income earned from commercial sources. The NCL successfully completed repayment of loan over a 10-year period, ending 2005, entirely from the surplus in earnings from industrial/ contractual research.

Single-Minded Devotion to R & D and Economic Boom Under Ratnasamy

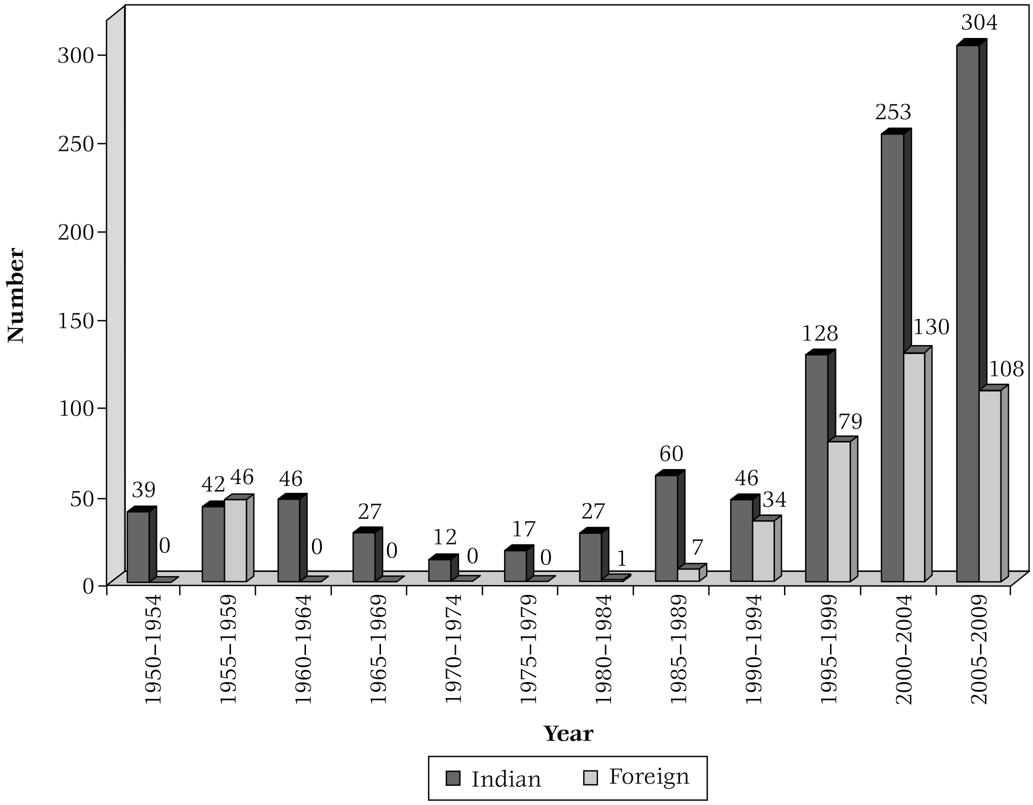
As this book is about the history of the NCL, I described in considerable detail the evolution of the laboratory during the first three domains under McBain, Finch, KV, Tilak, and LKD. Mashelkar's regime was also discussed but in less detail as it represented the transition between history and the present. The regimes of Ratnasamy and Sivaram are too closely identified with the present to admit of any historical perspective. They are therefore considered only briefly. This is not to say that they were any less important. In fact, some extraordinary developments occurred in their times. As Ratnasamy recedes into history, his contribution to the NCL's economic rise seems to attract increasing attention.

Ratnasamy, by common consent, "Mr. Catalyst" of India, is precisely that and more. Catalysis was his first love and continued to be so all through his official career at the NCL, including seven years of his directorship. He retired in 2002 but his first love never lost its position. He started off as Director on an inauspicious note. Within a few months of taking office, he had to undergo quadruple by-pass surgery. A routine visit to his cardiologist revealed that his arteries were 99% blocked. A day was the maximum they could wait for the surgery. All went well and he was back to work in less than two months. He did not curtail his travels but had to yield to his wife's insistence that all travel would be banned unless she went along with him. And so it was for sometime. Soon he was fully back to normal and was Mr. Catalyst again from where he had left off (if he had at all). His directorship was marked by an approach few had practiced. He laid down some ground rules, called the four Ps, reminiscent of US President Gerald Ford's four Cs in dealing with the Congress (communication, conciliation, compromise, and cooperation) (1965), and evaluated the scientists strictly according to those rules:

- *P*apers (publications)
- *P*atents (discoveries)
- *Paisa* (earnings)
- *P*h.D. degrees

A scientist had to perform according to the requirements under each P to earn some increment or a promotion. He completely eschewed any personal bias, refused to consider any deviation. He was deeply respected for this fair and impartial evaluation. On the other hand, one may have some excellent results which, for some reason, are not accepted, say, in *Nature*. He refused to make any allowance for this, his argument — a powerful one — being that even a single exception invites pleas for others. Notwithstanding this apparent aloofness, he was deeply interested in the laboratory and in the residential colony. The NCL's performance peaked during his time, both in respect of publications and patents (foreign and Indian). Figure 6.5 clearly illustrates the situation with respect to patents. The number of patents hit the average (for the 60 year period covered) during 1985–95 covering LKD's and Mashelkar's regimes, and rose substantially after that under Ratnasamy and Sivaram. As an organization, CSIR files the largest number of patents in India. Currently CSIR holds a portfolio of over 1000 patents granted in the US, of which approximately a quarter has been contributed by NCL. NCL was a pioneer in heralding

Figure 6.5: Indian and foreign patents over the years



the culture of patenting in CSIR. In the early nineties, Mashelkar, as Director of NCL, defined an IP policy for NCL which led to its scientists filing and securing a large number of patents, both in India and abroad. The NCL's premiere position within the CSIR in respect of patents is illustrated in Figure 6.5.

The laboratory experienced its greatest economic boom during Ratnasamy's regime, and remained practically at the same level during Sivaram's, as can be seen from Figure 6.6.

If Mashelkar was gregarious and learned to talk with panache and elegance, traveled extensively both within and outside India, was a member of countless government committees, gave lectures at scores of places, managed his time brilliantly, and was practically everywhere at the same time, Ratnasamy did not much leave Pune and preferred to work from the NCL. Apparently he did not make a single visit to the CSIR headquarters in Delhi as Director, a record by any standard. He sent his senior scientists to meetings in Delhi, did not accept too many engagements, and was all in all an NCL man at all times. It would be difficult to find two people more different from each other, impossible to find two successive heads of an institution with such diametrically opposite approaches. And yet, both were equally successful. If Mashelkar popularized the NCL among the general

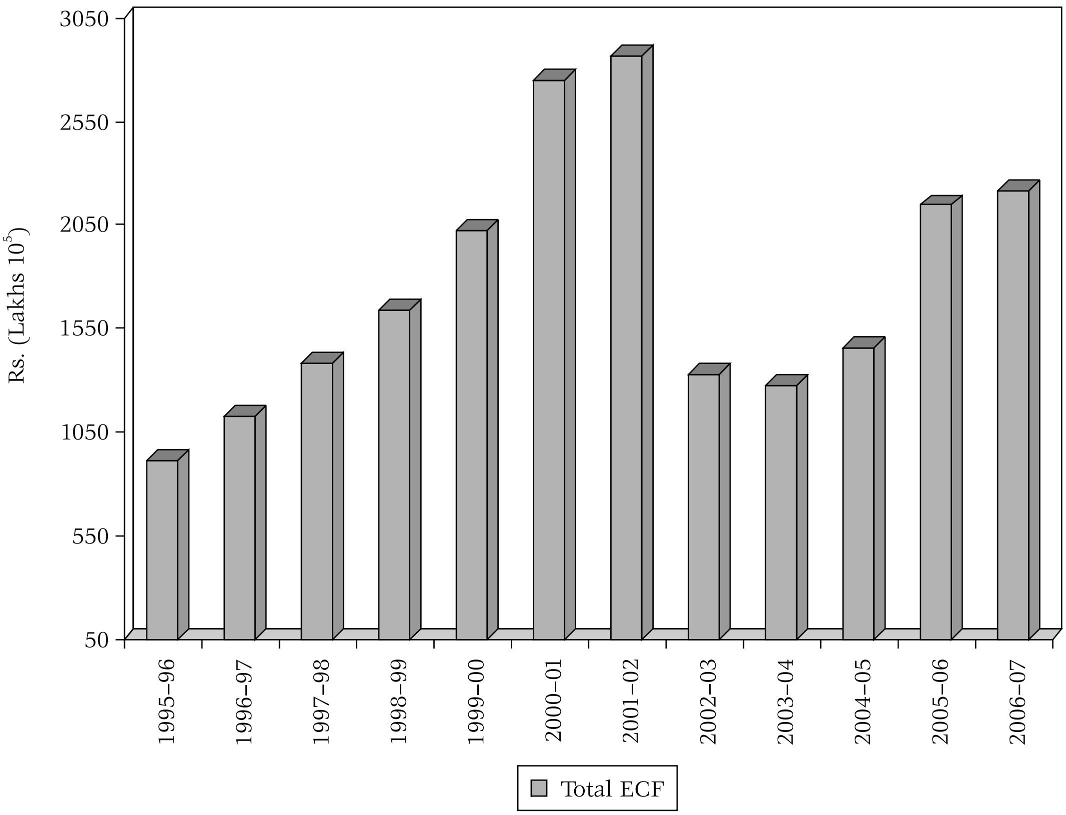
Box 6.1: Publications record — Comparison with other CSIR laboratories

Papers Published by CSIR Laboratories				
S.No	*LAB*	*2003*	*2004*	*2005*
1	IICT	379	414	433
2	NCL	350	410	417
3	CDRI	137	160	210
4	IICB	90	90	111
5	CCMB	69	116	113
6	CLRI	98	152	138
7	IGIB	54	60	70
8	CFTRI	100	95	112
9	NPL	84	100	120
10	IMTECH	35	37	62
11	NIO	82	64	127
12	NGRI	83	77	110
13	ITRC	59	64	65
14	CSMCRI	38	65	88
15	RRL–JOR	53	33	48
16	RRL–TVM	36	139	148
17	CGCRI	52	62	57
18	CECRI	56	86	106
19	NBRI	53	51	63
20	IIP	25	21	23
21	NML	42	57	68
22	NEERI	23	46	71
23	CIMAP	29	17	28
24	RRL-BHU	28	41	29
25	RRL-JAM	22	19	33
26	IHBT	16	30	50
27	NAL	18	23	11

public through lectures, TV appearances and press interviews and opened the door to collaborations and investments, Ratnasamy gave it an internal strength all its own and took its R & D to great heights internationally.

With all his absorption in catalysis he found ample time to improve the NCL's general amenities. Thus he had a modern hostel constructed for the growing number of research fellows at a cost of Rs. 1 crore (Rs. 10 million). True to his style, he did something typically Ratnasamy-ish. He invited A. V. Rama Rao, the then Director of the Indian Institute of Chemical Technology, to perform the opening ceremony. This was most appropriate as Rama Rao had joined the NCL as a junior research fellow under KV and rose to become a CSIR Director. LKD had established many amenities for the colony residents in the early 1980s soon after taking office. After about 15 years, they were showing signs of age and obsolescence. Ratnasamy renovated the children's park and called it *Nandanvan*, extended and beautified the *planned jungle* by planting rows of tissue culture raised trees and called it *Swarna Jayanti Vraksh Ropan*, and renovated the cultural center.

Figure 6.6: Economic boom in the post globalization era



His scientific and technical contributions reached a crescendo and are included in Chapters 8 and 11. After retirement he was accorded the signal honor of being named the Srinivasa Ramanujan Professor (after the mathematical genius from Madras) by the Indian National Science Academy, and was also named the Zeolite Ambassador by the International Zeolite Association. As Zeolite Ambassador, Ratnasamy was required to travel all over the world giving lectures on zeolites.

All-Round Modernization Under Sivaram

Sivaram is the "present" and by no means history; hence I should not be writing about him at all. But I justify a brief description of his regime here by referring to Chapter 18, where I dream of the future — even more so because he has initiated action on aspects largely neglected by his predecessors. This and his own scientific initiatives mark him out as potential history that places him among the best. In this age of quick changes, new concepts of management, taste and style that he has so abundantly carried forward from his days at the IPCL, and the need for keeping up with the best in every sphere of a laboratory's evolution, Sivaram has been leading the way as few others have. I may be prejudiced, for I like his attention to detail, his enthusiasm for novelty and elegance; in this I see a historical parallel with Pushpa Bhargava, the first Director of the CCMB at Hyderabad — in every other respect he is different.[5]

As can be seen from Chapter 13, polymers in the NCL has gone round a full circle. Starting as Plastics and High Polymers in 1950, it became Polymer Chemistry under Venkataraman. It then coexisted for a while with the newly created section of Polymer Science and Engineering in the Chemical Engineering and Process Development Division. After S. L. Kapur, who got his Ph.D. with Hermann Mark, a doyen of polymer chemistry of the mid-20th century, Sivaram is the only formally trained polymer chemist who has also had a great deal of exposure to polymer science and engineering. Sivaram integrated the two activities under one Division, called Polymer Science and Engineering under the leadership of Dr. M. G. Kulkarni. Sivaram also initiated the construction of a new laboratory building at NCL, called, Polymers and Advanced Materials Laboratory, to integrate polymer science with the broader discipline of advanced materials (see Figure 6.7).

Figure 6.7: A new state-of-the-art building was constructed for Polymers and Advanced Materials (PAM)

Sivaram's biggest scientific contribution came through his association with the GE project, which is described in some detail in Chapter 12. I am told by GRV and others that the success of this project owes much to the leadership and scientific acumen of

Sivaram. Many of the projects listed in Chapter 12 were initiated or extended during Sivaram's regime as Director. Sivaram also pioneered the concept of licensing patents to multinational companies. Several of CSIR's patents in the area of polycarbonates were licensed to GE, USA for a front end payment /royalty.

On the managerial side, Sivaram started activities that were not thought of or pursued by earlier directors, e.g. creation of resource centers; complete modernization of computer and IT facilities; conversion of an existing room next to the director's office into a state-of-the-art conference room; creation of an Innovation Park next to the NCL in the building formerly occupied by MERADO; creating a not-for-profit company, Venture Center, to promote start-ups and entrepreneurship; construction of a modern digital information center; revamping the library's reading room; streamlining and modernization of administrative facilities; archiving of old papers, reports and photographs; collection of alumni data; revamping of guest house (including construction of a conference hall with internet facilities), colony roads, gates and gardens; modernization of one of the NCL canteens; revamping the 25-year-old shopping center; contracting out most of the infrastructure activities like house keeping and gardening; procurement of an ambulance, bus, and other transport facilities; and many more. As a result of all these initiatives, the NCL is today state-of-the-art not only in its research and research facilities, but nearly so in its buildings and most other infrastructural activities.

A clearly discernable feature of Sivaram's management style is an increase in the number of independent units that report directly to him. As against the earlier practice of major divisions (less than 10) reporting to the director, special functions have been assigned to different groups of a division that report to him without the intermediacy of a division head. This perhaps increases the managerial role of the director but it also gives an opportunity for unit heads to interact directly with him. Both these models are in vogue in many R & D centers of the world and it is entirely a matter of the director's personal choice of the model. Sivaram has also laid greater stress on interdisciplinary collaborations within the NCL. In a decision that is likely to have far reaching implications for the future, Sivaram proposed to CSIR that the newly created, the Indian Institute of Science Education and Research (IISER), Pune, be co-located in the NCL campus. Accordingly a modern campus with an investment of over Rs. 500 crores (Rs. 5 billion) is taking shape in a 95 acre of land adjacent to NCL. In the years to come, this initiative will bring teaching and research closer, offering new opportunities to both the NCL and the IISER.

Shift in Economic Climate: Soft and Hard Sides

THE SYMBOLS OF CHANGE (SOFT SIDE)

I have already written at some length on the paradigmic shift in the country's economic philosophy and its effect on the NCL. The first two domains belonged fully to the planned development era, while domain 4 represented in full the free market era. Domain three straddled the two eras. While still operating in the planned development era, several overtures were made to multinational companies to have some NCL technologies exploited by them. Humphreys and Glasgow, Imperial Chemical Industries, United Carbon, are some of the companies with whom negotiations were conducted. However, the political climate in the country impeded any substantial progress, but, as mentioned in earlier chapters, collaborations were established with universities in Germany and England, and a massive program under the Overseas Development Agency in England was undertaken.

The complete changeover from one economic philosophy to the other is best illustrated by the way in which the Silver and Golden Jubilees of the NCL were conducted. The Silver Jubilee, (1975) celebrated during the heyday of the planned development era under Tilak, was presided over by Prime Minister Indira Gandhi, one of the chief architects of that philosophy. On the other hand, the Golden Jubilee, (1999) celebrated when the new era was in full swing in Ratnasamy's time, was inaugurated by Mukesh Ambani, CMD of Reliance Industries, the most visible symbol of the ascendency of free market economy. Government patronage, always necessary and desirable, was no longer paramount (Figure 6.8). The Golden Jubilee was concluded in 2000 by Prime Minister Atal Bihari Vajpayee.

THE FINANCIAL REALITY OF CHANGE (HARD SIDE)

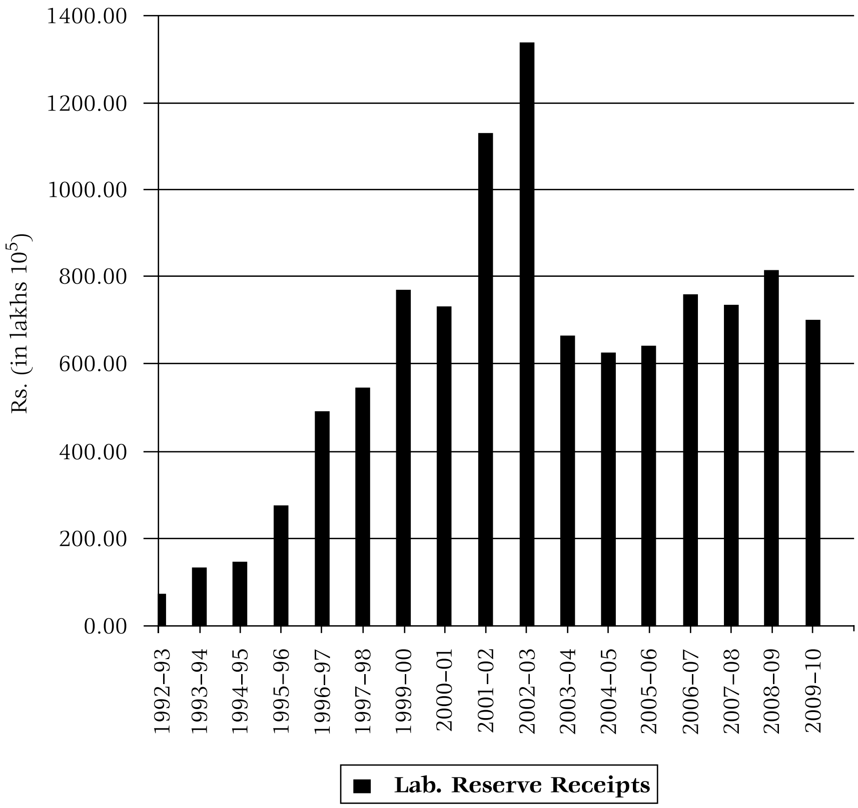
What made all the sophistication and relative freedom in spending possible? As already mentioned in this and previous chapters, the very philosophy of free market economy was the prime mover. More specifically, the CSIR used this opportunity to create conditions to translate this change into financial reality. Several liberalizing measures were taken but the following was, in my personal judgment, the most telling.[6] It introduced in the late 1980s the concept of lab reserve funds. This was a cumulative fund from the unspent money from the industrial earnings of a laboratory. It gave flexibility to the labs in financial planning since they were freed from the obligation to spend it before the March 30 end of a financial year. Since it was not money from the CSIR or any other government agency, the flexibility in using it was explicitly recognized, and the laboratories were allowed to accumulate these funds. (I mention this because there is usually a difference between the political statement of a philosophy and its implementation by the bureaucracy.) The bar plot shown in Figure 6.9 represents the amounts that accrued to this fund each year. It will be noticed that Ratnasamy and then Sivaram accumulated considerable sums of money under this fund, and used it to establish state-of-the-art facilities, such as resource centers (i.e. for combinatorial chemistry, digital information service), a modern student hostel, fully modernized scientific infrastructure, etc.

Oversight Versus Oversight!

There are two dictionary meanings of "oversight": responsibility of supervising something; a mistake, especially as a result of failure to do or notice something. The first is usually but not necessarily accomplished through a committee, and the second is usually assigned to an individual. If this were literally true, the director would not be directly responsible for oversight of the first kind — which is clearly absurd. He exercises this role through committees statutorily appointed by the CSIR or specially constituted by him. There is nothing in the rules that forbids direct intervention by him, but as a measure of safety

Figure 6.8: The Silver and Golden Jubilees of the NCL, inaugurated by Indira Gandhi and Mukesh Ambani, respectively, covering the two different economic philosophies (centrally planned and free market) within which the NCL evolved over the last 60 years

Figure 6.9: Growth of the NCL's reserve fund since it was started almost simultaneously with the free market era



every director would prefer to act under cover of a plurality of opinions reduced to a solid recommendation by a majority vote. Most directors seem to have opted for this mode of operation, Venkataraman and Sivaram in particular, each at one end of management's lengthening vocabulary. Venkataraman presided over the NCL when the only vocabulary available was the vocabulary of common sense, of raw thought processes, all garnished by pinches of experience, idealism, and imagination. Sivaram came when management had carved a niche for itself, complete with its own evolving vocabulary, with nuances too subtle for interpretation without the aid of a galaxy of emerging management *gurus*. Management consultants were freely appointed, even starting from the days of Tilak in the 1970s. Thus management became permanently entwined in the NCL's structure. While one can argue that too much of it, like of anything else, is bad, there can be little doubt that it helped raise the average individual level of efficiency at the NCL. Did this improvement in the average happen at the expense of the exceptional? There is no answer to this question yet. Certainly, stalwarts have been scarcer in the NCL today than in days past, revealing a trend that needs to be arrested/reversed. Natural leadership can never be fully replaced by its synthesized analogues. The NCL was witness to the management's inverse peak in its involvement with science in Ratnasamy's time. He laid out clear criteria for assessment, as already mentioned previously, and let the numbers speak for themselves. In my view, this was a good thing, though some worried that this might be misinterpreted to reflect a well-meaning director's disengagement with management. But, if statistics are any guide, this is far from the truth.

In general, since the early 1990s, the NCL has rapidly moved in the managerial direction (with a letup of 5–7 years under Ratnasamy). While it has certainly reaped the benefits of such a controlled evolution, it is never too late, even if sometimes too early, to pause and take stock. Chapter 18 ponders over this question in a more general response to the situation.

Oversight of the second kind has the potential to do much harm, but seldom does. It is generally more a definer of personality than a measure of action or accomplishment. If a mistake is committed and eventually goes public, the director must fully own the mistake and not point fingers at others, just as he would to himself for the good things accomplished. The NCL has been fortunate to have had directors, from McBain down to Sivaram, who never once blamed the laboratory's lapses on individuals, except in closed door sessions for review and course correction, or who took their woes to the CSIR in a preemptive move to artfully extricate themselves from possible future implications.

Were the Directors Good Leaders?

And finally a good leader is one who is as much interested in spotting potential as in promoting concrete achievement, for the two go together, not simultaneously, but with a time difference. The period between the two will not see visible evidence of achievement, but as Carl Sagan (1977) so beautifully put it, *absence of evidence is not evidence of absence.*

Consciously or unconsciously, many (but not all) directors of the NCL, who were probably unaware of this insightful observation, seem to have seen this "outside- the-visible-range" of evidence. This resulted in chancy achievements at first, followed by planned ones where talent was purposefully recruited for targeted research and, after unusually short periods of time, led to some remarkable practical achievements, as described in Chapters 8 to 12.

Many directors and some senior scientists recruited their own students, leading to a certain degree of inbreeding. This had the merit of continuity in certain important lines of research, but set a pattern of research that hindered bold departures. Fortunately, many such recruits broke away from this traditional constraint associated with Indian research, and did some outstanding research. Some directors brought in talent in then emerging areas such as NMR, catalysis, chemical biology, polymer science and engineering, chemical reaction engineering and nanotechnology, which has largely been responsible for the position the laboratory enjoys today. None of them was bold enough to deal with deadwood frontally, and preferred to side-step the issue in the naïve hope that restricted funding and impending retirements would make for a self-correcting outcome. This allowed continuation of some very mediocre work, and did not significantly alter the situation.

A particularly important leadership trait in a research director is to make sure that rivalries in an inventive group do not vitiate the search for knowledge. History is not lacking in such instances, even at the highest level, to be taken lightly.[7] Many NCL directors were not personally involved in discoveries, but were broad-minded enough not to inject themselves into the picture at the right time. What is even more significant is the need to realize that friendships forged in the heat of discovery often tend to be ephemeral. I cannot speak for the last three directors, for I was not personally associated with their regimes and could find no clues to draw meaningful conclusions from. Among the earlier ones, some were unconcerned, and two of them went out of the way to ensure that any such tendency was quickly curbed by assurances of just distribution of credit. In my view, this was an important factor in the NCL's overall success. Not that such situations did not exist but they were never allowed to assume destructive proportions.

Paying the Price

Call it by any name: as in the caption above, the lion that did not roar, the silence that did not pay, silence is not always golden, or whatever. Paul Dirac's (1858) famous advice: *Do not start a sentence unless you know how to close it* (in other words, do not talk!) does not always help. The fact is that a top scientist unwilling to expend more than the normal effort or, more importantly, without a consistent champion, is at the mercy of statistics to be recognized at the highest levels. The NCL's scientists, including directors, have not been blessed with the art of such talk. In spite of this, one of its top most scientists and a former Director, Mashelkar, has been most visibly recognized, and most deservedly so, for his outstanding contributions to polymer science and engineering. The culture of excellence in the NCL is so infectious that one can name a few more who were almost equally deserving. As this laboratory has been home to excellence in organic chemistry and biochemistry from the very beginning and in catalysis in later years, and as my association with these areas is by no means trivial, I am able to make a rational judgment on a few who have brought great credit to NCL and to India in chemistry: Sukh Dev, Venkataraman, Bhattacharyya, John Barnabas, Jagannathan, Paul Ratnasamy, S. Sivaram, Raghunath Chaudhari, Rajappa, Ayyangar, A. P. B. Sinha, B. D. Kulkarni, and Rama Rao.[8] Sukh Dev is unquestionably one of the most brilliant chemists of the country and is deserving of the highest accolades; Barnabas was a highly reputed evolutionary biologist who died prematurely; Bhattacharyya did his best work at the NCL and was well on the way to world recognition; Jagannathan was brilliant, thorough, and (thanks to his reticence) one of the most undervalued scientists of the country, KV (now deceased) was a pioneering researcher in organic chemistry whose researches and books have left a lasting impact; Rama Rao is a fine combination of the academic and the practical chemist; Ratnasamy is a catalyst chemist *par excellence*, a true world-class researcher; B. D. Kulkarni, a master thinker and researcher, who prefers the peace of seclusion to the faintest decibel of publicity.

❄

Part III
The Sinews of Excellence

The good of man is the active exercise of his soul's faculties in conformity with excellence or virtue, or if there be several human excellences or virtues, in conformity with the best and most perfect among them.

Aristotle, c. 350 BCE
See Aristotle, 1947

INTRODUCTION

This part lays considerable stress on basic research at the NCL, affiliations with universities, evolution of research areas, and process development at the NCL. Basic research, particularly that leading to doctoral degrees, has been a major feature of the NCL since inception, and is described in Chapter 7. Real industrial research, for which the laboratory was essentially created, came much later. As the laboratory is not a degree-giving institution, it offers degrees only through recognition by several universities as a center of research. The Ph.D. program remained static for a number of decades, in the sense that while scores of degrees were granted by the affiliating universities, the structure of the program remained unchanged. It was only around 2003 that a major change was introduced to provide a more university-like education to the students.

Chapter 8 describes in considerable detail the research programs of the NCL in terms of areas of research, describing how they evolved over the years. The laboratory has worked in a number of areas. The exact number is difficult to give, for many small areas have had little more than a fleeting existence. A partial list of the important areas is given in this chapter. Of these, the areas considered to be of the greatest importance are about 15. The chapter summarizes accounts of these areas written with the assistance of scientists who were largely responsible for developing them. Many other sources had to be consulted in some cases because the concerned scientists had passed on and records were hard to come by.

Chapter 9 provides a brief account of the various modes of industrial collaboration, but a discussion of some of the important projects is deferred to Chapters 10 and 11 of Part IV. These include mostly projects undertaken with the laboratory's own funds and a few in collaboration with the industry. Contractual projects which were not very many before 1990 became more the rule than the exception with the advent of globalization. Permissible details (close to negligible!) of these collaborations are given in Chapter 12 of Part IV.

7

A REWARDING CULTURAL PLURALISM

BASIC RESEARCH, LINKS WITH ACADEMIA

The scientist does not study Nature because it is useful; he studies it because he delights in it, and he delights in it because it is beautiful. If Nature were not beautiful, it would not be worth knowing, and if Nature were not worth knowing, life would not be worth living.

Jules Henri Poincare, 1854–1912

Basic And Applied Research[1]

Basic research (usually more academic than basic, as pursued by most universities) is almost always associated with graduate programs like M.Sc. and Ph.D. It is here that laboratories like the NCL find themselves in a difficult position. There is usually a conflict between institutional mandates and the scientists' desire for basic, publishable work. Since the regular employees of the laboratory are often too involved in time-targeted projects, they do not enjoy the luxury of publishable research. However, senior scientists, even junior ones with an outstanding record of research, can indulge in this research through a procedure allowed by the CSIR. They can employ research fellows selected by the CSIR by a procedure outlined previously and conduct their basic research using them. As the research fellows like to get more out of their work than just a few publications, the CSIR has encouraged senior scientists to get themselves recognized by one or more universities as guides for their M.Sc./Ph.D. programs and have the research fellows register themselves, usually at universities from where they received their B.Sc./M.Sc. degrees.

During the last 10 years, the personnel landscape has undergone a dramatic change. Instead of the regular staff (scientists of various categories), one sees a large student population enlivening the atmosphere with their youth, ambition, and enthusiasm. As of this writing, there were over 400 students (mostly research fellows) as against a paltry 30–40 in the early 1960s. Even so, the recruitment of scientists of high caliber has continued and they are, more often than not, encouraged to undertake basic research.

There are essentially two approaches to basic research:

- It is carried out purely for the sake of advancing knowledge.
- It is a spin-off from on-going or contemplated projects.

We shall see in this section how the two approaches have influenced the NCL. Whether the second approach leads to a better understanding of a general problem or is restricted to understanding just enough of a problem to complete a project at hand is a matter of debate. There is certainly much substance in the argument that the first approach denotes continuous devotion to a specific area, whereas the second would suggest that, once the required solution is obtained, one moves on to tackle another spin-off. As we will see later, the NCL is pursuing R & D in several areas of science and technology. With about 50–400 students (closer to 400 since around 2000 CE) working for their advanced degrees at any point in time (in addition to some junior staff), it is difficult to be dogmatic about this distinction. This combination of the academic and development aspects of research at the NCL has at once been its biggest source of strength and a perennial target for criticism.

It is also difficult to draw a line between basic and applied research. As will be seen from an incident narrated below, the word 'basic' seems to send an emotion of anger down the spines of those who (once) regarded basic research as foreign to the very concept of national laboratories. When Louis Pasteur ridiculed the concept of applied science (see Chapter 9), it was not just a question of semantics. There will be many who do not agree with him, but I do. Pure science and applied science make no sense. There is only one science and that is pure science, and then there is the application of this science. This is also the view advocated by Julian Huxley (see Bourne, 1917). To call the application of science as applied science is tantamount to declaring that it is a different kind of science from pure science — which of course it is not.

The terms basic research and applied research are not cast in the same mold of understanding, and are less offending. Therefore, I shall not use the terms pure science and applied science in this book and stick to basic and applied research instead.

AN INTERESTING ALTERCATION (NARIELWALA VERSUS KANE)

The NCL research committee meetings have often been enlivened by discussions and emotional presentations on basic research. I have already spoken about Kane, that honest and well-meaning stormy petrel of India's technical bureaucracy. At a rather contentious meeting of the NCL's Executive Committee, he was dissatisfied with the continuing basic research in the group of S. C. Bhattacharya (SCB), a renowned organic chemist who later became Deputy Director of IIT, Bombay, and was also a Vice-President of the Indian National Science Academy. SCB was sent for to answer some questions at the meeting and Kane immediately confronted him by accusing him of vacillating between basic and applied research, not knowing the difference, and called him wobbly. Narielwala, an industrial giant of the Tata Group and an ardent spokesman for Indian science, who was then the committee chairman, took issue with Kane and asked him to withdraw the word. True to his character, Kane refused. Narielwala's rejoinder was a classic. His actual words are not on record, but the following should be close:

> *Dr. Kane, all of us come here a couple of times a year, sit in this beautifully appointed room without even bothering to go round the laboratory and see for ourselves what these young scientists are doing, but are quick to pounce on them if their view on some subject such as basic research happens to be different from ours (yours in this case). Do you really know the difference between basic and applied research in a lab like the NCL? I suggest that it is you who are wobbly, not Bhattacharya!*

Coming from a doyen of the Indian chemical industry, this left Kane speechless! Narielwala's passing away was a sad day for the Indian industry. To end this reminiscence, Kane held strong views and expressed them bluntly, but was always forthright and never against individuals. He honestly believed that basic research was the university's province and that the NCL should not dabble in it, using government money allocated for industrial research. His fighting face projecting the appearance of a bully belied a deeply held belief in fairness and an unsuspected core of kindliness.

The Indian appetite for such debates is proverbial. There were those who closed the gap, those who widened it, those who saw no difference in the first place. I suspect the debate will continue and the list of opinions on what the NCL should be doing (for it is public money that sustains it) will never diminish. But to the NCL scientists, who once gleefully joined the debate, the issue ceased to be important somewhere along the line (in the mid-1970s). Henceforth, what mattered most was results and least, semantics, a pointless difference in the interpretations of those who did neither.

SIR FRANCIS BACON ON BASIC AND APPLIED RESEARCH

It is interesting to note that the difference was recognized long before the debates acquired their modern context. For instance, Sir Francis Bacon wrote in the archaic style of his times:

> *We have Three that try New Experiments such as themselves think good. These wee call Pioneers or Miners. We have Three that bend themselves, Looking into the Experiments of Their Fellows, and cast about how to draw but of them Things to Use, and Practise for Man's life and Knowledge. These wee call Dowry-men or Benefactours.*
>
> Bourne, 1917

Bacon's 'Pioneers' and 'Miners' are the devotees of pure science, and those who indulge in the application of science, not applied scientists — to keep old Pasteur from turning in his grave — are the 'Dowry-men' or 'Benefactours'. From what I can glean from later writings, this distinction has continued. It is useful to recall here that many practically useful results have emerged from basic research carried out with no eye to utility. Hence the question arises: Is there really a difference between the two types of research in terms of the larger scientific enterprise? The debate was always left over for another day, then to yet another, and continues to this day. There will never be a clear answer. Each laboratory must find its own optimum, depending on a variety of factors endemic to it. I believe the NCL, in its relatively short existence so far, has evaded coming to a clear-cut answer, leaving it to successive directors to deal with it in their own ways. Thus, no consistent policy was discernable.

AN AMERICAN PROFESSOR QUOTES FROM THE *BHAGVAD GITA* AND LORD RUTHERFORD TALKS DIFFERENTLY

Professor Jerold M.Schultz of the University of Delaware spent a year long sabbatical at the NCL during 1989–1990. He was interviewed by Ponrathnam of the Chemical Engineering Division. When asked if he had any professional advice to offer to NCL scientists, he responded:

> *Yes. There are several disconnected things which are useful. The most important one is the concept of non-attached work. One finds this in the Bhagvad Gita, but the concept is comfortable*

for Christians also. For instance, Krishna says to Arjuna: 'Renounce attachments to the fruits of your work. The work done with anxiety about results is far inferior to work without such anxiety, in calm self-surrender. For those who work selfishly, the results are miserable.' Krishna's advice here is very useful. Immerse yourself in the work, after you become convinced that the work is consonant with good, with no thoughts of how things will end up.

It is difficult to imagine an American professor saying this. Those in the government and those among the public who regard basic research as the ultimate way of wasting good money will do well to ponder over this profound advice. In the market and business driven direction most of our laboratories have been following the last several years, a touch of this profundity would not be out of place. Knowledge engineering, which is entirely fact and data based, should not be allowed to drown pure thinking, those flights of imagination which can later be put to test. It is my personal hope that the terms market-driven and business-oriented will not equally be allowed to drown true basic research at the NCL, such as that done by K. P. Sinha in the earlier years and John Barnabas and P. Ganguly in more recent times. One need not go back to the days of control and license, but one need not also shun government help to think — the government, because no other agency will fund pure thinking.

On the other hand, money is not something one can easily overlook. All over the world today, the extent of research is determined entirely by the amount of funding made available for it. It is generally held that the research output of America is greater than any other country's because it is rich and can afford huge sums of research dollars. It is unfairly believed that this financial largesse exempts the country from restricting research to only those who can bestow a great deal of thought on it. This sentiment could not have been more clearly expressed than in the following pithy words attributed to one of the greatest scientists of modern times, Lord Rutherford (1871–1937), author of the atomic theory: *Since we do not have money as the Americans have, we have to think*. Compare this with the belief that with more money you have better access to the latest equipment and hence can do better research.

As far as the NCL was concerned, the money problem went round a full circle: from government funding, to the earning of funds from outside sources, and back to government funding (with not much let up on the need for external funding). The new government funding came from the so-called network projects in which several laboratories of the CSIR were involved in a single project. This was reminiscent of the tasks and missions of earlier years. Further details on the CSIR's task, mission, and network projects can be found in Chapter 10.

Excellence and Equality

The NCL has always had a huge stake in a full appreciation of the meaning and practice of excellence and equality of treatment. The true scientist will see a contradiction in terms here and will perhaps agree with Justice Felix Frankfurter (1949) that *it is a wise man who said that there is no greater inequality than the equal treatment of unequals*... while the social philosopher will see none, asserting that one begets the other. I begin my discussion of this circular argument by echoing Charles Murray's beautifully expressed thoughts in his *Human Accomplishment* (2003): *Let us give unto excellence that which excellence demands and let us give unto equality that which equality demands.* In other words, there is no contradiction in terms. They can coexist without disturbing overall quality. I have often said to my colleagues that I believe in social and political democracy, but not in intellectual democracy. Many of my senior colleagues often accused me of playing favorites, of encouraging the cult of blue-eyed boys. I did not ever contradict this assertion, for it was true, if not as blatant as they implied. If this channel of encouraging the best is closed or denied, how else will excellence flourish? One can quote instances from the past, of a Faraday or a Ramanujan, who produced their best under dire circumstances, but we are living in a different day and age. If not properly encouraged, talent of the order I am talking about will migrate to greener pastures. No director should let that happen. So there is a conflict in treatments, equal and unequal.

Aware of this dilemma, the CSIR created the position of scientist in the director's grade to which scientists of exceptional merit would be promoted. They would have the privileges of the director but not his powers. This worked very well for several years but somewhere along the line, lost its meaning. It happened when the special grade, given only to a handful, was made a routine step (Scientist G) in the order of promotions, and thus lost its value as a means of recognizing exceptional merit. The exceptional and the not so exceptional were assessed by the same norms involving a host of present day question-and-answer exercises, resulting in a relatively large number of promotions. This was fine as long as another step was created for the truly exceptional, but this was done only indirectly. Two levels of directors were created and a selected number of directors were promoted to this grade. In itself, this was an excellent move for it brought the higher level of directors in line with the additional secretaries to government (and sent a message to Delhi's bureaucracy, I suppose) who, in turn, were only one step lower than the secretary, a status enjoyed by the director-general alone in the entire CSIR. True, the NCL continued to have outstanding scientists but the exceptional were no longer distinguishable from the very good, the Gs, in terms of their ranking. The quest for equal treatment had won and intellectual democracy of sorts seems to have prevailed.

In fairness, it should be said that the Gs of the NCL were still highly meritorious and were among the best in the CSIR. In my personal judgment, the laboratory failed to give unto excellence what excellence demanded and unto equality what, in the best traditions of the laboratory, equality would not have demurred. (I understand that this anomaly has been recently corrected by DG CSIR, Dr. Samir Brahmachari.)

NCL-Academia Link

It was realized by all the directors that a strong research base could be built, not in isolation, but only in association with institutions engaged in active basic research all over the world, namely, academic institutions. This was accomplished in four ways:

- Encouraging senior scientists to be recognized as guides for Ph.D. programs of different universities to enable them to guide research fellows and junior colleagues towards their degrees.

- Recommending students who obtained their Ph.Ds at the NCL to post-doctoral positions at universities abroad, thus establishing contacts with those universities.
- Deputing NCL scientists to reputed research organizations abroad under various schemes, and also permitting scientists to proceed to universities abroad on sabbatical.
- Inviting professors from universities within and outside India for seminars.

Of these, the first requires a narration of its historical development in the NCL, and is considered below. The others do not need any elaboration.

Before proceeding any further with the NCL's academic program (which essentially involves basic research leading to a Ph.D.), it would do well to remember that break-throughs in research come only through a total understanding of the physics of situations and not by mathematical modeling, however complex, which can sometimes be based on a wrong physical picture altogether. Nowhere is this more apparent than in the highest form of mathematics developed by early Hindu astronomers based on a false picture of the universe (the sun revolving round the earth). It is therefore necessary first to conceive a sound physical picture before applying the tools of mathematics. There are those who sing praises of people to whom every problem appears as a differential equation. The NCL has largely stayed away from this approach in the areas of its concern where mathematics has an important role, such as chemical physics, NMR, and chemical engineering science. It has almost always attempted to construct a realistic physical picture and then analyze it mathematically.

M.Sc., Ph.D. Programs

> *That* [referring to the doughnut magnet designed by Cockroft, an associate of Rutherford and a future Nobel Laureate, to focus alpha particles] *cost as much as a research student for a year-but does twice as much work.*
>
> Lord Rutherford, quoted in Gratzer, 1989

It used to be said of the NCL, in a lighter vein, that if one were in a hurry and ran into someone, the person would, as likely as not, be a Ph.D.! The NCL perhaps had, and still has, a greater number of Ph.Ds than the University of Pune, and one of the largest concentrations in the entire country. As on 31st March, 2010, the number of Ph.Ds in the laboratory was 440 as against a total scientific staff of 206 (not counting assistants) and the total strength 730. A majority of the senior scientists among its staff were also recognized post-graduate teachers, that is, recognized guides of students working for a Ph.D. degree. The number of recognized guides in 2005 was 110, which amounts to about 41% of the total scientific staff. All of them, with the exception of two, were recognized by the University of Pune, and about 25 by more than one university. In other words, quite a substantial number of the NCL's scientific staff were good enough to be Ph.D. guides of recognized universities.

There was also, however, a large body of research assistants in the staff who did not possess more than a bachelor's degree in chemistry. There was a feeling of inadequacy among these assistants. Experienced as they were in helping the scientists to conduct research, they realized that they were not qualified to conduct research independently. The NCL authorities had, for a long time, felt a need to help them to qualify further and had been encouraging them to appear for exams conducted by professional bodies like the Institute of Chemistry and the Institution of Engineers. But the feeling remained that the qualifications obtained by passing these exams were no match to a higher university degree.

The NCL authorities were not immune to this feeling and decided to create an opportunity for the junior members of its staff to work towards a Master's degree and later a Ph.D. degree. By doing this, the laboratory could also fruitfully tap the immense talent potential present in this layer of the staff. Thus began a series of discussions with the University of Pune on the possibility of the latter's starting a Master's program specially tailored to the needs of those at the NCL wishing to further their qualifications. It was a fortunate circumstance that the then vice-chancellor of the university was a man of great vision, Prof. G. S. Mahajani, a Cambridge Wrangler.

Prof. Mahajani was receptive to the idea and placed it before the Academic Council and other bodies of the university with his recommendations, and thus was born the M.Sc partly by papers and partly by research (PPPR) program, a course specially oriented to research workers of the NCL at a junior level. They would have six exams in four subjects conducted by the university, and after passing them, carry out research on a project approved by the university, under the guidance of a recognized scientist at the laboratory and submit a dissertation. After obtaining the university's approval of the dissertation and clearing a *viva-voice* examination, the candidates would qualify for the Master's degree.

The first batch of 30 staff members, chosen on the basis of seniority, registered for the M.Sc. (PPPR) in 1974, and in less than a decade, most of them had obtained their Masters and Ph.D. degrees. Although they had not been allowed to attend lectures at the university, they somehow managed to get a grip on the subjects and pass the exams, often with distinction. In an effort to understand the concepts that were entirely new to them, they would approach senior scientists and research scholars fresh out of university. The going was sometimes tough for them as they had to study for their degrees after completing their work assignments, but their enthusiasm more than made up for the occasional anxiety caused by the clash between the demands of work and course. But the years of study became memorable in the lives of the staff, and their careers took a dramatic turn for the better. Their rise became faster and a few of them rose to high levels in their professional lives.

At different stages in the evolution of the NCL, its association with academia took novel turns. Several senior scientists of the various divisions were often invited to give series of lectures at the university. A. P. B. Sinha was a popular invitee. In the early 1990s, the university started courses in chemical engineering and biotechnology, and sought the help of the NCL in drawing up the syllabi and in helping the faculty in some key subjects. This was something that the laboratory was more than willing to do. NCL scientists with teaching skills regularly visited the university and the colleges to give lectures, and the university-NCL chemical engineering division collaboration in biotechnology was so popular that students from the university regularly came to the NCL to attend lectures and do experiments with the aid of the advanced facilities that were available there. Mention may be made here of V. K. Jayaraman, who contributed greatly to this program.

The NCL-academia association has been an ongoing feature of its activities and, on an average, about 150 research scholars have worked for their Ph.D. degree at any given time. The actual number has fluctuated quite widely, varying from 50 to 450. On an average, about 50 students were awarded their degrees every year from various universities. As the NCL is not a degree-conferring organization, it can only provide facilities for carrying out research and the actual degrees have to be conferred by universities at which the students are registered. For any student, the concerned university must recognize the NCL as an approved place of research with the scientist guiding the research as a qualified Ph.D. supervisor. The number of supervisors from the NCL recognized by different universities grew from less than 10 in 1950 to 110 at the turn of the century. Starting from the University of Pune in 1950, the number of universities that recognized the laboratory grew steadily to 10 in 2005. This does not include the universities that might have recognized other scientists who had either died or were no longer active in 2005. Note that the recognition lapses as soon as the recognized scientist, if he is the only one recognized from the concerned university, dies or becomes inactive for any reason including retirement. Box 7.1 lists the universities that recognized the NCL as a center of research for Ph.D. over the years. The first NCL scientist to receive the degree was:

K. K. Chakravarti
University of Calcutta, 1955
Supervisor: S. C. Bhattacharya
Thesis title: Studies in essential oils

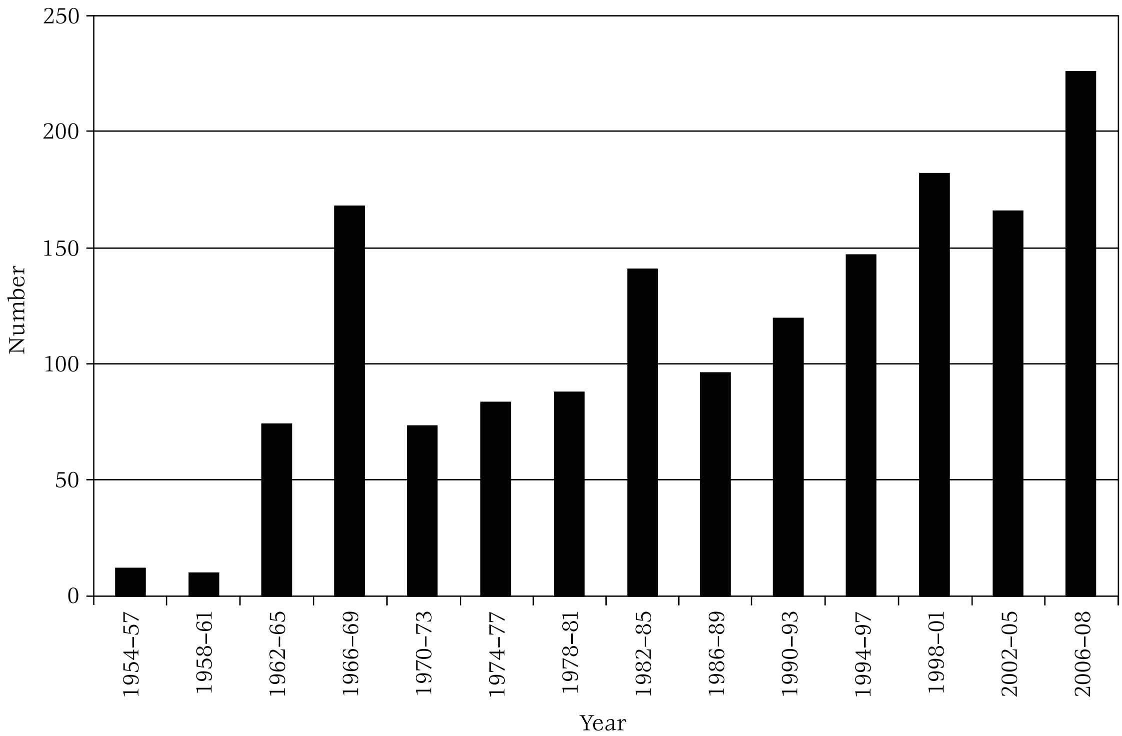
Since then, over 1700 research scholars/assistants have received their Ph.D. degrees from the universities listed in the table. Figure (7.1) provides a year-wise breakup of Ph.D. degrees.

Understandably, the maximum number received the degrees from the University of Pune, far fewer from other universities in Maharashtra (the state of the NCL's location), and even less from the rest of the country.

Box 7.1: List of universities that recognize the NCL as a center for Ph.D. research

1. Indian Institute of Technology, Kanpur
2. Indian Institute of Technology, Mumbai
3. Nagpur University, Nagpur
4. North Maharashtra University, Jalgaon
5. Osmania University, Hyderabad
6. Salford University (UK), Salford
7. Shivaji University, Kolhapur
8. Swami Ramanand Tirth University, Nanded
9. University of Bhavanagar, Bhavanagar
10. University of Calcutta, Kolkata
11. University of Mumbai, Mumbai
12. University of Pune, Pune
13. Yashwantrao Chavan Maharashtra Open University, Nasik

Figure 7.1: Yearwise breakup of Ph.D. degrees



An inherent weakness of the NCL Ph.D. program was that it was 100% research-oriented and the usual advantages and requirements of a university program were lacking: course requirements, periodic seminars and their evaluation, and discussions with students working in similar fields. As the program was going well, no director seemed to take this seriously till Sivaram took up the directorship in 2002. The way in which the program was revamped and reorganized by him is described in the next section.

REVAMPING THE PH.D. PROGRAM

Ph.D. programs all over the world are associated with universities, except in some countries where a few laboratories outside the university system are also allowed to undertake research leading to a higher degree from the collaborating universities. The collaboration is largely one-sided in the sense that the research is done entirely within the laboratory, and in some cases students are required to successfully complete a few selected courses at the concerned university. The NCL has perhaps the largest Ph.D. program in the entire CSIR, with almost 400 students registered at a given time since the mid-1990s. As stated previously, Sivaram squarely addressed the weaknesses of this program and revamped it to provide the students much of what had been missing in their education — education itself — more course work, lectures within the NCL by its scientists, a formal evaluation system. When these changes are fully implemented, the NCL holds the promise of turning out Ph.D.s with better research education (not training) than most universities can offer and with the same level of overall graduate education. An additional advantage is that the NCL scientist, not being a (professional) teacher, escapes the ambit of George Bernard Shaw's characteristically cutting remark (198) *He who can, does; he who cannot, teaches.* (Shaw, 1948)

Aristotle's educational acquaintance: A few other CSIR laboratories have a similar detailed involvement with the academia, notably the CLRI and CECRI. CECRI has gone one step further by offering degrees of its own. In other words, it doubles as a university. This entire question of having a complete university protocol at the NCL is a subject of great importance, for it imbibes in the student a desire to procure knowledge beyond the borders of his own field of specialization. The various subjects are so interconnected that unless one has some knowledge of subjects outside one's own, one might find oneself struggling with a problem for which a solution already exists in a different context in a different field. Innumerable examples can be cited to buttress this view, but instead, I would like to end this section by referring to some of the most inspiring words on education and specialization written about 2,400 years ago by Aristotle (in his *On the Parts of Animals*), the man who has given to modern thinking more than anyone else. His words apply to knowledge in all spheres but, considering the explosion in knowledge since his time, I would like to restrict them to allied fields, near and far.

> *Every systematic science, the humblest and the noblest alike, seems to admit of two distinct kinds of proficiency: one of which may be properly called scientific knowledge of the subject, while the other is a kind of educational acquaintance with it. For an educated man should be able to form a fair off-hand judgment as to the goodness or badness of the method used by a professor in his exposition. To be educated is in fact to be able to do this.*
>
> Aristotle, 1947

An 'educational acquaintance' in even distantly related areas is often sufficient to recognize the beginnings of a solution to a problem at hand in one's own field of specialization. The NCL's Ph.D. program was deficient in this respect till at the turn of the century, Sivaram greatly revamped it as outlined above to bring it, to an extent, on par with the university system.

WHY IS INDIAN UNIVERSITY RESEARCH NOT WORLD CLASS?

This, no doubt, is a provocative heading, but I believe there is much truth in it. Out of well over 400 universities, one can name no more than a few that turn out outstanding research. Institutes and national laboratories like IISc, TIFR, Jawaharlal Nehru Center for Advanced Scientific Research, NCL, IICT and a few others are internationally recognized. Such recognition has somehow evaded our universities except in a few selected areas. For a country with a billion people and several hundred universities and institutes, this is indeed a deplorable situation. There is no Harvard or Princeton, Cambridge or Oxford, Gottingen, Delft, Uppsala, or Sorbonne. Even the IITs are known for turning out outstanding graduates (partly because of the very strict rules of admission) rather than for research. They have become exporters of talent to top American and European schools, and are unable to retain students for research themselves. Usually, those who go to IITs for higher degrees are graduates of less known universities. This situation must be quickly addressed, and some of our universities must recapture the splendor of a Taxila or Pataliputra. Top committees and organizations like the Science Advisory Committee to the Prime Minister and the UGC must not lose any time in providing the foundation for this to happen and give India, by dint of its ancestry and tradition (and performances by scientists mostly from American universities), the place it deserves in the world of universities. Starting new centers like the Indian Institutes of Science Education and Research, though laudable, is a disconnected parallel step and hardly the answer. Further, it is restricted to science. As the sixth equation that transformed the world, attributed to Brahmagupta (see Chapter 1), clearly implies, 'Any very large number + a small finite number is still almost the same large number!'

PROBING THE DISCIPLINARY INTERFACES

It has become a financial driving force today (almost a farcical fashion) to talk about research at the interfaces of two or more traditional disciplines, including the interfaces between pure sciences, and the pure and engineering sciences. The usefulness, indeed the inevitability, of such an approach to discovery is indisputable. But it is necessary for the practicing scientist to get down from fashion to fact, from qualitative assertions to prove this point, to quantitative facts to uphold its importance. While the NCL has been moving in this direction, it is necessary to appreciate the historical background to this approach and use it as a necessary strategy to minimize experiments for a new discovery (Harwit, 1981).

Using simple statistical arguments, it can be shown that discoveries at the interface of disciplines can be made with much less effort than when carried out independently in the individual disciplines. Some of the major findings reported by NCL scientists have occurred at the interfaces (see Box 8.7), such as between organic chemistry and biology, materials science (nanoscience) and biology, physics and chemical engineering, etc. It is even more necessary that interfaces should be established between major laboratories like the NCL and NPL. This has not happened. The so-called CSIR missions have involved different laboratories but there were no interfaces. Different aspects of a broad subject were tackled by different laboratories as part of an integrated program, which is not the same thing as a hyphenated discipline. The NCL's evolution is a good example in India of the increasing realization of the usefulness of hyphenated areas. The best inspiration for such an approach comes from a much loftier effort: understanding the universe through the combined efforts (not integrated efforts) of cosmologists and particle physicists. As a chemical engineer, I would like to draw a parallel with a two-phase reaction where the reaction occurs most effectively at the interface, or as the interface is increased, than in the individual phases.

Major Collaborations with Universities/Government Agencies

To the end of 2004, 28 collaborative programs with universities/government agencies were undertaken. The first and largest was the program with Salford University in England and that country's Overseas Development Agency. This and a few other important programs are outlined below.

THE NCL/SALFORD RESEARCH LINK — THE FIRST AND LARGEST INTERNATIONAL COLLABORATION WITH A UNIVERSITY IN THE NCL'S HISTORY

This program with Salford University and Overseas Development Agency in UK resulted in 17 graduate degrees for NCL scientists from Salford, as many as about 200 joint publications in international journals, supply of five major heat pump units from the UK, and several national and international seminars at the NCL and New Delhi. A highly talented Indian chemical engineer, S. K. Devotta, was brought by LKD to the NCL from Salford, where he received his Ph.D. under Prof. F. A. Holland, to coordinate this huge program (he subsequently joined The National Environmental Engineering Research Institute as Director in 2003).

The joint NCL/Salford research and development program in heat energy recycling was initiated after a visit by LKD to Salford in 1978 and a visit by Professor Holland, the then chairman of the Department of Chemical and Gas Engineering, University of Salford, to the NCL in January 1979. The ultimate objectives of the program were to achieve a significant reduction in primary energy consumption in industrial processes, with particular emphasis on the chemical and processing industries and to incorporate heat energy recycling systems in the design strategy for new process plants. After detailed discussions between LKD and Holland and senior officials of the British Overseas Development Administration the (ODA) in London, the agreement was signed in 1981. The entire program was to be funded by the ODA. The British Council Division of the British Deputy High Commission in Bombay coordinated the program in India on behalf of the ODA.

This program provided for the installation of UK-built heat pump equipment at the NCL, the training of scientists at Salford and periodic visits by senior staff from the NCL to Salford and vice-versa. It was intended that a group of people would be established at the NCL with sufficient expertise to design, install and successfully commission heat energy recycling systems in the Indian chemical and processing industries. Therefore, the first phase of the NCL/Salford/ODA program included the training of NCL scientists/engineers at Salford, the installation of UK-built heat pump equipment at the NCL for research and demonstration purposes, collaborative research and development on heat pumps and their applications in industry, and technology transfer to the Indian industry.

The University of Salford made a very unique arrangement. The candidates were allowed to continue their Ph.D. research at the NCL after the completion of their training at Salford. Even the oral examinations were held at the NCL.

At NCL, top priority was given to the marketing of this technology to Indian Industry. Indian industrialists had significant interest in heat-pump assisted distillation and heat-driven absorption systems. The primary reason for the interest in heat-driven absorption systems was that they did not require compressors, which were difficult to obtain. The interest amongst Indian industrialists was increased after installation of the 5th heat pump unit.

LKD from 1978 to 1989 and Mashelkar from 1989 to 1995 made considerable efforts to interest the industry in heat-pump technology. Devotta, who joined the NCL in 1984 through the efforts of LKD and Holland, frequently visited industrial organizations to discuss the advantages of heat energy recycling. These visits helped in increasing the awareness of energy conservation and recycling in the Indian industry.

A one-day workshop was held in November 1989 for senior industrialists and government officials at Delhi, where Sir David Goodall, British High Commissioner, gave the inaugural address. A major three-day workshop was also held at the NCL in the same month, which was attended by many experts from UK, Germany, Mexico and Sweden.

A great deal of new information on heat-pump technology was generated, including the properties and behavior of working fluids and lubricants. These works were published in international journals followed by a booklet listing 192 publications from the collaborative research program between the NCL and Salford up to December 1988. A ten-part series on Heat-Pump Assisted Distillation was published in the International *Journal of Energy Research*.

The NCL/Salford/ODA cooperative research program was very successful in generating large amounts of data, which can be used to design industrial and commercial size heat-pump units. It was not only the first international collaboration undertaken but also the largest and most long lasting in the history of the NCL. The success of the program owed much to the high degree of commitment on both sides. Periodic visits by LKD and senior staff from the NCL to Salford, and Holland to the NCL ensured the progress of the program. Figure 7.2 shows LKD with Holland in the midst of the heat-pumps being assembled at Salford. The British Council staff, particularly Vijay Nesargi, and some of the senior officials, including the British Deputy High Commissioners in Bombay and the First Secretaries, Richard Hardwick and Kate Bailey, took personal interest in the successful implementation of the project.

The ultimate benefits of the cooperative research, both for India and the UK, extended well beyond the program. Based on this joint research, the NCL embarked on a major research program to develop environmentally friendly working fluids and refrigerants for heat-pumps and refrigerators as a replacement for the chlorofluorocarbons which have an adverse effect on the atmospheric ozone layer.

INDO-GERMAN COLLABORATION

The NCL-Erlangen University Link

Next to the Salford link, one of the important international collaborations that the NCL had was in the field of chemical reaction engineering with Professor H. Hofmann. From the NCL, R. V. Chaudhari was the coordinator. This collaboration focused on the exchange of expertise in the field of multiphase catalytic reactors and investigations on relevant reaction engineering issues concerning analysis of complex catalytic reactions in slurry reactors and high pressure reaction engineering.

The projects were supported by Volkswagen Foundation as well as the CSIR. A program with Kernforschungsanlage Julich GMBH (KFA) was continued between 1983 and 1992. Besides exchange visits of many scientists and developing specialized equipment (video system for bubble-size distribution in liquids), a major Indo-German workshop was organized by Hofmann and Chaudhari at the NCL, in which many eminent

Figure 7.2: Doraiswamy with Professor Holland at Salford in the midst of heat pumps for delivery to the NCL

German and Indian scientists participated. This project led to many joint publications and in general helped the NCL to evolve generalized approaches for the design and scale-up of multiphase reactors.

Other German Institute Links

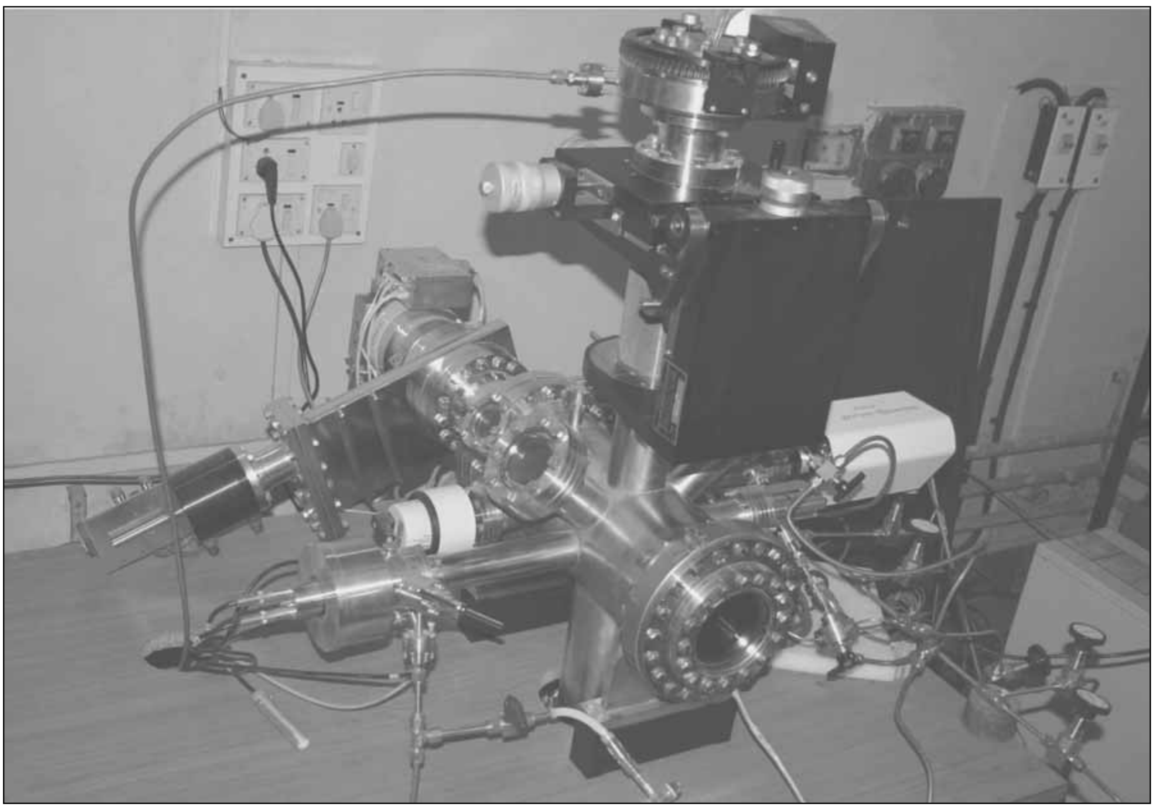
This collaboration with the Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, is an excellent illustration of how far the NCL's program on instrumentation had progressed over the years, from the days when the talented Momin started it under Finch in the laboratory next to the director's office (which in 2005 was converted into a state-of-the-art conference room by Sivaram). True, the object of the project was not to build an instrument, but it was a necessary first phase, and a very important one too. The project was funded by the Volkswagen Foundation within the Program of Partnerships, Joint research projects in the natural, engineering and economic sciences with institutes in Africa, Asia and Latin America. One such program was titled 'The mechanism and kinetics of NO reduction reactions on noble metal surfaces — from single crystal surfaces to supported catalysts.'

This involved a fundamental study of going from catalysis on a single crystal surface (the ideal catalyst) to its supported (industrial) form with all its heterogeneities and interactions. As a first step in conducting this study, a molecular beam instrument had to be constructed. This involved fabrication/procurement of a variety of sophisticated parts such as a ultra-high vacuum chamber, quadruple mass spectrometer, turbomolecular drag pump, sputter-ion gun, molecular beam doser, sample manipulator, power-thermocouple feed-through, and several more minor items, and assembling them into the final unit, which is shown in Figure 7.3. This appears to be the first unit of its kind anywhere in India. Experiments using this unit suggest that nitrogen formation occurs through a diffusion controlled mechanism.

INDO-FRENCH COLLABORATION

Composite materials based on the association of a polymer matrix (generally with cross-linking capability) and a reinforcing agent (usually inorganic but possibly also organic

Figure 7.3: A molecular beam instrument fabricated for the first time in India



as is the case with Kevlar^{R}) are considered to be exceptionally significant developments in the last 20 years, as they are able to advantageously replace conventional materials such as iron, wood, glass or concrete. However, one critical weakness of these materials is their sensitivity to external factors such as heat, light or fire, and consequently, their behavior towards aging. For a few years now, these have been competing with traditional insulators made of ceramic or glass because they are usually lighter and more impact-resistant. The new materials are usually made of epoxy/fiber glass composites covered by a varnish or a thick layer of elastomer which brings complementary properties such as outdoor protection against water, light, etc.

To develop such materials, a precise knowledge of the mechanism of their degradation is necessary and some other features of the reactions. A collaborative program with Professor Clermont-Ferrand's group in France was undertaken to resolve some of these issues. S. Ganapathy too had a very fine collaborative program on some aspects of NMR with the University of Lille.

INDO-PORTUGESE COLLABORATION

Much of the recent excitement in radiation, thermal and photo-stabilization was centered on hindered amine light stabilizers (HALS). A collaborative program with a professor in Portugal was undertaken to develop a novel approach to the design and synthesis of polymeric or polymer-bound HALS.

INDO-RUSSIAN COLLABORATION

Scientific collaboration between Russian and Indian laboratories has been a continuing activity since the 1980s, when an agreement was signed between the then USSR Academy of Science and the Department of Science and Technology as part of a larger agreement between the two countries at the highest level. One segment of this scientific agreement involved collaboration between the NCL and the Boroskov Institute of Catalysis in Novosibirsk. An agreement outlining the details of this collaboration was signed by the Director of the Institute Professor Zamariev and LKD (Figure 7.4). The agreement involved several institutions in India: the NCL, Central Salt and Marine Chemicals Research Institute, Indian Institute of Chemical Technology, Fertilizer Research Institute at Sindhri, Regional Research Laboratory in Jorhat, and Central Fuel Research Institute in Dhanbad.

The NCL was the major participant involving four well-identified projects under the leadership of Paul Ratnasamy, V. R. Choudhary, R. V. Chaudhari, and B. D. Kulkarni. A seminar was organized at Baku which was attended by all the project leaders from the NCL. Unfortunately, there were not as many joint publications as was anticipated. Several papers were published by NCL scientists in the areas selected for collaborative effort, with no involvement of the Russian scientists, such as V. R. Choudhary's papers on the activation of methane, a notoriously inert hydrocarbon available in plenty.

For a few years in the 1990s, this collaborative program was all but shelved, but soon it was revived, although not as extensively as the earlier one. A new integrated long term

Figure 7.4. Professor Zamariev, Director of the Boreskov Institute of Catalysis in Novosibirsk, and LKD signing an agreement of cooperation between that Institute and a number of institutes in India, including NCL

program (ILTP) was signed between the Academy of Science, Moscow, and the Department of Science and Technology, New Delhi, and involved several institutions in Russia and India. The NCL's program was concerned with bi-functional non-iron catalysts for low-temperature ammonia synthesis, the collaborating institute from Russia being the Boreskov Institute of Catalysis, Novosibirsk. The collaborating scientists were Halligudi from the NCL and Prof. V. A. Likholobov, Vice-Director of the Boreskov Institute in Russia.

Food for Thought?

Enough has been said in this and earlier chapters on basic research. I shall therefore end this chapter by alluding to something which is often missing in a scientist's makeup: an acquaintance with some sciences other than one's own and the arts.

I wish I could say that history is replete with instances of great scientists who were also accomplished musicians, painters, poets, or men of letters. There have been famous exceptions of course like Omar Khayyam, Leonardo da Vinci, Thomas Young, Varahamihira, Aristotle, Alexander von Humbolt, Benjamin Franklin, Francis Galton, Erasmus Darwin, and a few others. Very good but by no means in the same mold were India's Homi Bhabha of more recent times, father of India's atomic energy program, who was a connoisseur of music; and a former atomic energy chief, Raja Ramanna, who was a first-rate pianist. Abdul Kalam, the former President of India and one of India's top rocket engineers, is equally at home with music and education. Pushpa Bhargava, the first Director of the Center for Cellular and Molecular Biology, dared to face criticism from his contemporaries by providing facilities in his laboratory for artistic work. K. S. Krishnan, the first Director of the NPL, was a Tamil scholar. The NCL itself can boast of George Finch's great accomplishments as a mountain climber; scientists like V. S. Pansare, M. C. Srinivasan and G. Narasimhan who were also excellent musicians. But the great majority of our scientists cannot be accused of deviations from their scientific pursuits, even as sustained hobbies. One need not be a polymath of the order of Alexander von Humbolt, but there is much to be critical about the loneliness of a single interest, a dedicated pursuit denying itself the pleasures and advantages of a well-compounded mind. The following lines, intended perhaps to be at once a lament and a lesson, from no less a luminary than Charles Darwin should drive home the point forcefully:

> *Up to the age of thirty or beyond it, poetry such as Milton, Byron, Wordsworth, etc. gave me great delight. But now for many years I cannot endure to read a line of poetry. My mind seems to have become a kind of machine for grinding general laws out of large collections of facts. I have lost my taste for pictures and music.*[2]
>
> Charles Darwin

❄

8

REFLECTING THE CHANGING FACE OF RESEARCH

RESEARCH AREAS

Despite the popular notion that the work of the scientist is discovery — the creation of new ideas and the discovery of new facts about the universe — many of the books and articles that scientists publish are devoted to a third enterprise: the refinement of existing ideas…

John D. Barrow, *Theories of Everything*, 1991

The NCL started out with the 3rd enterprise (sometimes with no refinement either), and half way through its existence moved on, hesitantly at first and then more firmly, to the second. If the trend continues (see Chapter 18), and retiring talent of a high order is replaced by incoming talent of a higher order, ascension to category one with possibilities of major discoveries is well within its grasp.

It is important to remember that what is attempted in this book is a historical recounting of the NCL's evolution. As a result, some of the research described in this chapter will necessarily be out of date in today's context. As the narration extends all the way forward to the present, contemporary research also forms part of the chapter, as well as of Chapters 10, 11, and 12. This should unmistakably bring out the NCL's deep involvement in contemporary areas of interest using state-of-the-art tools of research.

We now come to the central feature of the NCL: its areas of research, where detail and non-detail, gene and plant, atom and reactor, laboratory and pilot plant — basic and engineering sciences in short — combine in a predictable amalgam to produce the best. A chronological recounting of the various areas of research in which the NCL was active during its almost 60 years of existence would read more like a progress report than a history. What would be more in line with the intent of this book is to list the many areas in which the NCL was active, followed by a historical (and minimally technical) narration of the important areas selected for inclusion in this book. Some of these are larger areas comprising more than one from the list. Box 8.1 gives the full list, out of which the following are described in this book.

- Theoretical chemistry, organic chemistry (including natural products chemistry, drugs and pharmaceuticals, entomology), biochemical science, plant tissue culture, bio-organic chemistry (chemical biology), catalysis, chemical reaction engineering, materials science, nanotechnology, polymer science and engineering, process design and engineering.

Box 8.1: List of areas in which the NCL has worked since 1950

Surface and colloid chemistry; thermistor bridge; electron and optical microsocopy; electron diffraction; solid state chemistry; crystal growth; x-ray diffraction; radioactive tracer technique; infrared spectroscopy; photographic emulsions; chemistry of rare earth elements; phase rule studies; inorganic analysis; natural organic products; natural coloring matters; synthetic dyes; synthetic aromatic chemicals; proteins; microbiology; biosynthetic preparation of labeled compounds; polymerization studies; solution behavior of polymers; theoretical investigations on solid state and molecular physics; materials for solid state devices; thin films; crystal and molecular structure; thermodynamic and kinetic studies; nuclear and radiation chemistry; synthetic inorganic chemistry; analytical chemistry; natural organic products; synthetic organic chemistry; physical organic chemistry; microbiology; growth of plant cells; enzymes; physico chemical studies of polymers; ion exchange resins; industrial polymers; surface coatings; industrial inorganic chemicals and catalysis; drugs pharmaceuticals and fine chemicals; perfumery and essential oils; organic intermediates, dyes and industrial chemicals; industrial polymers and related products; naturally occurring organic compounds and products; polymer resins and elastomers; chemical engineering and process development; pesticides and agro-chemicals; petrochemical and bulk organic chemicals; utilization of plant and forest resources; chemistry of biologically active compounds; utilization of mineral resources; organic metallic compounds; plant tissue culture; enzyme engineering and fermentation technology; catalysis and catalytic reaction engineering; organometallic compounds; polymer science and engineering; materials science.

Out of these areas, about 20 projects have been selected for a historical perspective in Chapters 10 and 11. The selection has been made based as much on their importance as on their ability to illustrate the modes of technology transfer adopted by the NCL and the transition of the laboratory from one to another of the four domains described in Chapter 6.

> ***Area and project***: *An area as defined here represents a long-term program involving both basic and project oriented work. A project is a well-defined goal oriented undertaking either by the laboratory on its own or in collaboration with industry.*

These definitions, schematically illustrated in Figure 6.2, have not changed significantly since first used nearly a quarter century ago; but the structure of the projects became much less defined and more flexible.

A feature of this chapter and of Chapters 10 and 11 is that the material presented tends to be somewhat technical. A completely non-technical description, it was felt, would strip the narration of much of its authenticity. But this justification is open to debate. It is perhaps more accurate to put it down to the scientific pretensions of the author and his inability to reduce technical statements to equivalent non-technical prose, particularly with respect to the section on theoretical chemistry. (It requires the understanding of a Richard Feynman to express the most complex ideas in layman's language with down-to-earth illustrations.)

There was, and continues to be, a certain degree of looseness in the relationship between division and area, which was perhaps an intentional managerial ploy. This flows over in the discussion of areas that follows.

The Main Areas

From the list of areas given in Box 8.1, the following has been selected for a brief description in this chapter: (Theoritical Chemistry, Organic Chemistry, Natural Products Chemistry, Drugs and Pharmaceuticals Chemistry — Synthetic Dyes and other Areas). Appendix to Chapter 8 at the end of Part III contains this discussion.

Mammoth Moments

> *Feynman was once asked by a Caltech faculty member to explain why spin 1/2 particles obey Fermi-Dirac statistics. He gauged his audience perfectly and said, "I'll prepare a freshman lecture on it." But a few days later he returned and said, "You know, I couldn't do it. I couldn't reduce it to the freshman level. That means we really don't understand it."*
>
> Editors of the *Feynman Lectures in Physics*

Every great research institution leaves its mark through publications in scholarly journals. Not all embellish them. Fewer still are revolutionary. Where the NCL is concerned, it is my belief that the laboratory has sporadically embellished scientific literature. It has left mammoth marks but no monumental etches, a situation equaled by some but surpassed by none in India, and the country as a whole trails the West. This is unfortunate, for the potential exists, infrastructure is no impediment, and pedigree is undeniable. I hope that soon there will be a confluence of these, and revolutionary results will begin to come.

Against this background of publications, I interacted with many outstanding scientists of the NCL to establish, from the thousands of publications those that gave the labora-tory its mammoth moments in research (See Appendix, Box 8.7).

APPENDIX TO CHAPTER 8: SOME DETAILS OF SELECTED AREAS

Theoretical Chemistry

Here let me pause — These transient facts,
These fugitive impressions,
Must be transformed by mental acts,
To permanent possessions.
Then summon up your grasp of mind,
Your fancy scientific,
Till sight and sound with thought combine,
Become of truth prolific.

James Clerk Maxwell, "Ode to the Chief Musician upon Nabla," 1882[1]

Theory was almost a bad word in the minds of many who sat on some of the most important committees of the NCL in its early years. It suggested to them a grave departure from Bhatnagar's charge to the NCL reproduced in Box 3.5. It meant channeling resources to unproductive areas of research. They and their kind, both within and outside the NCL, did not know the power of theory, how a correct theory can predict events to an incredible level of precision, how no laboratory can thrive without an element of theory in its program. I bring home this point with the following quotation from a lecture by Nobel Laureate Richard Feynman (1985), indubitably the greatest exponent of theory since Einstein:

> *Just to give you an idea of how the theory* [quantum electrodynamics] *has been put through the wringer, I'll give you some recent numbers: experiments have Dirac's number at 1.00115965221 (with an uncertainty of about 4 in the last digit); the theory puts it at 1.00115965246 (with an uncertainty of about five times as much). To give you a feeling for these numbers, it comes out something like this: If you were to measure the distance from Los Angeles to New York to this accuracy, it would be exact to the thickness of a human hair.*

So, as an understatement, good theory can be as good as useful experiment. It is to the NCL's credit that it created a flourishing school of theoretical chemistry in the laboratory, notwithstanding opposition in various degrees till the late 1970s.

Theoretical chemistry interfaces with almost all the major scientific disciplines; viz. chemistry, physics, mathematics, and computational science. This area of research has been greatly affected by the development of new theories, algorithms, and explosive growth in computer power. It is an exciting and increasingly important area of modern chemical research with tremendous academic and industrial impacts. It is further likely to have a major influence over the next 10 to 20 years on the disciplines of materials chemistry and biological chemistry, which currently are two prime research areas in chemical science.

Among the most outstanding scientists to join the NCL in its formative years were the two Sinhas, K. P. and A. P. B, the fine theoretician and the equally fine experimentalist. As K. V. remarked in his article on the occasion of the NCL's Silver Jubilee (see Chapter 17), K. P. Sinha "deserted" the NCL to seek his fortunes at the Indian Institute of Science, but A. P. B. Sinha stayed on to make some outstanding contributions. For many years, development of theory was associated with physical or inorganic chemistry. The NCL started out with strong divisional heads in each of these areas, A. B. Biswas (Truttwin was actually the first, but he soon left) and J. Gupta. For some reason, it did not flourish in inorganic chemistry. In fact, the area itself, after periods of random growth, went into near oblivion. Physical chemistry too experienced vicissitudes in its fortune, mostly because the leadership of the two divisions was never firmly in anybody's hands, except when A. P. B. Sinha did some outstanding research as Head of the Inorganic Chemistry Division. The fluctuating fortunes of the two divisions are recaptured in Box 8.2.

The era of the 70s and 80s saw a major effort worldwide in the study and understanding of interacting many-particle molecular problems. The molecular electronic structure theory was coming of age. This allowed the development of theoretical chemistry to the extent of being used by chemists as an important element in the understanding and prediction of chemical phenomena. In the early 80s, Doraiswamy took a major decision to formally initiate theoretical chemistry as an important area of research at the NCL. Thus, following the appointment of R. R. Tiwari, a highly competent theoretical chemist from TIFR, Sourav Pal, an outstanding theoretical chemist, was appointed to form and lead a group in theoretical chemistry in late 1982. Through the 80s, 90s and till the writing of this book, his group contributed significantly to the development of contemporary electronic structure theory in terms of novel formulations, computational codes, and standard tests for these. At the same time, in the 90s, the group diversified into topics like descriptions of reactivity based on density, molecular dynamics and modeling, and density functional theory. Thus, his group spanned the intellectually demanding and challenging aspects of methodological and conceptual developments with an eye to applications to chemical problems.

While talking of theory, it is pertinent to recall from Chapter 5 the fact that real break-throughs in theory (in the sense that existing theories were fully dismantled) have been very few — about half a dozen. On the

Box 8.2: The fluctuating fortunes of physical chemistry and inorganic chemistry at the NCL

Phase 1

The beginning could not have been more auspicious. The first two directors were physical chemists with huge international reputations, and the first head of the division, A. B. Biswas, had his research training under no less a luminary than Linus Pauling. Some highly talented scientists embellished the division: K. P. Sinha, A. P. B. Sinha, M. K. Gharpure, Anil Goswami, Hira Lal, S. B. Kulkarni. Inorganic chemistry under the talented J. Gupta made a good beginning too. The first few years were the best. And then it happened. Migration of talent between the divisions, no set goals in the increasingly industry-oriented approach of Tilak, and an overall sense of not being wanted in the NCL's new priorities had their own effect, and the steadiness of phase 1 began to waver.

Phase 2

Attempts in the early 1980s failed to revive inorganic chemistry, in spite of some good work under the husband-and-wife team of the Gopinaths in organometallic chemistry, J. Gupta in classical inorganic chemistry, and V. G. Neurgaonkar, D. Chakraborti, and V. V. Dadape in high temperature chemistry. Gurupada Das was brought in to strengthen the work in organometallic chemistry. Although a sound theoretician, he failed to make any difference. Physical chemistry too failed to flourish, in spite of the revived interest in water evaporation control and property measurement. The decline would have continued to near extinction had it not been for 2 important decisions around 1984.

Phase 3

Why not make a perceived weakness or irrelevance in the new environment an enduring strength — go against the wind? This was exactly what was done when Sourav Pal was brought in. Then came the change, in an unexpected surge in creativity and credibility, and the NCL soon became a renowned center of theoretical chemistry. Some of the achievements in this field are discussed under Theoretical Chemistry. Within a few years, the importance of materials chemistry, including nanotechnology, was forcefully reiterated under the leadership of a new entrant Murali Sastry.

What is even more important, catalysis was made the central edifice of the Physical Chemistry Division with Ratnasamy as the head. This was perhaps the most important step in triggering the ascent of the NCL to become a world-class technology delivering institution.

other hand, existing theories have been expanded and augmented in many original ways that have added much to our understanding of phenomena. A good part of the NCL's work on theory belongs to this category, generally referred to as "amplification:"

> *An amplification is a logical, as opposed to empirical, discovery about a theory T as a result of which p(T) — the probability assigned to T before discovery — has to be changed.*
>
> Andre Kukla, 2001

FRONTIER THEORETICAL DEVELOPMENT IN MOLECULAR ELECTRIC PROPERTIES

From the early 80s, Pal was actively engaged in developing theories of interacting many-electrons in molecules. Electrons are a very important part of molecules and the NCL's work related to the structure, spectra (spread and intensity of lines on exposure to certain types of radiation) and properties of molecules, taking into account the complex, correlated motion of electrons. Electrons repel each other, and electron correlation, which arises due to the two-particle inter-electron repulsion, was a major challenge to theoretical chemists. Any theory must hold at both the upper and lowermost limits of extrapolation. Any method which does not satisfy this requirement would give meaningless correlation energy per particle in the large particle limit and often a wrong dissociation limit at the lower end. The work involved formulations based on coupled-cluster theory (CC), which not only provided highly accurate values of correlation energies, but also led to the correct scaling property. This was based on an exponential excitation operator, acting on a so-called "model space," consisting of an important determinant or a set of determinants. The NCL group was the first to develop stationary formulations of CC theory using the linear response model, which was a great improvement over earlier theories. The codes developed by the group have potential use in the description of molecular materials with highly nonlinear (nonlinear situations are considerably more difficult to handle than linear ones) electric properties with possible applications in electronic devices.

At the next stage, the more demanding cases of open-shell systems were addressed. This creates physical problems, which are theoretically difficult to analyze. It is necessary that in this case, the theory must start from a model space of several important states. The CC description of this multi-reference model space has been generally termed as multi-reference coupled-cluster theory (MRCC). In the most significant contribution to appear from this group at the NCL, a method was formulated to compute accurate nonlinear properties based on the MRCC approach. This general-purpose formulation is the first of its kind for the MRCC method and is a significant development in quantum chemistry. However, this was essentially a non-stationary formulation and thus a stationary flavor had to be introduced for energy derivatives. In significant papers appearing from the late 90s to 2005, this problem was also addressed.

Very recently, the above formulations were used by the group to describe magnetic properties. For magnetic properties, the issue of gauge-dependence is an important one and the NCL group extended, for the first time, the treatment to the gauge-independent MRCC theory for magnetic properties.

THEORETICAL INVESTIGATION OF HARD-SOFT ACID-BASE RELATION

The qualitative principle underlying hardness and softness has attracted considerable attention in chemistry in recent years, in particular due to the role of these in the explanation of the stability and reactivity of chemical species. The principle of maximum hardness, proposed by Pearson and Parr, relating hardness to stability, has attracted much attention. In the 70s and 80s, there were qualitative verifications of the principle by different groups. The NCL group diversified its activities to include this area around 1992 and made early contributions by an extensive *ab initio* verification of the principle of maximum hardness. Their study established firmly the necessity of the constant chemical potential condition in the principle of maximum hardness. The group then took a major step towards the late 90s in working on local density-based concepts, e.g. local hardness, local softness and Fukui functions (FF). The basic local quantity is FF, defined as the change of local density with respect to the number of particles. The importance of FF in predicting reactions is that it can identify possible sites in a molecule for attack by different kinds of chemical agents (a major step in understanding chemical reactions). Parr and co-workers identified FF as important reactivity descriptors for these attacks. They proposed that the most reactive region has the highest value of FF. The NCL group proposed new reactivity descriptors, and in an important contribution proposed a method for an unambiguous rank ordering of the reactivity of atoms.

More recently, a variation of the local hard-soft-acid-base principle was developed by the same group at the NCL using the density perturbation approach to calculate interaction energies. This formulation has helped in calculating interactions between large molecular systems. A novel extension of the formulation was made to describe interactions between systems based on multiple pairs of interacting sites. Highly specific interactions in biological systems were also studied, e.g. interactions of DNA base pairs.

In collaboration with the French group in Montpellier under an Indo-French Center funded project, the NCL scientists studied reactions inside finite clusters of zeolites and structures of metal clusters as test systems. The behavior of Cu- and Na-zeolites in the presence of water molecules, i.e. change of coordination and position of Cu with respect to the framework, was explored. This is being used for several problems of interest currently.

Using *ab initio* molecular dynamics, it was recently shown that metal clusters, e.g. Al_4Na_4 and $Al_4Na_3^-$, behave as anti-aromatic. This is the first example of all metallic anti-aromatic clusters. Further, in an important work it was shown in collaboration with the group of Patrick Fowler that it is the sigma ring current which is responsible for aromaticity/anti-aromaticity in metal clusters, thus addressing the important problem of aromaticity in organic molecules.

APPLICATION TO PROBLEMS OF CHEMICAL PHYSICS

In addition, the theoretical chemistry group applied several standard quantum chemistry techniques to important problems in chemical physics. One of the application areas was catalysis, of great importance to the NCL. Using various techniques, the modeling of catalytic properties of zeolites (by energy calculations as well as the use of the concepts of hardness and softness) inter-molecular interactions between small organic and inorganic molecules were addressed. The following other applications were also studied: structure and spectra of medium-sized organic molecules by *ab initio* methods, molecular modeling of the structure and reactivity of zeolites, and a semi-em-pirical method to determine the structure and reaction of organic and organo-metallic systems.

HIGH PERFORMANCE COMPUTING

Electronic structure and dynamics codes are extremely computation-intensive. High performance computer codes were generated at the NCL in the above areas for application. In future, the plan appears to be to develop parallel codes which can be used for large-scale applications of the accurate methodologies developed over the last two decades at NCL.

And Now On to Experimental Research — Mostly

We are all aware of the Exclusion Principle in atomic structure of the great Wolfgang Pauli, the first step towards understanding chemical reactions; but how many of us know of Pauli's Second Principle (Gratzer, 1989)? It has to do with Pauli's implied lack of adroitness in the laboratory. In any case, his very proximity to it was seen as death to an experiment.[2] At the heart of research is experiment. It is the surest way to the truth. Nowhere is this fact better expressed than in Nobel Laureate Richard Feynman's exquisitely simple words, almost conversational in style and without the superficial embellishments of language that fascinate some readers (including me, I must confess) (1998):

> *An example of a test of truth, so to speak, that works in the sciences that would probably work in other fields to some extent is that if something is true, really so, if you continue observations and improve the effectiveness of observations, the effects stand out more obviously. Not less obviously. That is, if there is something really there, and you can't see good because the glass is foggy, and you polish the glass and look clearer, then it is more obvious that it is there, not less.*
>
> Feynman, 1998

With this introduction to experimental research at the NCL, I move on to organic chemistry, with no implication that B. D. Kulkarni or Sourav Pal (perhaps the best theoreticians of the NCL) had anything to do with some of the accidents that occurred in the laboratory (see endnote 2)!

Organic Chemistry

Take carbon for example then
What shapely towers it constructs
To house the hopes of men!
What symbols it creates
For power and beauty in the world
Of patterned ring and hexagon
Building ten thousand things
Of earth and air and water

C. P. Snow, *Atomic Architecture*, 1967

The Division of Organic Chemistry took shape under the leadership of R. C. Shah. Later, a few years after S. C. Bhattacharya joined the NCL in the early 1950s, a Division of Essential Oils was created by Venkataraman, who had taken over as Director in 1957. Sukh Dev joined the NCL in 1959 and took charge as head of the Organic Chemistry Division from R. C. Shah, who had been elevated to the position of Deputy Director (they were the days when there was only one deputy director, the second in command to the director, as against eight in 2005). With three brilliant chemists leading organic chemistry research, the NCL became the mecca of the country in this area and remained so for a number of years. With the retirement of KV and the departure of Bhattacharyya in quick succession in the mid-1960s (it is unfortunate there was no love lost between them), the reputation of the NCL's organic chemistry suffered in spite of the valiant effort of Sukh Dev. Tilak, who joined the NCL as Additional Director in 1965 and became director in 1966, was also a reputed organic chemist, but he left his mark on the NCL not for his basic research but for the industrial orientation he brought to the laboratory that ushered in a new era. R. B. Mitra came to the NCL from the industry to take charge of the Essential Oils Division. As he was brought by Tilak to bolster industrially-oriented synthetic organic chemistry, the division was renamned as Division of Synthetic Organic Chemistry, and the main division led by Sukh Dev, by no particular fiat, acquired the name Division of Natural Products Chemistry. Then, when Sukh Dev left in 1974 to take on the leadership of an industrial research center (Maltichem Laboratories), the NCL's organic chemistry literally nose dived. It took five years to revive and when it came back, it was once more near the top. This was largely due to the efforts of one individual, A. V. Rama Rao, but with a difference. While the NCL's earlier fame rested largely on its basic research, Rama Rao combined basic and applied research in a manner no other organic chemist in India had done before him. Since Rama Rao's research covered both synthetic and natural products chemistry, LKD renamed the two divisions as Organic Chemistry 1 and 2.

When Rama Rao left the NCL to become Director of IICT, many were quick to predict a 2nd period of draught in organic chemistry research at the NCL. N. R. Ayyangar, who succeeded Rama Rao, proved all these prophets of collapse wrong, and good work continued to come from his division. But Organic Chemistry 2, led by Mitra, was too fully involved in applied pesticides research to add to Ayyangar's efforts to maintain a decent level of research. The retirement of Ayyangar in 1990, and directors Mashelkar, Ratnasamy and Sivaram's desire to take the NCL's organic chemistry into the free market era, brought in a significant change in the programs of the two divisions. Organic Chemistry 1 was renamed Organic Chemistry (Technology) and placed under M. K. Gurjar, who has attracted considerable funding from big industrial houses both within and outside India. He continued Rama Rao's emphasis on pharmaceutical chemistry but the NCL's once dominant interest in the chemistry of pesticides all but disappeared. Organic Chemistry 2 was renamed Organic Chemistry (Synthesis) and placed under the charge of K. N. Ganesh, a bioorganic chemist, marking a significant departure from conventional organic chemistry. It also brought a part of the NCL's organic chemistry in line with its modern biological version.

Clearly, the scope of organic chemistry research as well as its quality underwent repeated changes. Through all these changes that must have been disheartening to the rank and file of workers, organic chemistry in the NCL never lost its preeminent position as a coherent discipline. In spite of migrations at the divisional head level, the senior and middle levels stayed solid and carried the day. Mention must be made of the excellent contributions of K. K. Chakravarti, C. R. Narayanan, J. L. Bose, Madhavan Nair (who helped interpret NMR data), P. K. Bhattacharya (who was actually a biochemist), K. G. Das (who helped interpret mass spectrocopic data), S. N. Kulkarni, A. S. Rao, S. C. Sethi, H. H. Mathur, U. R. Nayak, A. S. Gupta, B. A. Nagsampagi, T. Ravindranathan (who later became a divisional head), G. R. Kelkar, G. H. Kulkarni, D. D. Nanavati, S. A. Patwardhan, S. Gogte, G. T. Panse, and V. S. Pansare (who was in charge of microanalysis). Many more younger scientists, mainly J. D. Yadav and M. K. Gurjar, were also involved in later years.

Work in the Organic Chemistry Division covered several aspects of the subject: natural products, synthesis (mostly in the areas of drugs and pharmaceuticals and dyes and dye intermediates), new laboratory techniques, and development of industrially viable processes for certain commercially valuable organic compounds. The main thrust in the earlier years (1955–1980) was in the area of natural products chemistry, with emphasis on commercially important raw materials of the country, and on essential oils. These investigations not only prepared the ground for more sophisticated uses of these materials, but also resulted in major contributions to certain areas of secondary metabolites chemistry. A brief review of these studies is presented in the following section.

NATURAL PRODUCTS CHEMISTRY

> *In the Quarterly Journal of the Indian Chemical Society, which is now in its 4th year, I have only been able to find 9 papers which deal with the chemistry of natural products. Is it presumptuous to suggest to the organic chemists of India that they should study intensively the unique wealth of material which lies at their door, and devote less time to the study of problems of theoretic interest only?*
>
> J. L. Simonsen, Presidential address to the Indian Science Congress, 1928

Chemical investigations of natural materials have played a pivotal role in the development of organic chemistry. Hence it is not surprising that study of these materials (plants, animals, microflora) has held much fascination for the practicing chemist the world over. As noted in Chapter 1, the ancient Indians set great store by the use of plants for medicinal purposes. The art of Ayurveda was largely based on finding herbal remedies for a variety of diseases. The Indian organic chemists of more recent times have also been engaged, but in a more scientific way, in finding herbal remedies by identifying and isolating the plant principles responsible for the cures. Extensive volumes of literature listing all available medicinal plants are available. Simonsen of the Indian Institute of Science, in his presidential address to the Indian Science Congress (1928), was among the first modern scientists to suggest a detailed study of Indian flora to identify medicinal plants and isolating the active principles from them.

Research in organic chemistry in general, and natural products chemistry in particular, was the NCL's forte right since its inception. In fact, for many, the laboratory and organic chemistry were synonomous, even though, thanks mainly to McBain, Finch, the Sinhas (K. P. and A. P. B.), and Biswas, physical chemistry too was regarded as a major strength of the NCL; and so was biochemistry, thanks to V. Jagannathan (a true scholar), M. Damodharan and C. SivaRaman. But organic chemistry was unique. It was consistently strong except for a few years immediately following Sukh Dev's departure in the mid-1970s.

The two Phases of Organic Chemistry Research at the NCL

In natural products chemistry, the period starting from around 1950 proved highly productive, mostly because of the almost simultaneous development of newer spectroscopic methods of structure determination and induction of newer separation techniques. I would call this the first phase of 20th century research in organic chemistry at the NCL. Later, when the number of products to be identified and the properties against which they had to be characterized increased almost boundlessly, the need arose for a quicker assessment of their properties, which involved preparation and separation of compounds at rates unimaginable in the existing setup of the time. This led to a more sophisticated second phase in the identification/separation/

development of biologically active compounds, either from natural or synthetic sources. The NCL was quick to recognize and introduce this speed- and number-oriented methodology of research in its programs. It is against this backdrop that the NCL's work in organic chemistry will be reviewed. The first phase was led by KV, SCB, and (mostly) Sukh Dev. The second came under Ratnasamy and Sivaram, and was made fully operational by Gurjar and his colleagues. Rama Rao straddled the two phases, before his departure for the IICT. The two phases of evolution of organic chemistry at the NCL are summarized in Box 8.3. Phase 1 is briefly described below, while phase 2, which was pursued vigorously since around 1990, is described later in this Appendix in a separate section.

The raw materials for phase 1 were the trees, plants, shrubs, grasses, and other growths of the floral kingdom. The major findings for a few important items are discussed below as raw material-wise findings, emphasizing why a project was undertaken and what results of scientific and/or applied value resulted. The description is much briefer for other representative items. A particularly important feature of these studies was that they led to some new scientific insights.

Some Major Raw Material-wise Findings

***Pinus roxburghii* Sarg.** This tree is the commercial source for Indian turpentine oil. Unlike most other commercial turpentines which are rich in pinenes (> 90%), the major hydrocarbon in the Indian turpentine is carene (55–65%), and pinenes are present only to the extent of 25–30%; it also contains a significant percentage (6–10%) of the sesquiterpene, longifolene. It is obvious that to utilize this raw material efficiently, basic chemical information about these products would be required. Though the chemistry of carene had been fairly well worked out by then, much remained to be done to unravel the chemistry of longifolene.

Detailed investigations on the chemistry of longifolene and its isomerization product, isolongifolene, were carried out at the NCL. These studies generated significant knowledge of both scientific and applied interest. It will suffice to mention here that both longifolene and isolongifolene were converted into several aroma chemicals, of which acetyl longifolene and isolongifolanones were well received commercially and are being manufactured not only in India but also in countries abroad.

***Cedrus deodara* Loud.** This tree, the Himalayan cedar, is the source of an important Indian timber. Besides this, it has several medicinal attributes, and preparations based on this are considered useful for the treatment of cough, bronchitis, and skin diseases among others. An oil obtained from the wood is used in villages for treating insect infestation on cattle.

Lumbering operations, as well as further working of the timber for end uses, generate large quantities of waste, from which an essential oil, Indian cedar wood oil, is obtained. Practically nothing was known about its chemistry when work in the Division was initiated in 1960. These investigations led not only to complete

Box 8.3: The two broad phases in the evolution of organic chemistry research at the NCL

Phase 1	Phase 2
Traditional organic chemistry, with increasing use of emerging synthetic and analytical tools, mostly newer spectroscopic methods. Work was divided into two divisions with hazy boundaries, one called Essential Oils and the other Organic Chemistry. At one time both were heavily focused on natural products chemistry. The proportion of natural products research in the divisions changed over the years, till in the 1980s, ironically, there was hardly any natural products research in the Essential Oils Division (which became involved almost full-time in synthetic pesticides research).	Starting from the mid-1980s, propelled largely by changes in Indian patent laws, discovery oriented research commanded increasing attention. New molecules, natural or synthetic, became the new thrill, indeed the new necessity. This situation called for quick isolation/synthesis/separation of an endless series of compounds. Thus began the second phase of organic chemistry research at the NCL, involving combinatorial chemistry and other related areas, which brought the laboratory abreast of the best in the world.

characterization of its constituents (almost all of these were new compounds), but also to the identification of pharmacologically active components. The two Himachalenes (~50% of the essential oil) were identified as the anti-mange compounds. A commercial preparation (Flematic[R]) based on this finding is being marketed in India as a broad spectrum agent against various types of ectoparasites commonly affecting animals. Himachalol, another constituent of the essential oil, was shown to possess potent spasmolytic activity.

***Psoralea corylifolia* Linn.** This is an erect annual, found almost throughout India. Its seed powder is highly valued in Ayurveda for the treatment of vitiligo, psoriasis, and inflammatory diseases of the skin. Though the compounds responsible for its antivitligo activity had been characterized in the middle 1930s, work was undertaken in the Division with a view to characterizing the antibacterial constituents.

It was reported in 1964 that a crude fraction from the petroleum extract of *P. corylifolia* seeds exhibited potent antibacterial (*in vitro*) action against *Staphylococcus aureus* and was found to be more powerful than the commonly used antibiotic chloramphenicol. Work carried out at the NCL led to the isolation of the active principle, and was named bakuchiol. Since its discovery in 1966, bakuchiol has been demonstrated to have a variety of biological activities such as anti-microbial (anti-bacterial, anti-fungal), anti-acne, anti-psoriatic, cytotoxicity; it also exhibits mild CNS (central nervous system) activity and insect juvenile hormone activity. Bakuchiol has since been recognized as a potent anti-microbial agent against a range of bacteria both gram-negative (*Porphyromonas gingivalis*), and gram-positive (*Streptococcus mutans*, *Enterococcus faecalis*, *Lactobacillus acidophilus*, *Actinomyces viscosus*, etc.).

***Ailanthus malabarica* DC.** This is a large tree habitating the evergreen forests of Western Ghats. When incisions are made in the bark, an off-white colored, treacle-like gum resin oozes out. This resin, called *mattipal* in the local language, is highly valued by *agarbatti* (incense stick) manufactures, as it emits a pleasant aroma on burning. Work on this material was undertaken in the Division to understand the chemistry of the raw material.

The investigations led to the discovery of a new class of triterpenoids, designated malabaricanes, and represented by the major constituent malabaricol. The scientific import of this discovery is highlighted in a later subsection. Pyrolytic fragmentation of malabaricol into odorous components may be responsible for aroma generation in the burning of *agarbattis*.

Iphigenia spp. Colchicine is widely used in the treatment of gout and in plant breeding (to produce polyploids). Commercially, it is obtained by extraction from seeds of Colchicum autumnale Linn., which contain 0.3–0.5% colchicine. This plant does not grow in India. Following up on a report that a certain species of *Iphigenia* contains colchicine, several species of *Iphigenia*, indigenous to India and growing around Pune were screened in collaboration with the Botanical Survey of India. *I. stellata* seeds were found to be exceptionally rich (1.2–1.9%) in colchicine. This material is now being commercially exploited for the extraction of colchicine.

***Commiphora wightii* (Arnott.) Bhandari** This is a small tree, endemic in certain arid zones of India. On incision of the bark, the plant exudes a yellowish gum-resin which quickly solidifies to an agglomerate of tears or stalactitic pieces of reddish yellow or brown color with a balsamic odor. This material, the *guggul* of commerce, is greatly valued medicinally in Ayurveda, especially for treatment of rheumatoid arthritis, obesity and allied disorders. 44 Ayurvedic compound preparations contain this gum-resin as an important component. These claims appeared to be vindicated by several pharmacological investigations carried out during 1960–1970.

At the instance of C. Dwarkanath, the then adviser to the Health Ministry, Government of India, work was undertaken in collaboration with the CDRI, Lucknow, to identify the active constituents of the resin. Chemical investigations were entrusted to the NCL, while the biological screening was carried out at the CDRI. Chemical studies showed the resin to be a complex mixture of diterpenoids, triterpenoids, steroids, lignands, fatty tetrol esters, etc. Surprisingly, the resin part was found to be an exceptionally rich source of steroids (~4%), and more than 10 compounds were identified. Of these, *Z*-guggulsterone and *E*-guggulsterone were recognized as the constituents with hypocholesterolaemic (cholesterol lowering) and hypolipidaemic (lipid controlling) activity. Further investigations revealed that other constituents of the *guggul* resin appear to exert a synergistic activity, leading to the development of a useful therapeutic agent for hypercholesterolaemia. Related studies were carried out at the CDRI on a standardized ethyl acetate extract of *guggul* containing at least 4% guggulsterone. The NCL provided this standardized extract for the studies. Eventually, this product, trade-named *gugulipid*, was approved for marketing in 1986, and is being manufactured and sold by CIPLA both in India and abroad.

In recent years, guggulsterones have attracted significant international attention, especially with respect to their mode of action.

Phomopsis paspalli Kodo millet (*Paspalum scrobiculatum* Linn.; Sanskrit, *kodrava*) is a minor grain crop, which has been grown in India since ancient times, particularly in coastal areas. This has often been reported to cause poisoning in man and animals. The chief symptoms of kodrava poisoning are unconsciousness, delirium with violent tremors of the voluntary muscles, vomiting and difficulty in swallowing.

In collaboration with the Indian Drugs Research Association (IDRA), Pune work was started with a view to identifying the toxic constituents of this crop. It had been known earlier that the toxic principle resides in the outer coat of the grain, and a fungus is believed to be involved. Later work at the IDRA showed that the predominant fungus belonged to the genus *Phomopsis* and was designated *Phomopsis paspalli.*

This fungus was cultured on a synthetic medium, and a suitable extract, which showed symptoms typical of kodrava poisoning in dogs, was supplied by the IRDA to the NCL. Work in the division led to the isolation of two compounds responsible for the toxicity. The compounds were structurally characterized and were found to be new members of a group of compounds called cytochalasins, which were first discovered in 1966 as metabolites of certain molds. The new compounds were named kodo-cytochalasin-1 and kodo-cytochalasin-2. Both were highly toxic in mice.

It may be noted that cytochalasins are used as a research tools in biology (cytological studies and characterization of polymerisation properties of actin).

Lac The tiny insect *Laccifer lacca* Kerr. completes its life-cycle on a host tree, and during this cycle elaborates a resin, known as lac. This product has been known in India since ancient times, and finds several applications. Lac is a versatile resin and has considerable commercial importance even now. India continues to be the principal producer.

Research on this material was initiated at the NCL in 1962 at the behest of the Lac Research Institute, Ranchi. Though considerable work on this product had been carried out earlier, there was a distinct need to unravel the nature of the lac resin, so that this information could be utilized to work out more sophisticated uses for the product.

Detailed investigations were carried out on the building blocks and nature of soft and hard resins of lac. Jalaric acid known earlier was obtained pure for the first time and its structure established. Structures of five new acids (laksholic acid, epilaksholic acid, laccishellolic acid, epilaccishellolic acid, and laccijalaric acid) were elucidated. Pure hard resin was obtained for the first time. Based on detailed studies of the building blocks of the resin, its structure was established.

Essential Oils, Perfumery Chemicals, Flavones, Dyes, Carbohydrates, Neem, etc.

Essential oils Among the top essential oils of the world are eucalyptus, rose geranium, peppermint, lemon grass, tea tree, sandalwood, rosemary, jasmine, lavender, and cinnamon. S. C. Bhattacharya, assisted by his students led by K. K. Chakravarti, and by G. R. Kelkar, A. S. Rao, B. A. Nagsampagi, and G. H. Kulkarni, established a world re-nowned school of research in essential oils by chemically examining essential oil bearing plants, the oils such as dill, cubeb, Malabar lemon grass, spearmint, citronella, palmarosoa, sandalwood, wild ginger, terpentine, cyperus, valerian, vetiver, costus root, *Nardostachys jatamansi*, Agar wood and *Sassurea lappa*. Many interesting compounds belonging to the structural groups, sesquiterpenoids, sesquiterpene lactones and triterpenes, were isolated and characterized. Vetiver, costus root and *sassurea lappa* were studied in great detail and found to be rich sources of sesquiterpenoids. The group also developed processes that were commercialized. Among them were: a process for â ionone starting from citral (lemon grass oil), released to Industrial Perfumes, a Tata concern; and another for the manufacture of phenethyl alcohol (rose odor), released to Sunanda Agarbatti Co.

> **Perfumery chemicals** *A compounded perfumery composition comprising component A and component B, component B being from 0.1 to 95% by weight based on the weight of said compounded perfumery composition. Component B comprises at least one compound of the formula wherein R is at least one group selected from methyl, ethyl, propyl, iso-propyl, n-butyl, sec-butyl, tert-butyl, pentyl or hexyl.*
>
> US patent 3963648, 1959
> See Steffen Arctander, 1960

Starting from naturally occurring compounds, commercial processes for perfumery chemicals, namely civetone, exaltone, dihydro jasmone, isoambrettolide and dihydroambrettolide were developed by S. C. Bhattacharya and his co-workers.[3]

Flavonoids, wood phenolics, and plant pigments KV and his group carried out considerable research in this area, which was later continued by Rama Rao. The plant species examined were *Artocarpus, Gardenia, Garcinia, Morus, Taxus, Pinus and Maclura* to isolate a large number of plant phenolics, of which isocycloheterophyllin, cycloheterophyllin, rubroflavone A, B, C, D, scanthochymol, albanol A, B, isoxanthocymol, morellic acid, morellin and deaxymorellin possessed novel skeletons. P. M. Nair, an expert in NMR spectroscopy, contributed a great deal to the interpretation of NMR results of many compounds of this class of plant phenolics.

Work on the isolation of the active allergen from *parthenium hysterophorus*, bioactive principles from marine algae and gorgonians and plant growth regulators from pollen grain of various crops was initiated by Nagasampagi's group. Parthenin was identified as the allergen causing contact dermatitis in sensitive human beings. Later on, in the late 70s, an ambitious project entitled "Pest control agents from plants" was taken up by three groups led by A. S. Gupta, D. D. Nanavati and B. A. Nagasampagi. About 350 plant extracts were screened for insect control activity, and neem extract was found to exhibit oviposition deterrent activity in potato tuber moth. Nagasampagi and his co-workers pursued the work on neem seed extract to develop commercially viable processes for two products namely *Neemrich*-I and *Neemrich*-II representing the active rich fractions (see under Entomology). Stable formulations were made and extensive field trials were conducted on major crops at various agricultural extension centers (see also under UNDP project in Chapter 10). After generating the efficacy and toxicological data, registration for both the products was obtained from Central Insecticide Board, Faridabad. Four Indian and five American patents were filed (one process and four product) and the technology was released to four Indian parties for commercialization. SWOT analysis and cost evaluation were carried out. During the course of the screening program and the development of neem products, a number of sesquiterpenoids, diterpenoids, triterpenoids, flavonolids, plant phenolics, and sterols were isolated. Several bioactive azadirachtin derivatives, fatty acids, and sterol glucosides were also isolated from neem extracts.

Synthetic pest control agents Δ^3-Carene, a monoterpene, is one of the major constituents of pine oil which forms the starting material for the synthetic analogues of a class of pest control agents called pyrethroids. Good chemical processes for synthetic pyrethroids were developed by groups led by R. B. Mitra and G. H. Kulkarni. Similarly, starting from the naturally occurring geraniol and citronellol, many synthetic insect juvenile hormone analogues were prepared for commercialization by S. A. Patwardhan and co-workers.

Naturally occurring colorants For centuries now, naturally occurring coloring compounds have been used to provide color to clothing and other materials used by humans. Cultures dating back to Mesopotamia have been known to use natural colors, and ancient Indians were perhaps the first to use indigo (principle indigotin) to provide an attractive hue of blue to clothing. The NCL was perhaps the first post-independence laboratory to work on natural dyes. An example is a process developed for the isolation of enocyanins (anthocyanins), non-toxic food colorants from pomace (grape skin), by Nagasampagi and his group.

Carbohydrates A small group led by J. L. Bose and T. R. Ingle isolated and characterized disaccharides and hemicelluloses from some plants. After a gap of many years, M. K. Gurjar's group utilized various sugar molecules in the synthesis of antibiotics and anti-cancer compounds such as etoposide and teniposide (see under Drugs and Pharmaceuticals).

Constituents of neem The neem tree has held a great fascination for Indian chemists since ancient times. More recently, some western sources claimed to have discovered the curative properties of neem, known to Indians for centuries, and even sought, unsuccessfully as it turned out, patent protection for this discovery.[4] Nearer the present period, Nimbin, the major bitter principle of neem oil, was isolated in 1942 by Siddiqui (who was to become the first director of the NCL, but did not accept the post). Its structure was established by C. R. Narayanan and co-workers at the NCL in 1964. Vepinin, deacetylnimbin, nimbinin, a hexacyclic tetranortriterpenoid, and vilasinin (named after Narayanan's wife) were the other constituents of neem oil isolated by this group. The same group also isolated triterpenoids and steroids from Kurchi bark.

New Chemical Structures Proposed by NCL Scientists

A particularly important aspect of research in organic chemistry is structure determination of known entities that have eluded discovery for various reasons, and the discovery of new molecules and assignment of structures to them. Interesting tales can be cited concerning some of these discoveries, but as far as the NCL is concerned, no such tales have come to light.[5] I am therefore restricted to a prosaic statement of these discoveries covering over 50 years of the laboratory's existence. The sheer numbers as well as the stature of journals in which the structures were published are evidence of the general quality of research in organic chemistry at the NCL. Keeping in mind the fact that some of these discoveries were truly outstanding, the reputation enjoyed by the NCL in this area is brought home in no uncertain terms. Even though many of these structures reflect original work of a high order, the numbers are too vast to justify even a brief discussion here. The following bare facts tell their own story:

TOTAL NUMBER OF STRUCTURES DETERMINED: 210

NAMES OF JOURNALS IN WHICH MANY WERE ANNOUNCED:
Tertrahedron, *Tetrahedron Letters*, *Journal of Organic Chemistry*, *Indian Journal of Chemistry*, *Journal of Scientific and Industrial Research* (over 80% in the first 2)

Plant-based drugs A process was developed by Rama Rao and co-workers for the production of vinblastine and vincristine from leaves of *Catharanthus roseus*, two anti-cancer drugs and the process was released to CIPLA (see Chapter 10). Later on, Nagasampagi and his group developed a simpler process for vinblastine and the technology was released to two Indian parties for commercialization.

Processes for the isolation of both immunostimulant and immunosuppressant fractions were developed from two well known Ayurvedic plants, *Ashwagandha* and *Shatavar*i, by the group led by Nagasampagi. The same group also screened, in collaboration with Sunderland University in UK, a number of pure naturally occurring compounds for anti-malarial activity and obtained some valuable leads.

International consultancy assignment The natural products group of the NCL led by B. A. Nagasampagi was awarded a four-year consultancy assignment (1998–2001) for the better utilization of Indonesian natural resources (essential oils, rosin and natural dyes) by the Indonesian government (see Chapter 7).

DRUGS AND PHARMACEUTICALS CHEMISTRY

An epidemic of influenza that swept the globe in 1918 killed from 20 million to 50 million people — 2 to 5 times more deaths than were caused by World War I (1914–1918).

Hill 2001

Health for all by 2000 was accepted as a national policy of the Government of India and the availability of drugs in the required quantities was obviously a major part of this. In view of the projected increase in the country's population resulting in a several-fold increase in the demand for drugs, the capacity for drug production was sought to be geared for corresponding increase.

The R & D effort in the developed countries is usually aimed at discovering new drugs. Clinical evaluation of new drugs is the ultimate test of their efficacy and side effects. The expenses involved in discovering a new drug generally exceed $20 million, and if the cost of failures is apportioned to the successful drugs, the total expenditure in developing a single new drug may exceed $40 million. Further, the time taken for the development of a new drug is 7–10 years or even longer. For these reasons, drug research in India was mainly confined to process innovation for well-identified drugs discovered elsewhere. The liberalized patent law of 1970, referred to earlier, made this legally possible, although questions remained at an international level.

Realizing the vital role of organic chemistry in the synthesis of drugs, emphasis was laid in the NCL on the development of technologies for various basic drugs using new innovative routes. Drug research at the NCL covered a number of classes of drugs:

- Anti-tumor agents
- Anti-infective agents includings required for tropical diseases
- Analgesics and anti-inflammatory agents
- Vitamins
- Cardiovascular drugs
- Anti-depressants
- Semi-synthetic penicillins and cephalosporins
- Drug intermediates

The Early Years

The initial emphasis was on drugs for cancer. Cancer is not a single disease but rather the name for a large group of diseases characterized by uncontrolled growth of abnormal cells. There is no single drug that can combat all forms of this disease. No one form of cancer creates enough demand for drug(s) for treating it to justify the expensive research and development required for develping the drug(s). For this reason, much of the R & D effort in cancer chemotherapy has been confined the world over to government laboratories and government aided institutions. Radiation therapy and surgery have been the most effective form of treatment. However, in recent years, drug therapy has been in the frontline of cancer treatment. Most anti-cancer agents were imported at an exorbitant cost. For this reason, the NCL undertook an ambitious program of research on anti-cancer drugs. These therapeutic agents included plant products as well as antibiotics.

Among the various anti-tumor agents in use, natural products seemed to show greater specificity than synthetically derived products. Vinblastine and vinchristine among the plant products and daunomycin and adriamycin among the antibiotics showed considerable usefulness in combating various types of cancer. A description of the NCL's success in isolating vinblastine and vinchristine and their successful production by CIPLA is deferred to Chapter 10.

The usefulness of anthracycline antibiotics such as daunomycin and adriamycin as anti-cancer agents was accepted for quite some time. Adriamycin was regarded as the most effective single agent among all anti-cancer tumors known a few years ago, but these anthracycline drugs are also not free from side-effects (cumulative dose dependant cardiotoxicity). They were all made by microbiological fermentation, and the yields were low. Further, it was shown that introducing a small structural change in the molecules probably resulted in a compound with superior therapeutic properties. For this reason, there was continued interest in achieving the total synthesis of these molecules and one of its analogues. The NCL also entered the fray but success was only partial. No viable process could be developed. The laboratory also undertook research on another newly introduced anti-cancer agent Fredericamycin-A produced by Streptomyces griseus. Here again no viable technology could be developed.

On the other hand, the NCL's work on anti-inflammatory drugs such as ibuprofen was highly successful, and a process was passed on to CIPLA for commercial production. A process was also developed for vitamin B6, and in view of its highly successful production by Lupin Laboratories, it is described in Chapter 11.

The Later Years

The new Indian patent laws of 1970 created a boom in the chemical industry in general and the pharmaceutical industry in particular. Under these laws (see Chapter 4), product patent was forbidden while process patent was allowed for a period of seven years. The pharmaceutical industry in India was now able to introduce drugs in the Indian market in spite of the fact that they were under product patent protection in Europe and USA. The only criterion was that the process to make these drugs should be different. This was not an issue because by the time the product was launched in India, the period of seven years would already have passed in many cases, but more importantly many patented processes used for manufacturing drugs by Indian companies were ignored.

During the early 70s, the R & D centers of a large number of Indian companies were at a near-primitive stage with poor infrastructure, no skilled manpower, and insignificant analytical facilities. Therefore, these companies had no choice but to seek assistance from national laboratories such as the NCL, which were far more advanced in these respects. A. V. Rama Rao, then Head of Organic Chemistry Division, had a personal rapport with many pharmaceutical companies and was able to impress upon many of them the desirability of sponsoring process development work for drug molecules which were introduced in the USA and Europe but not available in India. The concept was clear: The company would identify the drug for development, the chemistry was done at the NCL on the laboratory scale followed by demonstration, and the company would scale up the process and introduce the product in the market. This strategy worked very well till the early 1990s. It had its own disadvantage in that innovation in process research usually took the back seat and repetition of already published work was the prime procedure, although less glaringly than in the earlier years. This was exemplified by the fact that hardly any patent application was filed by the NCL during this period. However, many drug molecules like salbutamol, vincristine, vinblastine, vitamin B6, chloramphinicol, chloquine, ranitidine, ibuprofen, trimethoprim, sulfamethaxazole, albendazole, etc were introduced at significantly lower prices. The processes for some of them were innovative (i.e. for vitamin B6) but a lack of patent consciousness of those years saw none of these processes patented. Many Indian companies such as CIPLA, Lupin, Ranbaxy, Centaur, Sudarshan, etc. were greatly benefited.

In the meantime, R & D labs of companies also improved their infrastructure and many drugs were developed in-house. The overall impact of this was indicated by the fact that the share of the Indian pharma companies in the country improved from 15% in 1970s to 85% in the 1990s. The credit for this spectacular increase in the sale of drugs by Indian companies went to NCL for pioneering this idea. In turn, the laboratory was benefited by way of enhanced external cash flow under sponsorship by the pharma companies. During the early 1990s, when the economy of the country opened up, Indian industries started looking into the regulated markets of Europe and USA for export of bulk drugs and their formulations. Since labor was cheap, the processes were optimized to bring down the prices and it was possible to export drugs at much lower prices. The government also provided considerable incentives for export of drugs.

Soon, however, this strategy began to fail when it came to the export of drugs. Therefore, the Indian companies began to explore innovation in process development, particularly for generic drugs. It is pertinent to mention here that in any multinational company the process patent for a particular drug is filed after 5–7 years from the date of product patent. This means that the process patent is applicable even if the product is off patent at least for 5–7 years. This new scenario put the NCL in a situation charged with possibilities. For example, if a company decided to manufacture a generic drug in a regulated market, it had to manufacture the drug using a non-infringing route, and simple reverse engineering ceased to be an option. The Indian drug industry started looking towards the NCL for developing non-infringing processes for generic drugs. The laboratory had the distinct advantage that it carried out high-class basic research and the knowledge from this could be applied to process development with a high degree of innovation. Drugs developed thus by non-infringing routes could be exported to regulated markets. Hence the NCL modified its approach in the mid-1990s and went forward from reverse engineering to innovation in process research. Many products were developed since 1995 based on NCL technology, e.g. amlodipine, cetirizine, ciprofloxacin, prostaglandins, nevirapine, abacavir, irinotecan, pioglitazone, dorzolamide, cialis, etc.

Drug Discovery at the NCL

With free market conditions in full bloom by the late 1990s, the NCL's strategy in drug research changed considerably. Discovery of new drugs emerged from the sidelines and was openly advocated. Thus in 1998, the laboratory embarked on a concerted attempt to develop molecules with specific structures (the so-called chiral drugs) instead of following the old route of preparing mixtures (racemates) of different structures (enantiomers) and isolating the molecule of the required structure from it. Many chiral versions of racemic drugs were developed and later commercialized by Emcure pharmaceuticals. For example, S-amlodipine besylate was for the first time introduced in the world, and became a blockbuster drug for the company. In addition, chiral drugs such as S-pantoprazole, R-ondasetron, S-atenolol, S-metoprolol, etc. were also introduced for the first time.

In 1995, India signed the WTO and TRIPS agreements under which both process and product patents were protected for a period of 20 years. However, India received a grace period of 10 years to implement these agreements. Thus any product which was patented before 1995 was allowed to be introduced in the country. Products patented after 1995 would not be marketed. Realizing the reality of the opportunities offered by the new patent law, a few companies began in the mid-1990s to establish new drug discovery programs. Some laboratories such as Ranbaxy, Lupin, Wockhardt, Dr. Reddy's, Dabur, Alembic, FDC, Nicholas Piramal, Glenmark, etc. initiated new discovery programs so that they could develop new drugs that would be globally competitive. Many of these companies evinced keen interest in collaborating with the NCL in this exciting new effort.

In drug discovery, a large number of molecules are synthesized, screened, and the promising ones are taken up for further development. Since the NCL biology group is not in the human health area, it could collaborate with the industry only in matters of synthesis. Being outstanding in synthetic organic chemistry and possessing a combinatorial chemistry laboratory together with natural products fractionation facility (see Chapter 5), the NCL started collaborating with major companies by providing a large number of molecules for screening. The natural products group, synthesis groups, and combinations of these became active collaborators. New structures were isolated from natural products and new chromophores were synthesized. All this brought a sense of excitement to organic chemists that was lacking for some years. Several new patents were filed, and many molecules synthesized at the NCL were identified as lead molecules by the industry. For reasons of confidentiality, these molecules could not (and should not) be revealed by the laboratory.

In order to become a drug discovery laboratory, the NCL needed to establish a sound screening facility, animal house, toxicology, microbiology and pharmacology laboratories. Although it had been doing throughput screening, it lacked in assays suitable for HTS. The lack of the latter facility was realized by earlier directors, but they took a conscious decision not to expand along these lines since they felt that these were outside the scope of the NCL. But following liberalization, times changed and it became necessary to reverse this decision, which is what Sivaram did. While this book was being written, the NCL had almost completed the process of adding these facilities as part of the phase 2 program mentioned earlier and outlined in Box 8.3.

SYNTHETIC DYES AND OTHER AREAS

*Get a **mauve** on.*[6]

Rita Adrosko, *Natural Dyes and Home Dying*, 1971

With the arrival of KV in the NCL from the Mumbai University Department of Chemical Technology (UDCT), chemistry of synthetic dyes had made a forceful entry into the laboratory. Backed by his international reputation as a dyestuff chemist and his position as the laboratory's first Indian Director, things moved fast and a "director's lab" was soon set up for the many students he had brought with him from UDCT. Even without KV's knowledge, job cards from his lab received priority. His students and other scientists associated with him never let him into this secret (if it was one) but continued to enjoy the perks that came with the job! If KV knew about this, he did not feel it necessary to change his policy of non-interference in such 'routine' affairs! His successor Tilak inherited and continued the practice as a matter of course (particularly since he was also a dyestuff chemist). This continued till I put a stop to it by discouraging the culture of the "director's lab." I believe no subsequent director saw the need to revive it. The point of this digression is that dyestuffs chemistry established a strong foothold in the laboratory not only in terms of leadership but also in terms of all required facilities. Scores of papers were published, many patents taken, and books written. As part of KV's grand plan for synthetic dyes at the NCL, a new Division of Organic Intermediates and Dyes (OID) was created to ensure scale-up and smooth transfer of technologies for dyes and intermediates to the industry, and I was installed as its head. Further details of this new division and its fate are given elsewhere in the book. At the end of it all, however, the surge of the free market era took its toll, and by the early years of the new century, synthetic dyes in the NCL was barely a shadow of its earlier presence. In terms of marked scientific impact, it had left none (unlike catalysis, natural products, pharmaceutical chemistry, biochemistry and polymer chemistry), save the excellent books written by KV, some outstanding papers published by him and Tilak and their students, B. S. Joshi, A. V. Rama Rao, N. R. Ayyangar, G. T. Panse, V. N. Gogte and a few others. Many technologies were also transferred to the industry where they were commercially exploited but won no special encomiums. The momentum given to indigenous technology development in dyes by KV and Tilak from UDCT by helping establish the Indian Dyestuffs Industries Ltd. (IDI) in Kalyan near Mumbai was not sustained at the NCL. The contributions from the NCL to this industry continued to be important but were less momentous.

Early in the 1960s, a project on reactive dyes (i.e. dyes that, under suitable conditions, are capable of reacting chemically with substrates such as textiles to form dye-substrate linkages), which were new at the time, was taken up on sponsorship basis for Amar Dye-Chem Ltd., Mumbai. The company took up processes for some of the yellow, red, and blue dyes developed at the NCL, for commercial production. Later, the mechanism of reactive dyeing was also extensively studied.

Preliminary work on the dyeing properties of Remazol Brilliant Blue R (Cl Reactive Blue 19) and the corresponding vinyl sulfone provided an interesting result: the formation of the vinyl sulfone in the dye-bath is unfavorable for the dyeing process. Its formation on the fiber (which made it a reactive dye) could not be excluded, but an alternative mechanism of dyeing involving an SN2 reaction (a basic organic reaction) was also considered. To settle this and other issues, much more experimental work using a variety of dyes of the Remazol type under several dyeing conditions was carried out. Some of this work — involving reactive dyes, azoic coupling components, azophenol-quinone hydrazone tautomerism, vat dyes, use of NMR spectroscopy in determining the structures of synthetic dyes, studies on steric effects, following reaction paths, and studying dye-fiber interactions — was presented at a symposium in the Department of Chemical Technology, Mumbai, in February 1969.

Many of the disperse dyes (those that are substantially water-insoluble and exhibit substantivity, i.e. attractivity to one or more water-repelling fibers such as cellulose acetate, and are usually applied from fine aqueous dispersion) with their chemical structures, which were worked out in N. R. Ayyangar's group, were listed in The Color Index, UK (typically: Disperse Red 303, Disperse Yellow 139, and Disperse Yellow 232). A few other representative studies on dyes and intermediates were quinacridone pigments, with shades ranging from bright orange red to purple, are characterized by very high all-round fastness properties comparable to the phthalocyanines with known fastness properties. Work on these, not manufactured in India at the time, was undertaken in 1969 and completed.

The Marschalk reaction (organic chemistry abounds in name reactions, and this is one them) was used at the NCL earlier for the synthesis of several naturally occurring anthraquinones, a class of useful organic intermediates. The reaction was also the subject of recent patents on disperse dyes. Using NMR spectra for following the progress of the reaction, its mechanism was elucidated.

Extensive studies were carried out on vat dyes (a dye, such as indigo, that produces a fast color by impregnating fiber with a reduced soluble form that is then oxidized to an insoluble form, the vat dye). One of the objectives was to prepare polycyclic quinines possessing the requisite volatility for mass spectra and solubility for NMR spectra determination. This was the period when organic chemists all over the world were increasingly using NMR and other spectral methods to elucidate organic structures and the NCL quickly fell in line (see footnote to Box 5.7 for a comprehensive review by Venkataraman and colleagues on the subject).

A large number of papers were published by Venkataraman, Tilak, Ayyangar, B. S. Joshi, G. T. Panse, T. Ravindranathan and others on the structure, dyeing properties and several other features of a variety of dyes. Considerable work was also done on process development for several organic intermediates. Only one, involving messy alkali fusion in a pilot plant reactor, was rigorously studied by S. Balasubramanim using statistical methods, and another (BON acid, see Chapter 10), was scaled up by P. G. Phadtare from first principles, both in the short-lived Division of Organic Intermediates and Dyes under LKD.[7]

A GENERAL OBSERVATION ON TECHNOLOGY TRANSFER FOR SMALL- AND MEDIUM-VOLUME CHEMICALS

Processes for many small-volume chemicals were developed and passed on to the industry for commercial production, without rigorous parameter optimization or scale-up studies. Some of these were mentioned under Drugs and Pharmaceuticals. They were not the best, but certain sectors of the industry, as they were constituted then, were satisfied and put them to commercial use. Examples of such process transfers are plenty but unremarkable. A few from the dyes group, listed below, are eminently illustrative of a much larger number of the NCL's process transfer mechanism of the organic chemistry group operating in isolation. They are outside the scope of projects discussed in Part IV, which were taken up as major laboratory (i.e. multi-divisional) projects with time-targeted commitments, often with the director's involvement.

Carbimazole, by Indian Schering Ltd., Mumbai (a sponsored project); diethyl-m-aminophenol, by Sahyadri Dyestuffs and Chemicals (P) Ltd., Pune (a sponsored project); cationic dyes for acrylic fibers: growing use of acrylic fibers in the country and their non-availability had created a need for undertaking developmental work on these dyes, e.g. a blue cationic dye, and red and yellow cationic dyes 3; new ingrain dyes: these dyes were in good demand because of their excellent fastness properties (e.g. Phthalogen Blue, C. I. Ingrain Blue 2); a number of new dyestuff intermediates based on phenolic derivatives and containing groups which could modify the tinctorial and fastness properties were prepared, but went nowhere from there (a not uncommon situation at the NCL), and pigments, disperse dyes and cationic dyes were prepared from these intermediates.

Biosciences

Like an awl-tip breaking ice
the green shoot cleaves the gray spring air.
The young boy finds his school-pants scuffs
too high above his shoes when fall returns.
The penciled marks on the bathroom doorframe climb.
The cells replicate,
Samototrophin
comes bubbling down the bloodstream a busybody
With instructions for the fingernails,
Another set for the epiderm

H.G. Wells, *Food of the Gods,1904*

Research in the biosciences at the NCL has a historical background that is quite unique. From its inception to the present, it has gone through three broad phases of evolution, as summarized in Box 8.4. It is well to remember that these phases evolved hand-in-hand with some phases associated with the evolution of other areas of the NCL. This will become self-evident as we walk through the evolution of the important areas of the NCL in this chapter.

One of the first research activities undertaken by the NCL was in the area of biochemical sciences in the Fermentation Hall (Room 33) of the laboratory by a group of young and enthusiastic scientists who had come over from Delhi. One of the earliest projects to come into existence was the Microbial Culture Collection, which was acquired by M. Damodaran, the first Deputy Director of the NCL, and which has grown over the years. It was recently declared as a resource center by Sivaram and is discussed further under that section in Chapter 5. Progress in biochemical sciences has been the result of outstanding achievements in the twin

Box 8.4: Evolution of the biochemical biosciences at the NCL

Phase 1

Biochemistry was one of the edifices on which the NCL's research program was built. It had therefore all the trimmings and character of traditional biochemistry spearheaded by P. C. Guha in Calcutta and M. Damodaran at Madras (who is credited with starting biochemistry at the NCL). With the entry of Jagannathan (the brightest star in India's biochemistry of the time) on the scene, plant tissue culture became an integral part of the NCL's biochemistry program. Emerging areas such as enzymology, molecular biology, plant genetics, etc. were added to it even as they evolved in the country. Together they formed a single discipline that retained the name biochemistry. This may rightly be called Phase 1 of the NCL's biochemistry.

Phase 2

As the NCL's research in biochemistry became increasingly identified with plant tissue culture (PTC) under the leadership of Jagannathan and his students (primarily Tony Mascarenhas), it became clear that PTC was the dominant component of the NCL's research in biochemistry. At the same time, the use of the blockbuster name biochemistry to describe the NCL's involvement in the area of life sciences came increasingly under criticism. It was finally decided to rename it bioscience, and a few years later, to cull out PTC as a separate unit. In addition, a new pilot plant facility for PTC was established under DBT funding. Considering all these developments, three distinct entities could be identified: bioscience, plant tissue culture, and PTC pilot plant, and each was given a separate status. This may be regarded as the second phase in the evolution of biochemistry at the NCL.

Phase 3

Interaction between biochemists, physical chemists, organic chemists and chemical engineers started to increase from the mid-1970s, prompting the creation in the early 1980s of a biochemical engineering group headed by N. G. Karanth in CEPD, followed after some years by the appointment of K. N. Ganesh as head of a small bio-organic group in Organic Chemistry 2. This group expanded rapidly till Ganesh was named head of the the division under a new name (Chemical Biology). This strengthening of the interactive mode involving several divisions/groups, such as nanotechnology headed by Sastry, marked the beginning of Phase 3 in the evolution of biochemistry at the NCL.

disciplines of biology and chemistry, which to a considerable extent has been symbiotic. Natural products chemistry owes its spectacular progress to landmark achievements in unraveling the mysteries of molecules synthesized by biological systems, while understanding the chemistry of life including the stunning advances in molecular biology and genetic engineering have contributed significantly to the progress in biological sciences. Looking back it almost seems prophetic that in this chemical laboratory, biological sciences took deep root right from the start.

THE EARLY YEARS

Much of the credit for the progress achieved in the Biochemistry Division of the NCL must go to the efforts of its first two heads of division, M. Damodaran and V. Jagannathan. Damodaran established the Biochemistry Division and made it one of the best-equipped laboratories in India. He initiated work on bacterial amylase and synthesis of vitamin C. With his pioneering vision, Jagannathan established one of the first schools of enzyme chemistry in India at the NCL. The initiation of high-level basic biochemical research in plant, animal and microbial systems coupled with utilizing the research efforts for technology development useful for generating consumer products has left its lasting imprint on the NCL. Research papers of high quality published in leading biochemical and microbiological journals on enzymes like hexokinase, nitrate reductase and carbohydrate metabolism enzymes in citric acid fermentation by molds bear testimony to the significant achievements of that time. Undertaking research and development projects on vitamin C, bacterial amylase, citric acid, etc. at a time when fermentation technology in the country was in its infancy required courage and conviction in those who were at the helm of planning. The vitamin C project required coordinated efforts from the biochemists and chemical engineers and the multi-step process included a bacterial fermentation to convert D-sorbitol to L-sorbose followed by several chemical steps ensuring good yields to finally obtain the product. Close collaboration among the scientists, S. S. Subramanian, P. N. Rangachari, B. V. Ramachandran, T. R. Ingle, and M. Goswami during the laboratory-scale development of the process was a commendable feature of the effort. Later, when the process was transferred to Hindustan Antibiotics Ltd. (HAL), the scientists mostly involved were V. Jagannathan, L. K. Doraiswamy, M.V. Kunte, G. R. Venkitakrishnan and many others. The further story of this project, one of mixed fortunes, is told in Chapter 10.

A project which was successfully completed and transferred to industry was the manufacture of the textile desizing bacterial amylase. Inderjit Babbar developed the process on a pilot plant scale. Babbar, along with M. Goswami, M. V. Kunte and others from the Chemical Engineering Division was responsible for transferring the process to the manufacturing plant at Thane and for putting the process on stream.

ENZYMOLOGY

An enzymatic reaction involves a large molecule — the enzyme — and a relatively small molecule — the substrate.

Derek H. R. Barton, Nobel Laureate, 1999

As mentioned under Early Years, the Biochemical Sciences Division as a composite unit focused its research efforts in the areas of enzymology, enzyme technology, and plant tissue culture. Jagannathan and his group discovered six new enzymes: NADP-specific glycerol dehydrogenase from *A. nige*r, succinyl coA-citramaate CoA transferase and citramalyl-CoA lyase of *Pseudomonas,* a specific plant acyl phosphate, and a calcium requiring phytase specific for phytate from *B. subtilis.* Pyruvic oxidase from muscle, hydrogenase from *Desulfovibrio* and hexokinase and aceyl cholinesterase from brain were obtained for the first time in soluble form. All the above enzymes as well as a metallo aldolase from *A. niger* were obtained in purified form and their properties were studied. High quality research on microbial enzymes from bacterial systems leading to well cited publications came from C. SivaRaman, J. C. Sadana and others. Enzymes of nitrogen metabolism in the marine luminescent bacterium *Photobacterium fischeri* (Sadana), citrate lyase from *Aerobacter aerogenes* (SivaRaman) and enzymes affiliated to carbohydrate metabolism and citric acid cycle in fluorescent *Pseudomonas* are among the other significant contributions to enzymology from the division.

BIOTRANSFORMATION

An active school of research on terpene metabolism and biotransformation of terpene compounds by bacteria and fungi was pioneered by P. K. Bhattacharyya and his students and their publications are widely cited.

MICROBIAL SCIENCES

Ugly creatures, ugly grunting creatures
After their death we let the ugly creatures
Run in pieces along the white expanse
Of the paper electrophore
We let them graze in the greenish-blue pool
Of the chromatogram
And in pieces we drove them for a dip
in alcohol
in xylol.

Miroslav Holub, 1967
(A Czech microbiologist and poet)

Microbial sciences for the development of process technologies using industrially useful enzymes continued to be of focal interest after the pioneering efforts on alpha amylase technology transfer mentioned earlier. Under the initiative of Jagannathan, the then head of division, and Professor G. N. Ramachandran (known the world over for his elucidation of the structure of collagen), Dr. Atma Ram, the then DG-CSIR, agreed to support a program on the utilization of cellulosic materials by enzymatic hydrolysis to glucose or by microbial conversion to single cell proteins for animal feed, A Silver Jubilee grant from the CSIR was awarded, after which two UNDP supported programs were also obtained. These projects, discussed in greater detail under the UNDP project in Chapter 10, aimed at (1) identifying microbial strains which could secrete high levels of the cellu-lase complex of enzymes that could be utilized for conversion of cellulosic residues to clean burning liquid fuels, notably ethanol, and (2) identifying microbes which could upgrade the protein content of agricultural residues by fermentation for supplementing feeds in animal nutrition. A group of scientists consisting of M. C. Srinivasan, Mala Rao, Vasanti Deshpande and others under the leadership of V. Jagannathan identified strains of cellulase-producing *Penicillium*. The studies on cellulolytic enzymes from *Penicillium funiculosum* and protein-rich microbial biomass product from *Penicillium janthinellum* re-sulted in several publications in international journals of repute. The direct conversion of cellulose and hemicellulose to ethanol using *Neurospora* cultures was demonstrated by Mala Rao and co-workers.

Work was also undertaken under the UNDP project mentioned earlier to improve the efficiency of ethanol fermentation through the application of novel flocculating yeast strains by C. SivaRaman and his collaborators. Laboratory scale studies as well as fermentation trials on pilot plant were undertaken with indigenous cane molasses and a better understanding of the basis of flocculence in the yeast strain as well as the relative merits and demerits of employing such a technology could be evaluated through these studies.

SivaRaman and his colleagues also standardized the protocols for immobilization and reuse of the penicillin acylase enzyme for the manufacture of 6-aminopenicillanic acid from penicillin — a key intermediate in the manufacture of semisynthetic penicillins. In collaboration with Hindustan Antibiotics Ltd., Pimpri, the technology was successfully scaled up to commercial levels. An improved process was later developed by Ponrathnam (see Chapter 11).

CELLULASE-FREE XYLANASES

As an extension of the work carried out on cellulases under the UNDP project, *Chainia*, a rare actinomycete isolated by Srinivasan proved to be of technological interest. It showed the unique ability to secrete high levels of glucose and xylose isomerase as distinct enzyme proteins for the manufacture of high fructose syrups. The organism was capable of secreting significant levels of xylanase which was unusual in that it was not associated with any cellulase activity and at the time of its discovery very few reports of such cellulose-free xylanases from naturally occurring microorganisms existed. As a further development in the area of xylanases, an unusual fungal strain belonging to the genus *Cephalosporium* was isolated and shown to grow above pH 10 and secrete cellulase-free xylanase. In the pollution conscious developed world, there appeared to be a demand for such enzymes for application in the pulp and paper industry where such xylanases offered opportunities to considerably minimize the quantities of chlorine compounds employed for bleaching, thereby containing the environmental pollution hazards. The NCL's efforts to established a joint program to evaluate the *Chainia* xylanase in collaboration with the Iowa State University, Ames, and International Papers Inc., USA, were not successful, largely because of a dispute over the NCL's claims. The matter was never resolved, since the two institutions held on to their views.

SCREENING OF MICROORGANISMS FOR NOVEL ENZYMES

During 1982 and the immediately following years, a surge in the efforts to screen novel or little investigated microorganisms for their potential as sources of novel enzymes and metabolites was witnessed, thanks mainly to Srinivasan and his colleagues. The discovery of *Conidiobolus* strains secreting high levels of alkaline protease compatible with detergents and with potential applications in animal cell culture and the leather industry for pollution-free enzymatic treatment of leather hides led to several publications of high quality, both on the basic mycological aspects of the fungus and properties of the enzyme from a biochemical standpoint. As a follow-up of this discovery, strains of the fungus were developed holding potential for a commercial process for alkaline protease manufacture and application in the leather industry, by a team consisting of Vasanti Deshpande, Mala Rao, Seeta Laxman and a few other scientists from the NCL and Central Leather Research Institute (CLRI), Chennai, with funding support from the DBT and NMITLI. A US patent was granted for this work in 2004. Subsequently, the second phase of the NMITLI project was approved in 2006, thanks mainly to the sustained efforts of Mala Rao and Seeta Laxman.

With funding from the DBT, New Delhi, Mala Rao initiated studies on the molecular biology of industrially important enzymes, cellulases and xylanases. Identification of genes, cloning and expression of the enzymes were carried out which resulted in many high quality publications. On the basis of one of her publications, Mala Rao was invited to take up an industrial project sponsored by Genencor Inc. USA, for studying potent cellulolytic organisms. The application of thermo-alkali-stable cellulases for biostoning denim fabrics in the textile industry was demonstrated in collaboration with ATIRA, Ahmedabad, as an offshoot of the project on cellulases.

Basic studies on a rare fungus, *Benjaminiella poitrasii*, exhibiting yeast-mycelial dimorphism in relation to its chitin metabolism was carried out by M. V. Deshpande and his co-workers. The studies are significant in having the potential for identifying specific targets for developing novel anti-fungal agents based on interference with their chitin metabolism in cell wall formation.

SECONDARY METABOLITES, INHIBITORS AND DRUGS

Considerable efforts were expended on the design and synthesis of inhibitors of proteolytic enzymes for generation of new therapeutic agents. For the first time, a biologically derived HIV-1 protease inhibitor from an extremophilic *Bacillus* sp. was isolated and characterized by Mala Rao and her students. This work was published in the *Journal of Biological Chemistry* and also received wide publicity in leading newspapers in India and reported by most of the television neworks.

STRUCTURE FUNCTION STUDIES

The chaperone mediated folding and unfolding of the enzymes, xylose reductase, xylanase and HIV-1 protease, was studied by Mala Rao and her students and led to publications in prestigious journals. The scientists in the division carried out work on purification and characterization of industrially important hydrolytic enzymes such as endoglucanases, proteases chitonases and pectate lyases to elucidate their structure-function relationships. The purification and immobilization of monooxygenases which are involved in biotransformation of pharmaceutically important compounds like 19 HETE and 20 HETE were also carried out.

X-ray crystallographic studies and protein engineering of penicillin V acylase were initiated as a Link Program with the Univeristy of York in UK in 1997 by H. SivaRaman. This program was continued further by C. G. Suresh, A. A. Prabhune and A. V. Pundle. The Link Program facilitated an exchange of scientists and students between the NCL and York University. The collaborative research resulted in a joint publication in *Nature Structural Biology*.

Paul Ratnasamy, the then Director, encouraged the setting up of the Macromolecular X-ray Crystallography facility in the division in March 2002 with the efforts of C. G. Suresh.

NANOBIOTECHNOLOGY

During 1996–97, scientists from the Biochemical Sciences and Murali Sastry of the Materials Sciences Divisions initiated work on nanobiotechnology involving the encapsulation of biomolecules of fatty acid lipid layers and nano gold membranes. Mala Rao, Anil Lachke, Asmita Prabhune, M. I. Khan and Absar Ahmad from the Biochemical Sciences Division contributed significantly to the area leading to a large number of publications and patents.

EVOLUTIONARY BIOLOGY

The Biochemical Sciences Division was moved by LKD to a new independent building in 1984, and this provided the opportunity to expand its activities further through better facilities as well as availability of laboratory space. John Barnabas, who was the Head of the Division, brought to the laboratory his expertise in basic biochemistry and the application of chemical knowledge to the interpretation of evolutionary biology. A renowned biochemist and a member of Prime Minister Indira Gandhi's Scientific Advisory Council, Barnabas initiated work on evolutionary biology at the NCL.

PLANT MOLECULAR BIOLOGY

Jagannathan, with his futuristic insight, realized the importance of including research in the area of plant molecular biology at the NCL. Plant molecular biology as a distinct unit in the Biochemical Sciences Division became a reality through the efforts of Ranjekar and his colleagues. A number of externally funded projects from national agencies like the DST, DBT etc. and an internationally funded project from Rockefeller Foundation of USA were undertaken by Ranjekar, Vidya Gupta and their colleagues. In 1996, a prestigious McKnight Foundation Research grant was awarded to Ranjekar, Vasanti Deshpande and Vidya Gupta to work on increasing the efficiency of production and nutritional value of chickpea. The program facilitated the visits of eminent scientists from abroad to the NCL as well as visits of collaborating NCL scientists and students to various institutions abroad. This program was ongoing as of this writing. Establishment of DNA finger printing techniques and identification of pathogen resistant genes in crop plants through molecular techniques as well as the application of molecular techniques for sex determination in young papaya seedlings were some of the noteworthy contributions with scope for application in agriculture and horticulture.

Research on the application of plant tissue culture techniques to a wide range of problems of agricultural interest in India was initiated as early as 1962 by Jagannathan and B. Ranganathan, and in 1965, an active school of research in plant tissue culture was established. As this has grown into a huge, distinctive area (see Box 8.4), it is discussed separately below.

Plant Tissue Culture

> *The most important idea I was able to introduce was "mass propagation." Our aim was to multiply the King's tissues indefinitely!*
>
> Hascombe, Julian Huxley's friend, 1989[8]

Tissue culture at the NCL had no such royal beginning. The aim was not to mass propagate the directors or Jagannathan! It was concerned exclusively with the plant kingdom, hence we always refer to it as PTC, plant tissue culture.

Historically, plant tissue culture holds a unique position at the NCL. When the laboratory was started, the various disciplines that comprised its research program were time honored ones like organic chemistry, physical chemistry, inorganic chemistry, biochemistry, and chemical engineering. Outstanding contributions came out of these disciplines at the NCL, and they all kept up with the times, moving into new areas as they emerged. Plant tissue culture was unique in that it was started as the major component of the Biochemistry division, even as it was finding its fledgling feet in some of the other laboratories of the world. Under the visionary leadership of D. Jagannathan, the NCL become one of the pioneering centers of research in plant tissue culture, and over the years never lost its appetite for discoveries. Almost all disciplines went through vicissitudes of perceived relevance, but nowhere was this more glaring than with PTC. There was a time when it was perceived as irrelevant to the NCL's program and there were vague rumors of its impending demise but it survived. And when rural development became a major activity of the NCL, its importance was rediscovered and it was reinstated as a major research area. Then, as though to reinforce its continuing importance, within a decade of its rumored extinction, it gave the NCL one of its proudest moments — through a discovery (bamboo blooming) that was splashed across the world, from Japan and Thailand in the East to Europe and USA in the West. Very few laboratories in the world can claim the distinction of having pioneered a whole discipline that continues to make contributions of far reaching significance.

In 1991, a separate Plant Tissue Culture Division was carved out of the Biochemical Sciences Division, with A. F. Mascarenhas as its first head. Later this division was split into two distinct units, the parent Plant Tissue Culture Division and the Tissue Culture Pilot Plant Unit, with separate administrative heads. What follows in this section will give glimpses of this history.

PTC made its beginning at the NCL when Jagannathan assembled a small group, with Mascarenhas as the group leader in his division, to work in this emerging field. The initial endeavor of this group was to establish callus cultures to study their nutrition and metabolism. These studies were later followed up with studies on clonal propagation of different crop plants and tree species.

SPICE CROPS

The group started gaining recognition by its pioneering work in regeneration of monocot spice crops, viz. cardamom, ginger and turmeric.

One of the first breakthroughs was the development of a tissue culture (TC) protocol (this term is used to mean the series of steps in *in vitro* manipulations to achieve plant propagation) for cardamom — the Queen of the Spices. That time, India was facing tough competition and was losing out its number one position in production and export of cardamom to Guatemala. The latter had the advantage of much higher productivity. Increasing productivity thus became an urgent necessity. Fortunately, the crop showed much variability for productivity, thus rapid and large scale clonal propagation of a few selected superior genotypes was clearly the fastest way of achieving high productivity. The NCL-PTC group took up the challenge and the protocol for the clonal propagation of superior cardamom genotypes was standardized in the early 1980s. Later, this technology was transferred to A. V. Thomas and Company Ltd., Cochin, for commercial exploitation. Cardamom technology was the first tissue culture technology to be successfully transferred for commercial exploitation in India, and the NCL achieved one of its firsts in the rapidly developing field of plant tissue culture.

In the case of the other two spices (ginger and turmeric), the problem was slightly different. Both being vegetatively propagated from rhizome cuttings, it is necessary to keep aside 25–30% of the annual yield of rhizomes for raising the following year's crop. This results in a loss to the cultivators, as rhizome is a produce of economic importance. Moreover, there are the dangers of transmitting soil-borne pathogens and losing stored rhizomes to contamination and decay. Protocols for clonal propagation were standardized for both. In turmeric, a high curcumin-yielding variant was isolated (but could not be multiplied and established).

FOREST TREES

The late 1970s saw a new phase in the NCL's PTC program, when interest in forest trees was created after a discussion with I. M. Qurishi, the then Chief Conservator of Forests, Maharashtra, followed by a visit of NCL scientists to the forests of Allapalli in Chandrapur district, Maharashtra. Among the tree species, protocols for the clonal propagation of mature *elite* genotypes could be very beneficial, as tree improvement programs are beset with many problems (long juvenile phases, lack of knowledge about the inheritance of desirable characters, open cross pollination, etc). Though clonal propagation was possible from juvenile (seedling) explants, it was not possible from mature tree-derived explants. In the late 1970s and early 1980s, attempts at clonal propagation of mature trees were so frustrating that it used to be considered impossible.

There were 200-year-old trees in that area, very majestic in height, appearance and with superior quality wood. The main problem faced by the conservator was the production of multiple copies of these majestic trees, since their seed production had decreased: seeds were not viable, and the seed raised progeny showed much variation. Jaganathan felt that tissue culture could be the answer to this problem, by which multiple copies (ramets) of mother trees could be produced using vegetative buds.

A search of the literature of the 1970s showed that all studies on the micropropagation of forest trees were only with embryonic or seedling tissues. Such juvenile material was not the correct starting material, particularly when the objective was to replicate traits expressed at maturity, which were not forthcoming at a juvenile age. All the reports available invariably mentioned that mature trees were recalcitrant and could not be cultured. Undeterred, it was decided to take up this work as a challenge. The first report from the NCL on teak micropropagation was well received by the scientific community all over the world. P. K. Gupta, who was responsible for this accomplishment, moved to the USA to work with Weyerhaeuser Company.

Being one of the first reports, it evoked worldwide interest since it suggested a tremendous potential for improving forest trees. As a result of the success with teak, forest corporations and other state departments showed keen interest in it.

A research program at the NCL was thus initiated to develop the micropropagation protocols for fast growing trees. The idea was that if this could be achieved, it would be a great boon to our forest-based industries and also to meet the fuel wood demands of the local populations. It was therefore decided to pursue this idea with all the possible risks involved, since this would be the first experiment of its kind in the world for forest tree improvement, utilizing tissue culture raised plants of mature tree origin.

At this point, the NCL sought answers to three important questions:

- How will the plantlets behave in the field?
- Will all the rametes of the clone be uniform?
- Will there be any advantage of this technology?

To answer these questions, extensive work of a multi-dimensional nature seemed inevitable. This was where The National Bank for Agricultural Research and Development (NABARD) stepped in and the director (LKD) became personally involved. The NABARD was set up in 1982 to support the country's rural development programs. Several initial meetings were held with Venkataraman as the principal spokesman for the NABARD, following which a fabulous lunch was hosted by the NABARD's Chairman, R. K. Kaul, where the outlines of a collaborative program were formulated. Prof. M. G. Bhide, Vice-Chancellor of the University of Pune, was requested to examine the proposal and make recommendations to Kaul. Although Bhide was a personal friend of mine, it is remarkable that he took a completely professional view of the matter and even asked for a meeting to discuss the proposal in all its ramifications. Evidently he was satisfied and strongly recommended the proposal. Notwithstanding this recommendation and the NABARD chairman's full support, many more bridges, some dangerously wobbly, had to be crossed before the project was finally approved. I mention this in some detail because of its historical significance.

Realizing the importance of biomass in rural life, especially rural economy, and the relevance of increasing biomass production for rural development, and recognizing the expertise developed by the NCL's plant tissue culture group in the area of tree tissue culture, the NABARD sanctioned a project for developing protocols for the clonal propagation of *Eucalyptus*, *Salvadora persica* and bamboo and for transfer of the technologies developed. In this project, the NCL acted as the apex center. There were three participating agencies (PAs): (1) Central Salt and Marine Chemicals Research Institute (CSMCRI), Bhavnagar, (2) Harihar Polyfibers, Harihar and (3) Tamil Nadu Forest Plantation Corporation, Trichy. The technology was developed at the NCL and was transferred to the PAs. In collaboration with different forest agencies, field trials were conducted at different locations to ascertain the superiority of tissue culture raised plants. Though the results of these field trials were not conclusive, they emphasized the need for much more extensive field trials. The project received a total grant of Rs. 136,00,000 lakhs from the NABARD.

The NCL-NABARD project was a new experience for many of the scientists. It had a challenging research component, the curiosity to see the results in the field and coordination with several partners such as foresters, industry and financial agencies. Computerization of the entire data was really a new experience at that time when computers were just being introduced in a major way at the NCL. All in all, it helped in capacity building of the scientists.

Besides, it took the PTC scientists to unknown and uncertain terrain. As collection of bud-wood material from far-flung forests throughout the country was a part of the work, it took them to remote forest areas and some strange experiences. Once, two scientists went to a forest to collect bud-wood material. After a day's work late in the evening, they went to the forest guest house at a place called Kimmangudi, deep in the forests of Karnataka, where accommodation had been arranged. A little later, news came that a tiger was on the prowl in the vicinity of the guest house. The scientists had to spend a sleepless night on empty stomachs. In the morning, they realized that the guest house which appeared like a *bhoot bangla* (a haunted house) in the night was in fact a nice old building in a most panoramic setting. Another time, a pair of scientists on their way to collect bud-wood material came very close to a herd of wild elephants. As the elephants were in a forgiving mood and busy with their own engagements, the scientists had a miraculous escape.

In 1988, a tragedy struck the group. One of the Research Assistants, Lata Gupta, committed suicide. The loss of a colleague was a painful experience to the group members.

THE BAMBOO STORY

One of the spectacular developments of this time was the breakthrough achieved in the rapid acceleration of reproductive development in bamboo through tissue culture. Bamboo is well known for its peculiar behavior of flowering and seeding only once, at the end of very long vegetative growth phases. In three species of bamboo, viz. *Bambusa arundinacea, Dendrocalamus brandisii* and *Dendrocalamus strictus,* which take 30–60 years to flower, flowering could be induced in 3–6 months. The results of this work were published in *Nature* with a special *News and Views* report by the editors. This work received national and international acclaim. The interest of world media in bamboo was because of three reasons: (1) bamboo as a structural material and a fiber crop is very important to a large section of the world population, living mostly in the developing countries, (2) in its long history, no attempt towards its genetic improvement could be made because of its peculiar flowering behavior, and (3) bamboo is very important to the environment; its peculiar flowering behavior and death thereafter are considered to be one of the many reasons for the extinction threat faced by the giant pandas. This discovery thus raised the hope of: (1) perennial seed production for seed propagation, (2) producing bamboo hybrids which combine many desirable qualities, and (3) unraveling the mechanism underlying the peculiar flowering behavior of bamboos. As bamboo was considered not amenable to breeding, there was not much work done on its floral biology and breeding behavior. Basic research to understand these is essential for attempting bamboo hybridization. The NCL studies revealed the role of BAP, the cytokinin involved in the induction of flowering. Using this as a biochemical marker, further studies were focused on understanding the mechanism of flowering at the molecular level.

This spectacular success brought the scientists world acclaim. Rajani Nadgauda, the principal author of this paper, was elected Fellow of the Linnean Society of London. Other marks of world recognition this work brought to the NCL were described in Chapter 5.

A tissue culture pilot plant facility with a production capacity of one million plants per year with a greenhouse was designed at the NCL, largely in Doraiswamy's regime, with financial support from the Department of Biotechnology, New Delhi, and constructed and commissioned in 1992 by Mashelkar. This facility has a semi-automated, fully air-conditioned laboratory and greenhouse, monitored by an advanced computer system. The forest tree species being multiplied in this unit, *E. Tereticomis, E.camaldulensis (eucalyptus.), Dendrocalamus strictus (bamboo) and Tectona grandis* (teak) were selected on the basis of their economic importance.

The field trials were designed as progeny trials, provenance trials, and clonal trials with the following objectives:

- to test the clonal homogeneity of the micropropagated plants;
- to assess the performance of micropropagated plants over seed-raised progeny;
- to identify suitable provenances for different clones so as to realize the full potential of individual genotypes

The growth data collected from different sites and analyzed revealed that the tissue culture plants exhibited high uniformity and higher biomass, leading to early rotation and indicating the possibility of using this technology to increase the production per unit area.

DEMONSTRATION PLOT ON FARMERS' LAND

In order to disseminate the laboratory-based results, a demonstration plot was planted with tissue culture-raised eucalyptus plants on farmers' fields with the help of the Cooperative Agroforestry Federation, Nashik, Maharashtra. This is an apex body of the Cooperative Tree Growers Society of Maharashtra, and has been successful in developing a system for eucalyptus marketing. In this program, the production was decentralized and marketing was centralized, whereas the price was linked with quality. This built quality-conscious-ness, set product evaluation standards, and geared the production to market needs.

The trials demonstrated higher growth rates and shorter rotation leading to a higher cost-benefit ratio (1:3) and fetched 39% more value for wood, which resulted in a 42% increase in net profit.

Realizing the potential economic benefits of this technology, the Federation encouraged farmers to undertake large scale plantations on their fields using micropropagated eucalyptus plants of selected genotypes. This created a market demand leading to the establishment of a commercial arrangement with M/s EPC Industries Ltd. at Nasik, with a production facility of one million plants per annum to cater to the needs of the farmers.

MICROPROPAGATION TECHNOLOGY PARKS

These projects contributed to the building up of a strong knowledge base leading to the establishment of Micropropagation Technology Parks to act as knowledge based catalysts for the development of tissue culture technologies for subsequent transfer to industries. These parks were housed in the premises of existing tissue culture pilot plants and operated with the assistance of the staff trained there.

Extensive efforts in the country, including the establishment of the two pilot plant units for taking the technology from laboratory to land resulted in the development of commercially viable indigenous technologies. The field verification trials and testing at the molecular level confirmed the feasibility of these tissue culture methods for clonal forestry. Commercial plantations resulted in generating confidence and awareness among foresters, farmers and industries of the benefits of micropropagation.

MICROPROPAGATION CONSORTIUM

Under the micropropagation research and technology development program, a consortium was soon formed with two micropropagation technology parks as nodal centers at the NCL and the Energy and Resources Institute, known previously as the Tata Energy Research Institute, New Delhi. The R & D projects were networked for the supply of *in vitro* protocols. The regional facilities linked to these parks helped in technology and high-quality product dissemination at state/region levels. The National Facility for Virus Diagnosis and Quality control using molecular markers was the service facility for testing and certification of plants.

The main objectives of the program centered at the NCL were: research and development for improvement; socio-economic development of poor farmers/entrepreneurs; institute-industry link up; and human resource development. The sustained effort in this area gave a clear indication of its continuing contributions at the scientific, commercial, and societal levels.

In order to conserve the endangered plants of India, the Department of Environment (DOE) funded an All-India coordinated program on Conservation of Endangered Plant Species by Tissue Culture (1984–99). The project activities envisaged the development of *in vitro* propagation procedures for several rare and endangered plant species located in southern India. As the principal participant in this program, the NCL successfully developed micropropagation methods for *Delphinium malabaricum (Ranunculaceae), Vanilla walkeriae (Orchidaceae), Cyathea spinulosa (Cyatheaceae* — tree ferns*), and Pterocarpus santalinus (Leguminosae).*

PARTICIPATION IN NATIONAL COORDINATED PROGRAMS

- Mango: In 1994, the Department of Biotechnology initiated a multi-institutional, coordinated national program on the micropropagation of mango (*Mangifera indica L.*). *Alphonso*, the most sought after and the leading export variety, was assigned to the NCL. Some very good work was done, partly at the University of Florida by Rajani Nadgauda on cry-propagation.
- Cotton: A network program on development of insect resistant transgenic cotton varieties was funded by the Department of Biotechnology (1994–1999). The NCL was part of it and made significant contributions towards aspects of *in vitro* regeneration, micrografting and plant transformation. Results obtained under the leadership of V. K. Krishnamurthy were published in peer-reviewed journals.
- Grape: Under a program (2001–2004), funded by the World Bank (through the Indian Council of Agricultural Research), the NCL studied the resistance to downy mildew (a fungus disease) in Thompson Seedless and Flame Seedless varieties using breeding and *in vitro* embryo rescue methods. This project was undertaken in collaboration with the National Research Center for Grapes and the Agharkar Research Institute (of the Maharashtra Association for the Cultivation of Science), both located in Pune. A second project on grape funded by the DBT (2002–2005), also in collaboration with the National Research Center for Grapes and Agharkar Research Institute, was undertaken. The objectives of the project were to develop micropropagation methods for four grape cultivars. Both the projects were carried out under the leadership of D. C. Agrawal.

MAJOR INTERNATIONAL COLLABORATIONS

It is noteworthy that there have been more international collaborations in PTC, considered an unlikely candidate for such recognition, compared to many other more likely areas, in the last two decades. This is a tribute to the farsightedness of Jagannathan and the dedication of the group he initiated. These collaborations, coming in the wake of the massive NABARD-NCL project, gave the PTC group an unusual place among the projects of the NCL. Till the time when this book was written, there were three major international collaborations:

- ALIS Link with Britain on coconut tissue culture
- Indo-Swedish project on tissue culture of pine
- FAO/IAEA project on improvement of the fruit trees, cashew and mango, through mutation and biotechnology

In addition, the technology on the tissue culture of teak was transferred to the International Plant Laboratories in England.

All the three projects were carried out under the leadership of Nadgauda. The first collaboration was with the Wye College, University of London. The second was with the Upsala Genetic Center with the group of Professor Sara von Arnold. The third, with the International Atomic Energy Agency and Food and Agricultural Organization of the United Nations, was on improvement of tropical fruit trees through PTC.

TURN-KEY PROJECTS, NATIONAL AND INTERNATIONAL

The NCL scientists were exposed for the first time to turn-key projects when Tilak, in the 1970s, offered turn-key plants for acetanilide and chlorobenzenes to Hindustan Organic Chemicals. The trials and travails of this venture are described in some detail in Chapter 10. Considering the nature of PTC, little did one expect at that time that similar turn-key assignments would one day be undertaken for PTC. That is precisely what happened. The overall expertise developed was imaginatively channeled in commercializing bench-scale protocols. But unlike in the case of chemical processes, these were state-level undertakings. Thus, the NCL undertook to establish tissue culture laboratories for different states and train local personnel in the methods of tissue culture on a time targeted turn-key basis. It also undertook a foreign assignment. These assignments were:

- Andhra Pradesh: K. V. Krishnamurthy and group
- Maharashtra: R. S. Nadgauda and group
- Cairo, Egypt: K. V. Krishnamurthy and group

The last was a particularly prestigious assignment. A photograph of Ratnasamy signing an agreement with the Egyptian authorities appears in Chapter 12.

TISSUE CULTURE PILOT PLANT FACILITY

A tissue culture pilot plant facility with a production capacity of one million plants per year with green house was designed and commissioned in 1992. This facility has a semi-auto-mated, fully air-conditioned laboratory and a greenhouse, monitored by an advanced computer system and is at par with most sophisticated laboratories in the world. The forest tree species being multiplied in this unit were selected on the basis of their economic importance. The objectives were:

- Development, refinement and scaling up of protocols by reduction in the number of stages, use of minimal media, rapid multiplication rates, and improved survival rates
- Development of methods for successful transportation of plants from greenhouse to field

Plant Protection Chemicals

Man has only a thin layer of soil between himself and starvation.

(There is an unverified attribution, but it is best to call it anon.)

Genetic modification of crops, better methods of farming, abundant production of fertilizers of various types, and extensive production of plant protection chemicals took India to self-sufficiency in food. The NCL's involvement was largely restricted to developing processes for a variety of pesticides and insecticides (described below), and genetic engineering (discussed in a later section). Its interest in fertilizers was short lived and did not yield any exploitable processes (with some interesting results on the use of phosphatic rocks).

There are over a million insect species in the world, of which about 10,000 (1%) are considered significant pests. These insects attack humans or their domestic animals and destroy large quantities of available food and fiber supplies. The agricultural loss due to pests and diseases in India is estimated to be about 50% of the total production. Compared to this, the loss in USA and other advanced countries is just about 10%. This prevention of loss has largely been due to the use of appropriate pesticides, in spite of the environmental pollution problems caused by them. Since the discovery of the insecticidal activity of DDT in 1939, it was the most extensively used insecticide till the early 1940s, but its use declined as insects began to develop resistance to it. This led to the development and use of more resistance-free insecticides in the Western world. Within a few years, the use of many of these spread to India, and soon thereafter, the NCL developed its first insecticide and by the early 1970s, a massive program had been launched in the laboratory.

PESTICIDES, A COORDINATED PROGRAM OF THE CSIR

The realization of self-sufficiency in the production of food grains has been one of the most remarkable scientific achievements of post-independent India. The Green Revolu-tion, followed by continuous scientific inputs to farming was clearly the most crucial and decisive factor in this achievement. However, a large share of the credit should also go to the agrochemicals industry for preventing loss of plant products in fields to insects and other pests. Since the first production of DDT and BHC in the 1960s, this industry has been one of the fastest growing chemical industries in the country. Along with the pharmaceuticals industry, it was also the one which has showed the greatest commitment to the development and use of indigenous technology. As a result, the CSIR formulated a coordinated program of research and development involving three of its chemically oriented laboratories, the NCL and the Regional Research Laboratories (RRLs) at Hyderabad and Jorhat (the former has since been renamed the Indian Institute of Chemical Technology — IICT and later as North Eastern Institute of Science and Technology — NEIST) to avoid duplication and be of the greatest benefit to the pesticides industry. The NCL's role was largely restricted to organophosphorus pesiticides and a few conventional chlorinated insecticides that were widely used but not manufactured in India. The laboratory started out as the unnamed lead laboratory, but soon its interest was increasingly confined to pharmaceutical and other areas and the IICT became the lead laboratory. By that time (early 1980s), the IICT had developed a strong competence in process design and project engineering, and was in a position in many cases to undertake turn-key jobs. As a result, the NCL's interest moved to newer classes of pesticides like pyrathroids.

At the same time, the laboratory's involvement in a few selected organophosphorus pesticides like Endosulfan continued with added vigor, which in itself is a fascinating story and is told in Chapter 10. The IICT and RRL (Jorhat)'s involvement became more and more exclusive, with turn-key offers for an increasing number of processes (particularly from the IICT), while at the same time, the NCL's interest in pesticides dwindled considerably till by the late 1990s, it practically ceased. The initiation, rise, and decline of the laboratory's interest in pesticides is now a part of India's pesticides saga, with almost an entire division working on it at its peak, and no narration of the NCL's history would be complete without a description of it.

A FULL DIVISION FOR PESTICIDES

Most of the development activities named above were carried out under the leadership of R. B. Mitra, a outstanding chemist who was the first Ph.D. student of Tilak at UDCT and was later a post-doc with Nobel-Prize winning Corey at Harvard. He was working at Cibatul when he was brought to the NCL by Tilak as part of his reorganization of organic chemistry research at the laboratory. S. C. Bhattacharya, who was the head of the Essential Oils Division created by Venkataraman, had left the NCL to join IIT, Mumbai. Tilak took this opportunity to initiate a massive program of developmental research in the field of pesticides by appointing a scientist with an industrial background to head that division. He also felt that essential oils were not important enough to justify a full division in the unfolding industrial scenario of the country. The division was now renamed the Organic Synthesis Division, and the main division from which this had branched off earlier as Essential Oils Division was renamed the Natural Products Chemistry Division. This reorganization did not really reflect the true nature of the projects carried out in the Natural Products Division, for considerable synthesis work was also done there, particularly by N. R. Iyengar, A. V. Rama Rao, and some other senior scientists. There were therefore further reorganizations of the two divisions in later years, which also took into account the more modern trends in organic chemistry (see Chapter 13).

LEVELS OF TECHNOLOGY TRANSFER

The important classes of chemicals falling under the broad category of plant protection chemicals are pesticides, insecticides, herbicides, weedicides, and fungicides. The NCL's interest in these chemicals dates back to the 1950s when processes were worked out for the extraction of the insecticide, nicotine sulfate, from tobacco wastes and for the rodenticide, warfarin. Of these, the former was released to many parties, of which only one took it to production. Since then, during the height of the NCL's interest in, 1970–78 under Tilak, two dozen processes for different classes of insecticides were developed. Of these, 10 (including pesticides such as dimethoate, ethion, and phenthoate and plant growth regulators such as maleic hydrazide, naphthylacetic acid) were in production, five were primed for production, and work was in an advanced stage of development on the rest. Some changes in the production pattern of these products had occured by 2000, but the actual figures are not important.

A large measure of the success of the 1970s can be attributed to the definite strategy adopted for the development and transfer of technologies for pesticides. As most pesticides are produced in batch processes, a practical gradation of the level of development and transfer of technology was defined:

- Level 1, laboratory scale (1–5 kg per batch) as laboratory data;
- Level 2, on small pilot plant scale (10–100 kg per batch) as process package with basic chemical engineering design data;
- Level 3, as turn-key plant through a project engineering firm with guarantees of performance.

The level at which it was decided to transfer a technology depended on several factors such as the level of complexity of the technology, the scale of production, and the ability of the recipient to scale up the technology. Usually the NCL would decide on the level of transfer for a particular technology, but it would be open to offer at a different level if the receiving party was keen on it. Examples of the different levels of transfer are:

- **Level 1:** Weedicides/fungicides: Simazine, Atrazine, Nitrofen and Dalapon; insecticides/rodenticides: nicotine sulfate, Phenthoate and Warfarin; and plant growth regulators: 1-naphthylacetic acid, maleic hydrazide and Ethaphone
- **Level 2:** Organophosphorus pesticides, Dimethoate and Ethion
- **Level 3:** Endosulfan, which turned out to be quite controversial — details are described at some length in Chapter 10.

It is worth noting that by 1981, several Indian firms had started commercial production of technical grade pesticides for the first time in the country, based on NCL technology. Tilak's goal of indigenizing pesticides production had got off to an excellent start. But, with the drastic change in the economic scenario from 1990, the entire commercial strategy of Indian firms changed and with it, the research strategies of the CSIR and other laboratories. Hence Tilak's goal (along with the IICT's), that was right on track for close to a decade, perished in the country's new found quest for imported technology and development partners.

MOVING TO NEWER CLASSES OF PESTICIDES

Having developed a whole series of pesticides at levels 1 and 2 and transferred many of them to the industry, Mitra's group decided, as part of Tilak's big picture on pesticides, to invest almost all further time and effort in developing processes for some newer classes of pest control agents like juvenile harmones, synthetic pyrethroids, and pesticides based on natural products. Slow release of pesticides by microencapsulation and other techniques was becoming a popular method of application around that time and thus naturally slid into Mitra's program.

Juvenile hormones are regulatory agents important in controlling insect growth. Insects produce these hormones and secrete them. Their secretion has to be stopped at a certain stage to allow the larvae to develop into sexually active adults. If not stopped, they die or develop into abnormal adults. This fact has led to the use of analogues of juvenile hormones to control some insect species. The NCL's studies on some reported analogues indicated excellent control of aphids, scale insects, mealy bugs, and several stored grain insects. Unfortunately, work was stopped before fuller evaluation could be done.

Another class of compounds called pheromones is known to disrupt the mating of certain categories of insects. Work was undertaken on the synthesis of a few compounds known to be effective on over a dozen economic insects of the Lepidoptera genre. This was later proposed to be carried out in collaboration with the Indian Agricultural Research Institute, particularly the highly complex chemistry involved. Here, again, unfortunately, the study was abandoned because of the post-1990 management's decision to taper off the pesticides program as a whole.

Screening of plant materials for insecticidal activity and isolation of the compounds responsible for this action have been a major program of organic chemists in India for a long time — in fact, starting from Vedic times (see Chapter 1). The NCL was no exception. Although earlier studies on natural products chemistry were largely centered on essential oils and derivatives of carene and flavones by Bhattacharyya and Venkataraman, medicinal chemicals were also included only after Sukh Dev joined the laboratory in the mid-1960s. The program was further expanded to include insecticidal chemicals when Tilak joined the NCL and embarked on a massive program of developmental research on pesticides.

Natural products of plant origin are especially preferable because of their biodegradable nature. India is a rich source of botanical species and a number of plants are reported to possess insect controlling properties. Insect control agents of plant origin can be classified as insecticides, anti-hormones, anti-feedants, juvenile harmonies, repellents, attractants, and oviposition deterrents. Several species of plants belonging to the Compositae, Labiatae, Euphorbiaceae, Verbenaceae, Rubiacaea and a few other families were screened for biological activity and some promising leads were obtained. For example, parthenin, isolated from *parthenium hysterophors* was found to be a general anti-feedant. From seed extracts of neem, a fraction was isolated which showed remarkable oviposition deterrent activity against potato tuber moth and mosquito.

Entomology[9]

> *We can allow satellites, planets, suns, universe, nay whole systems of universes, to be governed by laws, but the smallest insect, we wish to be created at once by special act.*
>
> Charles Darwin,
> Quoted in Desmond and Moore, 1991

By the late 1960s, concepts and practices of insect pest control were changing rapidly, with rising emphasis on the protection of the environment from pollution and hazards of synthetic organic pesticides. The NCL, for a long time a leader on the Indian R & D scene in the pesticides field, was not immune to these. The Zoecon Corporation in the USA had actually started developing novel chemical molecules which would mimic the insects' own natural hormones, playing havoc with their physiology and development. Prominent in this field were the juvenile hormone analogues or JHAs, some of which had been synthesized in the West, and were even being tested on insects. In a timely step, in the early 1970s, the NCL also decided to venture into this new field, which was now more popularly being called Pest Management. Actually, the Organic Chemistry Division in the NCL, led by Sukh Dev, was already synthesizing molecules with possible JH activity. There was, however, no way of evaluating these at the laboratory, and very few Indian institutions had facilities for this, which were also essentially in-house. Thus, in consultation with senior national experts in entomology, R. N. Sharma, an expert in entomology and a faculty member of the Center for Advanced Studies in the Zoology Department of Delhi University, was appointed to head a group in entomology in 1974.

THE EARLY YEARS

The entomology group made its beginning in A. S. Gupta's laboratory in the Organic Chemistry Division under the overall charge of Sukh Dev and reared the first batch of insects for JHA testing, despite the fact that the chemical fumes often wiped off entire colonies (unlike now, the NCL was not environment or safety conscious to the required degree in those years). The need for a new location for the entomology division was clear. Unfortunately, chemical fumes of all descriptions emanating from the various laboratories, including the exhausts opening on the roof, precluded any possibility of finding a suitable location anywhere in or on the main building. Eventually, a large room in the chemically less noxious Fine Chemicals Project building was selected, and soon the Entomology section grew both in terms of its insect colonies and staff.

The new Entomology Section (with biologists among a sea of chemists, as Tilak put it) flourished both at the scientific and academic levels. There was good rapport between the chemists and the new group and, of course, the chemists were only too happy to have an in-house facility for the immediate testing of the molecules they developed by synthesis or extraction. While the work on JHAs was still continued, newer environment-friendly vistas centering on development of pest management products affecting the physiology, development or behavior of insect pests and vectors were explored. A new CSIR-NCL funded project was initiated to investigate the abundant Indian flora to develop new eco-friendly pest-vector management products. Three groups of chemists led by A. S. Gupta and the entomology group led by Sharma combined to give shape to this project, which ran successfully for more than five years. Various parts of Maharashtra and Goa were toured extensively, collections made of new, mostly uninvestigated plants, and these were transported back to the NCL for chemical extractions by the chemists, and evaluations for manifold bioactivities by the biologists. The influence of entomology on natural products chemistry saw this long reputed forte of NCL organic chemists take on a new dimension in which allelochemicals, or chemical analogues or mimics in plants or insects which governed insect biology in diverse ways, became a popular area of research.

The NCL Entomology Section not only increased its insect colonies to numbers not reared in any other Indian institution, but also extended the laboratory's bio-evaluations to encompass innumerable newer activities which could be instrumental in decimating pest and vector populations without the environmental damage the synthetic pesticides caused. Apart from pests of agriculture and storage, vectors of various dreaded diseases were also inducted into the program to include the public health sector. This enabled a much wider scope of testing the NCL compounds. The NCL work on neem, which became a distinct part of a bigger project, soon yielded good results which became the focus of much attention. The most important finding was the development of a formulation from neem seed kernels with the name *Neemrich* (LKD made it a point to be always involved in naming new NCL products and processes as long as he was the Director). Considerable work was also done in identifying the active chemical moiety in the oviposition deterrent activity for the potato tuber moth, a remarkable instance of a non-toxic herbal compound preventing damage by an insect pest. This product was actually tested in field potato storage in collaboration with the Potato Research Centers of the ICAR in Maharashtra and Himachal Pradesh with encouraging results. Unfortunately, further studies had to be abandoned since it was reported that potato tuber moth damage could be averted simply and more easily by storing the tubers in cold godowns.

The UNDP project mentioned earlier under Biochemical Sciences included a component on the development of controlled release devices (dispensers) for pesticides, especially for vector management. This stimulated novel research in polymers and entomological evaluations. Several scientists of both groups also visited polymer and pest/vector management laboratories in the USA and UK as part of this program.

ADJUSTING TO THE GLOBALIZATION ERA

As time passed, there was change of directors (Doraiswamy was succeeded by Mashelkar), as well as policies at the NCL, dictated largely by the advent of the free market era in India. All groups were expected to raise their own resources for research. Since the entomology group was already well known for its assorted collection of insect colonies and state-of-the-art evaluations under one roof, it was not only able to stay afloat but do very well, getting projects both from Indian and global companies. The funds from these various projects helped in the acquisition of the latest technical instruments for carrying out sophisticated biological research.

Sharma was nominated as the entomology expert for the Western area by WHO, and assigned as such to annual inspection teams of medical doctors and biologists to monitor and evaluate the National Program on Eradication of the Guinea Worm. A herbal remedy, *Gwincil*, was developed by the NCL based on the discovery that a plant oil showed biocidal activity towards the guinea worm. However, further development work was not pursued since the country was declared guinea worm-free in 1998.

The DOE and the Gharda and Kanoria Companies sponsored projects on structural (buildings/materials) pests — the termites. This was a source of considerable satisfaction to NCL entomologists because of the several unique contributions they were able to make, e.g. the use of IGRs (Insect Growth Regulators) for termite control in fields, a unique strategy for studying termiticidal action in small constructions simulating actual building standards, and the development of protocols for field evaluation of residues of insecticides.

The Entomology Section operated as a unit of the Organic Chemistry Division with the objective of evaluating the molecules synthesized by the organic chemists for their insecticidal activity, and occasionally participating in the synthesis program. With the increasing influence of globalization in the NCL's research, the role of this section was expanded and more clearly defined. These may be stated as follows:

- Interfacing entomology with natural product chemistry to gain insight into the interrelationship between insects and plants in order to develop eco-friendly products/application strategies of a wide range of "semiochemicals" (plant secondary compounds) in different pest/vector management strategies
- To act as resource center for the pesticides industry to solve their problems of evaluation and development of safer pest/vector control products
- To be a center of excellence for entomological science, underpinning integrated pest/vector management concepts and to deliver high quality research and consultancy services

Bioorganic Chemistry, Renamed "Chemical Biology"

I must be a classic example of ***rising*** *between 2 stools.*

C. P. Snow
(in *Memoirs of* a *New Man* by William Cooper, 1966)

This new field of science was launched in the NCL in 1987 as a result of the interaction between John Barnabas and Krishna Ganesh of the Center for Cellular and Molecular Biology (CCMB) at Hyderabad. Trained as an organic chemist at Delhi University and later at Cambridge University, UK, Ganesh spent six years at the CCMB learning to apply organic chemistry to biological processes. LKD, who was interested in a similar endeavor at the NCL, offered a position to Ganesh, which after the usual due process was formalized, and Ganesh joined the NCL in 1987. This was another milestone in the NCL's determination to be a world-class center of research in India. Ganesh initiated his work in the Division of Organic Chemistry-1 (Synthesis) headed by R. B. Mitra, who assigned three scientists: A. A. Natu, Vaijayanti Kumar and Anita Jadhav (presently Anita Gurjal) to work with him.

Beginning with sparse facilities, the group started work on the design and synthesis of oligonucleotide conjugates with ligand X which could be a metal complex, peptides/protein for therapeutic applications, or fluorescent chromophores for diagnostic uses. The only major instrument they had was a fast protein liquid chromatography unit along with a major chunk of supplies brought from the CCMB. The work was difficult, particularly since the entire junior staff had to be trained from scratch. As a result, success was late in coming, but when it started coming in 1991, there was no looking back.

SOME EARLY RESEARCH

With the first project from the DBT in 1992, Ganesh could establish an automated DNA synthesizer (Pharmacia) at the NCL and this machine served ably for many years to provide synthetic oligonucleotides at nominal cost to several biological institutes in and around Pune such as Pune University, NARI, NCL Biochemical Sciences, B. J. Medical College and to some institutes/hospitals in Mumbai. In a way, it triggered basic interest in oligonucleotide-based diagnostics in nearby hospitals. Around 1993–94, the first PCR machine was installed at the NCL and a workshop on PCR-based applications in molecular biology and diagnostics was organized in the Organic Chemistry Division. This, in a way, established the roots of bioorganic research at the NCL. Ganesh and his team made fluorescent oligonucleotides and used them as primers to amplify target DNA, which then becomes fluorescent. This made several collaborative efforts in ODN applications for molecular biology, DNA sequencing and non-radioactive PCR diagnosis of diseases possible.

Simultaneously, basic research in nucleic acid chemistry continued on the development of nucleic acid transformations, conjugation of fluorophore, drugs, and metal ligands. In particular, the conjugation of cationic polyamines to anionic oligonucleotides to produce zwitterionic DNA was a novel contribution from the NCL group, as this method would lead to DNA modifications without destroying the inherent structural features of DNA. Elucidation of the molecular mechanism of triplex stabilization by these conjugates inspired several other groups including ISIS Pharmaceuticals, USA to develop complementary and combinatorial approaches to polyamine-DNA conjugates. This period also saw solutions to other problems such as elucidating the mechanism of DNA cleavage by metal complexes of the anti-thallessimic drug, Desferal (to understand the toxic effects) and mimicking ribonuclease active site by 8-histamino-adenine nucleotides.

PNA WITH A DIFFERENCE: *PEPTIDE NUCLEIC ACIDS* TO *PUNE NUCLEIC ACIDS*

The years 1995–6 were significant for they marked the beginning by Ganesh and Vaijayanti Kumar of a new class of DNA analogues, Peptide Nucleic Acids (PNA), which over a period of 10 years, evolved into a generic class of “Puna Nucleic Acids.” Peptide Nucleic Acids are perhaps the most talented analogues of DNA, having no sugar-phosphate backbone. These bind to DNA/RNA very strongly with high fidelity of base pairing, but lack the ability to enter cells. The NCL’s objective was to create PNA analogs that could distinguish between DNA and RNA in binding and which were inherently cationic and chiral. Several modifications of the original PNA structure were evolved at the NCL with progressive induction of desirable properties based on the rationale of tuning the conformational rigidity of backbones. The result of this evolutionary learning was the emergence of cyclohexane and cyclopentane PNAs to discriminate between DNA and RNA bindings. The NCL pioneered a highly novel and original contribution in this area, which is now recognized internationally. This happened due to the fact that the group got into this area at very early stages of its growth, resulting in the work becoming a key component of the PNA literature. This is an important lesson — get into a new area at the earliest stage — even at the risk of being characterized as *hyped*. This gives a chance to grow with the area, even direct its growth and make novel and original contributions. The saga of the PNA adventures is told in Ganesh’s recent review in *Acc. Chem. Res.*

SOME ORIGINAL FINDINGS ON COLLAGEN

Parallel to the Pune Nucleic Acids, other research topics at the interface of synthetic organic chemistry and biology/material science evolved in the bio-organic group. Collagen structure has been an area of historical/scientific interest to India since G. N. Ramachandran in his seminal paper, published in 1954, proposed a triplex structure composed of a novel coiled structure, the only precedent structure being the DNA double helix in 1953. Yet after 50 years, the molecular origin of the triplex structure has remained a mystery. The point of debate is the structural role of the 4-hydroxyl group of proline, suggested to be involved in H-bonding. This became inconsistent with the observation that 4-F-pro-line (no H-bonding like OH) further stabilized the triplex and led to the postulation of the stereoelectronic effects of 4-substituents in proline. The NCL’s idea of using 4-NH_2^- substituted proline as a probe of collagen structure was novel as it can exhibit a dual role, as a H-bonder (like OH) and as an electron withdrawing group (NH_3^+) like fluorine. 4-Aminoproline collagens formed more stable triplexes as a function of pH and shed light on the possible molecular mechanism of stability as a consequence of several molecular parameters. This generated new thoughts on pH-induced conformational changes. Such collagen mimetics have potential practical application in wound healing, bone therapeutics, and cosmetics.

SERENDIPITY AT WORK

Cross-disciplinary research can be triggered by simple coffee-time (in south India) and tea-time (in north India) discussions with colleagues from other disciplines, as much as by a programmed approach. A creative interaction of Ganesh with Murali Sastry in the area of nano-science led to a series of a dozen publications in prestigious journals on methods of using macromolecules such as DNA/PNA/Peptide as templates to align gold nanoparticles in an ordered way. The novelty of the method lies in the use of electrostatic encapsulation as the principle to produce nanoparticle arrays to develop nano-devices/sensors, etc. The high point of this interaction was a sort of serendipity: two complementary groups *accidentally* initiating joint work at the right juncture to address contemporary challenges leading to new initiatives in biomolecular nanoelectronics. This has now led to a major project by the DST in nanoscience and technology, making it possible for the NCL to acquire state-of-the-art atomic force and transmission electron microscopes.

This story would be incomplete without reference to another serendipitous happening. Many times, students can reverse roles and be good supervisors! Inspired by a course given by Ganesh on nucleic acid-protein interactions, Dinesh, a biotechnology graduate student, asked an unusual question: Tat is a protein involved in TAR-RNA recognition as a key step in HIV genome transcription. The question asked was: why could it not bind to DNA? In collaboration with Debashish Mitra of the NCCS (National Center for Cell Science), Pune, Dinesh employed the exciting tool of SELEX to fish out the DNA sequences that bind to Tat protein — they were nowhere similar to TAR-RNA sequences. A genomic search revealed that they were akin to NFKB protein binding DNA sequences! This serendipitous finding had even more unexpected implications. NFKB is the master transcription regulator and the possible binding of Tat to NFKB regulatory sequence was a total surprise in HIV biology. This helped explain the role of Tat-NFKB binding in regulating/modulating several inflammatory processes. It also invoked protein-protein interaction in NFKB-HDAC-SP systems and opened up a new topic for NCL research — investigating protein-protein interactions using small molecules to develop a new therapeutic intervention for HIV. The moral is that one should not be shy of ideas out of scientific ignorance and it does not matter from where the idea comes, provided it is pursued with an open mind with due acknowledgment.

Historically, classical bio-organic chemistry was dominated by bio-transformations and the NCL had deep traditions in this area due to the pioneering contributions of P. K. Bhattacharya before his migration to IISc, Bangalore. During the past 15 years, this area unfortunately has not received much attention, except for sporadic attempts at developing a hydantoinase for the resolution step in phenyl glycine synthesis and the use of Amano PS for chemo-, regio-, and enantioselective resolution of some pharma intermediates. Recently, the NCL Research Council suggested fresh initiatives in this area for very novel applications in synthetic/process chemistry. The area is still of contemporary relevance in the post-genomic era and only needs to be looked at from a contemporary perspective with inputs from modern molecular biology, microbiology and genetics — in particular, the application of biogenetic pathway engineering to produce either the desired enzyme or the products of utility by design. This would allow the engineering of enzymes with intended selectivity and performance for a broad range of industrially important reactions.

As Ganesh wrote when I sought some clarification from him:

> *LKD and John Barnabas (JB) planted the seeds of modern bio-organic chemistry at [the] NCL at the right time. The successive directors of [the] NCL continued to nurture and support this area. Mashelkar recognized the role of chemistry in biology and supported the establishment of DNA synthesis, PCR, etc, even with limited resources available to [the] NCL during an economically difficult period. Paul Ratnasamy firmly wanted biology to be rooted in NCL organic chemistry and, along with [the] CSIR, insisted that biomolecular screening should be a part of organic chemistry, with unprecedented financial support. His generous and forceful thrust culminated in the establishment of modern robotic high throughput screening (HTS) facility at [the] NCL, coupled with a natural products processing unit (extraction and fractionation) and a combinatorial synthesiser. This is a unique state of art facility in the country, all under one roof for 21st century natural products research. The present director, Sivaram, provided an impetus for effective usage and financial security by formally institutionalizing the facility as a Resource Center, with aggressive recruitment of competent*

scientists in screening and combinatorial chemistry areas [see Chapter 5]. *Taking advantage of such a committed support from [the] NCL's management and the available diverse expertise, the NCL is now embarking on establishing an active chemical biology program to address the chemistry in the post genomic era, where chemists and biologists work in a converged interdisciplinary culture towards solving challenging problems of both fundamental and applied nature. [The] NCL has also been tremendously benefited by outside expertise and guidance, particularly from Professor S. Ranganathan, IICT, Hyderabad, who is the original bio-organic leader in the country.*

To quote Ganesh again,

The years since 1987 have seen the establishment of the roots of bio-organic or now termed chemical biology research at [the] NCL and have been a period of both learning and achievement: learning to cross boundaries of chemistry, biology and material science, and achievement because of integration with global advancements in areas of biomolecular therapeutics, entering at an early stage. Bio-organic culture made us ask important questions, born out of biology, rather than those limited by organic chemistry. It made us move from the edges to the center stage in the modern era of research. The bio-organic group efforts since inception have led to more than 150 research publications in international journals, several Ph.D.s, and a modern chem-bio research facility at the NCL comparable to the best, all thanks to the far visions of LKD and JB.

The NCL's efforts in the bio-organic area have received fair recognition nationally and internationally. Besides Ganesh receiving accolades such as Fellowships of Academies, the Bhatnagar Prize in Chemical Sciences, etc, his colleague Vaijayanti Kumar has carved a niche for herself through invitations received to speak at international conferences, write reviews and edit special issues in international journals. The NCL also hosted a major international conference in 2000 — ISBOC 5, attended by more than 100 foreign participants, including bio-organic stalwarts such as Ronald Breslow, Albert Eschenmoser, Andrew Hamilton and Henry Kagan. The NCL also organized the first ever American Chemical Society (ACS) meeting in India in Organic Chemistry Chemical Biology (OCCB 2006) in January 2006, attended by Robert Grubbs (Nobel Laureate, 2005) and Peter Dervan. Such international events and visits certainly bear testimony to the laboratory's preeminent position in chemical biology at the global level.

Catalysis[10]

Many bodies have the property of exerting on other bodies an action which is very different from chemical affinity. By means of this action they produce decomposition in bodies, and form new compounds into the composition of which they do not enter. This new power, hitherto unknown, is common both in organic and inorganic nature — I shall call it catalytic power. I shall also call catalysis the decomposition of bodies by this force.

J. J. Berzelius, 1886

Catalysis has been an area of great interest to the NCL almost since its inception when S. B. Kulkarni (Ms.) and M. K. Gharpure (who worked for sometime with Paul Emmett, a yesteryear doyen among catalyst chemists), but no acclaimed school was built till the arrival of Paul Ratnasamy. Chapters 5 and 6 contain details of how he came to the NCL and the beginnings of a school which soon became the most outstanding in India and one internationally acclaimed in the field of zeolites and catalytic reaction engineering. A separate section outlines the basic research in the area of catalysis, mostly zeolites, while another section is devoted to the NCL's contributions to the area of chemical reaction engineering (mostly catalytic reaction engineering). Simultaneously with the arrival of Ratnasamy, R. V. Chaudhari, an outstanding student of LKD, had embarked on a career of research in catalysis that was to make him a prolific researcher at the NCL. The NCL's major contributions in homogeneous catalysis are outlined in another section.

HETEROGENEOUS CATALYSIS

No justification is needed to support the importance of basic research, particularly studies in surface science, in heterogeneous catalysis. Even so, Union Carbide's experience quoted below is hugely relevant:

However, through the use of surface science and fundamental characterizations, 3 such "sad stories" turned into "success stories" at Union Carbide. In addition,...the early use of surface science and fundamental studies led to the discovery, development and enhanced understanding of several catalyst systems.

Bhasin
Union Carbide, 1999

The NCL's contributions in heterogeneous catalysis can be linked to two major groups, one led by Paul Ratnasamy and involving three of his most valued colleagues, V. Ramaswamy, S. Sivasankar and R. Kumar, and the other led by V. R. Choudhary. The contributions of these two groups are briefly outlined below.

Choudhary was engaged in extensive research and development in frontier areas of great practical importance, such as zeolites and zeolite-like micro- and meso-porous materials, methane/natural gas conversion into value added products, lower alkane conversion, environment-friendly processes and greenhouse gas conversion/emission control, involving multiple disciplines (chemical, physical and engineering sciences and technology). His timely scientific and industrial research in these frontier areas/ hot topics led to a number of outstanding contributions in the form of publications in leading journals, and several international (US) patents. Choudhary has the largest number of publications from the NCL; what is more important, he has by far the largest number of citations (over 3000). His most important R & D contributions are as follows.

I have already referred to Rutherford's remark that those who are not blessed with funds are forced to think. Choudhary is an excellent example of this observation. He developed a number of simple, cheap experimental techniques/apparatus to carry out his studies, for example, an apparatus for measuring pore-size distribution of macro-porous solids, a volumetric apparatus for accurately measuring diffusion of liquids in medium-pore zeolites, and a gas chromatographic pulse method for measuring irreversible adsorption on solid catalysts.

His basic studies have covered a wide spectrum of subjects, e.g. zeolites and zeolite-like micro- and meso-porous materials; activation of methane, such as beneficiation due to addition of water in-feed, causing a large increase in selectivity/yield and complete suppression of tar formation in oxy-pyrolysis of methane to ethylene, low temperature selective partial oxidation of methane (POM) to syngas using non-noble metal catalysts (NiO-CaO; NiO-MgO and NiO-rare earth oxides catalysts) at extremely low (millisecond) contact time (covered by US patents); and direct non-hazardous oxidation of hydrogen by oxygen to hydrogen peroxide (which is considered a *dream reaction*) using a novel composite palladium-membrane catalyst. Choudhary's group is considered one of the leading groups in this area; he was a member of the Scientific Advisors Committee of the International Symposiums on Natural Gas Conversion.

Ratnasamy has combined basic research with catalyst development of an order one rarely sees in any field, and in the area of zeolites he is perhaps unequaled. With the help of his colleagues Ramaswamy, Sivasankar, and Rajiv Kumar, he has built up a school of research in zeolites which was largely responsible for propelling the NCL into the high-tech era. A brief description is given below of the basic work done in this area at the NCL.

Much of the early research (in the 1970s) was related to understanding the mechanism of synthesis of zeolites such as the popular varieties A and Y. With the creation of a formal catalysis group and a division in 1979, research on the synthesis of newer zeolites more suitable for catalytic applications was undertaken. One of the objects of research at this time was the synthesis of zeolites using newer templates, besides of course synthesizing novel zeolites with entirely new structures. A notable success was in the synthesis of ZSM-5 using a new template. Research was then taken up on the isomorphous substitution of Al in zeolites by other elements such as Fe, Ga, Ti and V to obtain new materials (called metallosilicates) with modified acidity and possessing the desired catalytic properties. A large number of new metallosilicates, especially ferrisilicates, were for the first time synthesized at the NCL during the 1980s and 1990s and several well-cited papers were published.

Besides devising methods for the synthesis of novel metallosilicates, this research also necessitated the proving of the location and the state of the substituent metal. Various locations for the metal in the zeolitic framework were identified. Research on the synthesis of new zeolites led to an understanding of the mechanism of nucleation and crystallization of zeolites and metallosilicates, besides the discovery of methods to enhance the speed of synthesis of these microporous materials. A notable publication on this topic by Rajiv Kumar et al. appeared in *Nature* (see Box 5.3). New methodologies were also identified for rapidly synthesizing TS-1, a very versatile oxidation catalyst, and ETS-10 (Engelhard Titanosilicate-10), a novel titanosilicate. Another aspect of basic research was understanding the synthesis methodology for optimization of the location of the active component in the framework of microporous materials so as to obtain better catalysts. A success in this area was the maximization of isolated Si^{4+} ions in SAPO frameworks to produce more acidic materials.

Another goal of the basic studies during the 1980s and 1990s was to understand the role of the different zeolite properties on its activity. Many reactions such as the transformation of C_8 hydrocarbons, shape-selective cracking of paraffins and alkylation reactions were investigated by different groups. These studies revealed that certain zeolite properties, such as crystallite-size and ratio of external to internal surface areas, had a large influence on the catalytic properties of zeolites. The effects of these properties were quantified for many reactions and zeolite systems. Subsequently, methodologies to synthesize zeolites with the desired properties for the desired reactions were also developed.

Basic research in catalysis then deviated from synthesis and reaction aspects and became more oriented towards the understanding of the diffusion phenomena and the dynamics of reactant and product molecules inside the pores of zeolites. Much of this research was centered on theoretical methods rather than on experimental work. *Ab-initio* calculations were used for identifying site occupancies by metal atoms like Al, Ti and Fe in the silicate framework of different zeolites. These studies enabled, for example, the identification of the location of Ti atoms in TS-1 and and Fe atoms in MFI, and extra framework atoms in ETS-10.

Though much of the research in catalysis was centered on acidic zeolites, some research was also carried out on the basic characteristics of alkaline zeolites and ETS-10. Theoretical studies employing restricted Hartree-Fock methods revealed that Pt, when supported on basic zeolites, possessed a greater negative charge through the flow of electrons from the support to the metal and was more active in the aromatization of n-hexane than when supported over acidic or neutral zeolites.

Another area of research where substantial efforts were put in was the preparation of inorganic mimics of enzymes using zeolites and transition metal complexes. A number of metal complexes, such as salens, phthalocyanines and cyclic tetraaza compounds were encapsulated into the cavities of zeolites or tethered to the walls of meso-porous silica. These materials containing inclusions of transition metal complexes were quite active in a number of reactions including selective oxidation of alkanes, hydroxylation of phenol and epoxidation of olefins using hydrogen peroxide or TBHP (tertialy butyl hydroperoxide). An interesting observation made during this period was that Cu-acetate, encapsulated inside Y, was a good catalyst for the selective o-hydroxylation of phenol by atmospheric oxygen. Careful studies on the catalyst revealed that the Cu-acetate dimer present inside the cavities of the zeolite possessed a shorter Cu-Cu distance (2.4Å) than in the neat Cu-acetate dimer (2.64Å) and this enhanced the *oxygenase* activity of the en-capsulated cu-acetate dimer. Similarly, it was found that Mn and Co oxides encapsulated inside zeolite Y made excellent catalysts for the oxidation of *p*-xylene to terephthalic acid (used the manufacture of polyesters). The purity of the terephthalic acid produced was higher than that obtained in commercial oxidations today.

HOMOGENEOUS CATALYSIS

Homogeneous catalysis is the success story of organometallic chemistry.

Cornills and Hermann, 2002

An area in which the NCL lacked expertise was homogeneous catalysis. R. V. Chaudhari, had done an excellent job in the field of gas-liquid reactions. He obtained a post-doctoral position at the University of Edinburgh to work under Michael Davidson, an acclaimed expert in homogeneous catalysis. Soon after Chaudhari's return to India, he was offered a position in NCL to start a school of research in homogeneous catalysis. In the early 1980s, there were thoughts of starting a major school of homogeneous catalysis in the Inorganic Chemistry Division when Taqui Khan, an INSA Fellow and co-author of a book on homogeneous catalysis with the then *guru* in that area, A. E. Martinell, was being seriously considered to head that division. For various reasons, this did not happen, and Chaudhari continued to be NCL's top scientist in homogeneous catalysis. This turned out to be a very good thing for NCL, for he did a remarkable job not only in research but in attracting participation from companies like DuPont, Rhone Poulenc from France, and others, as part of NCL's changed emphasis on such efforts in the globalization era starting from Mashelkar. Mashelkar in 1990 lifted the homogeneous catalysis section, which was part of CEPD, to the status of a separate division with Chaudhari as head. This division has forged a niche for itself in the area of catalysis in India, with an international reputation through many outstanding publications including one in *Nature* by Chaudhari et al. (see Box 5.3). The scope of homogeneous catalysis was further extended when S.B. Halligudi, another student of LKD, was appointed by Mashelkar to form a separate group on the chemistry aspects of homogeneous catalysis as part of the Catalysis Division. Halligudi too has attracted participation from universities from many countries (see Chapter 7) and has been doing a very good job.

Chaudhari's group believes that they have processes for a few organic reactions, the most important being for the conversion of ethanol to propionic acid in a single step using a homogeneous catalyst. The reaction is called carbonylation in which the reactant is treated with carbon monoxide in the presence of a homogeneous catalyst. This is perhaps the first of its kind in the world, but has unfortunately not been commercialized for various reasons.

Recovery and reuse of homogeneous catalysts pose serious problems. But this is essential if any process is to be economically viable, since the metal used is a noble metal, which, even in catalytic amounts can add enormously to the product cost. These problems can be overcome by anchoring the catalysts to polymeric or other solid supports, leading to the so-called "heterogenized homogeneous catalysts." The method of synthesis of the rare reagents required for binding the metal complexes to the polymers was standardized (a situation peculiar to laboratories in developing countries where such reagents are not readily available, the very reason that prompted KV to initiate the Fine Chemicals Project discussed later in Chapter 10). Known homogeneous catalysts were bound to styrene resins. The successful catalyst showed comparable activity to that in the dissolved state.

> In keeping with the NCL's earlier practice of giving any new process, material, or catalyst a name that usually, but not always, reflected its NCL origin, the important catalysts developed by Chaudhari's group were also appropriately named (ENCICARB for the NCL carbonylation and NCIOX for the NCL oxidation). Several ENCICARBs and NCIOXs were developed for a variety of reactions, but for various reasons (mostly non-technical) they were not commercialized.

It does not escape notice that none of the processes developed by the NCL based on homogeneous catalysis have been commercialized. Some of them were taken to the pilot plant scale and one to the semi-commercial scale. The main contributions of this group were the establishment of a center for homogeneous catalysis which, for the first time in India included process development, the establishment of a very high level of competence in this difficult area, which augurs well for the future, and a number of high level publications in reputed international journals.

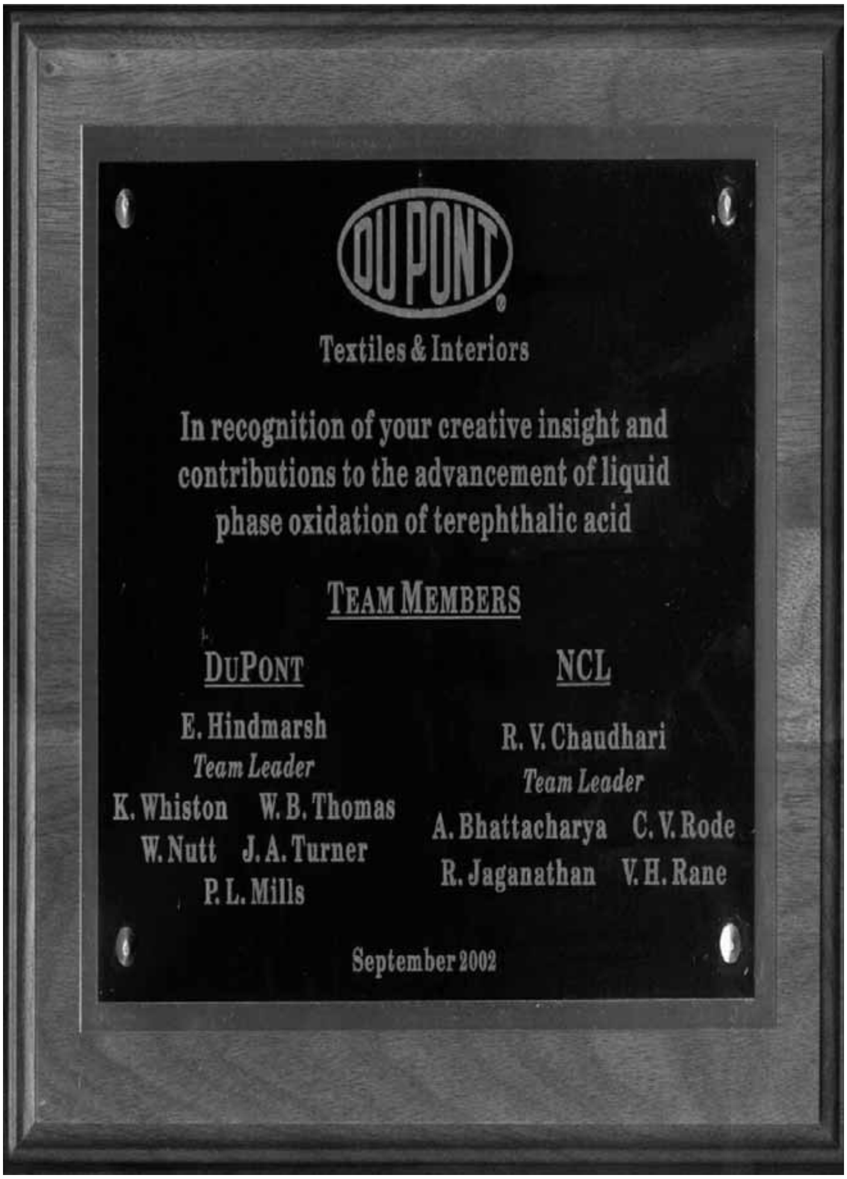
Research in homogeneous catalysis was primarily focused on C-1 chemistry with the aim of utilizing cheap feedstocks like CO (carbon monoxide) and syngas (CO + H2) and develop alternative synthetic routes for industrial chemicals. Many important processes for bulk commodities exclusively use homogeneous catalysts but the major industrial production is dominated by solid state heterogeneous catalysts. However, one must appreciate that understanding organometallic catalysis is feasible on a molecular level and may provide a logical approach to understand the mechanism of many catalytic reactions, including those using solid catalysts. In the course of over 25 years, the activities in this area at the NCL progressed very rapidly, mainly through external funding generated by its scientists and now has world-class facilities for high-pressure reactions.

The research programs involved industrially sponsored projects, basic research projects and consultancy projects. A total of about 20 projects were completed on a pilot plant or semi-commercial scale, almost half of them from reputed multinational companies. The processes involved carbonylation and oxidation. Following the Bhopal accident, there was pressure to substitute the phosgene based process used earlier at Bhopal by non-phosgene routes and the NCL joined the effort by undertaking such a project under the sponsorship of EXCEL industries and another (for diphenyl carbonate and oligomers from phenol and bis-phenol-A by a non-phosgene route) under a five-year contract with GE, USA. It had two contracts with DuPont of USA, which formally recognized the creative contributions of the NCL team in liquid-phase oxidation by presenting a plaque to the laboratory in 2002 (Figure 8.1).

Other firms with which the NCL had research contracts included ICI Polyurethanes of Belgium, Huntsman Polyurethanes, and Invista of UK (among multinationals), Deccan Sugar Institute of Pune, the NOCIL of Mumbai, Vinati Organics Ltd., Mumbai, Gujarat Alcohol and Allied Chemicals, Ahmedabad, Indian Oil Chemicals Ltd., Faridabad, Lupin Laboratories, Mumbai, and many more (among Indian firms).

In addition to sponsored research, several projects were undertaken on a collabora-tive basis with a few European agencies: Indo-French project with ENSIGC, Tolouse, on reaction engineering of gas-liquid-

Figure 8.1: DuPont's citation for the homogeneous catalysis group



liquid reactions, with particular reference to their application in hydroformylation; with the LGPC, Lyon, on modeling of non-isothermal catalytic reactors funded by the European Commission; and the project with Erlangen University mentioned earlier.

It is noteworthy that the HCD was selected as the Outreach Research partner of the Center for Environmentally Benign Catalysis (CEBC), NSF Center at Kansas University, Lawrence, Kansas, USA. It is also noteworthy that RVC, the head of HCD, recently accepted a position as Ackers Distinguished Professor of Chemical and Petroleum Engineering at that Center (see Chapter 5).

As in most other projects of the NCL, basic research was a part of the program right from the beginning. The homogeneous catalysis group published over of 200 research papers in prestigious journals, has been granted over 60 patents (in USA, Europe, and India), and has produced 30 Ph.D. theses. Research papers in homogeneous catalysis were published in prestigious journals, such as *Nature, J. Am. Chem. Soc, Chem. Mater., Org. Lett., J. Catalysis, J. Mol. Catalysis, AIChE J., Chem. Eng. Sci., Ind. Eng. Chem. Res., Langmuir, Appl. Catal.,* etc. The HC group was the first from the NCL to be granted a patent in USA.

The research areas included: design and development of catalysts (synthesis of new ligands, heterogenization of homogeneous catalysts — biphasic catalysis, encapsulation and ossification); isolation and characterization of catalytic intermediates; kinetic modeling, analysis of multiphase catalytic systems and development of reactor performance models; development of environmentally sustainable routes and laboratory scale processes for fine chemicals; and catalysis in supercritical reaction media.

The homogeneous catalysis laboratory is well equipped with a variety of micro to macro scale (50 ml to 2 lit. capacity) stirred pressure reactors; fixed-bed catalytic reactors (30 and 120 ml catalyst capacity); trickle-bed reactor with switchable up-flow and down- flow modes, CSTR, etc. The analytical facilities include several GCs with auto-sampling, HPLCs, GC-MS, FT-IR, CombiFlash LC system, UV-spectrophotometer, etc.

The group initiated new activities in the following areas:

- Asymmetric catalysis (by which only the desired structure, i.e. the desired enantiomer, is produced)
- Liquid-phase oxidation technologies
- Molecular modeling
- Catalysis in supercritical reaction media
- *In situ* techniques to probe catalytic reaction mechanisms

Materials Chemistry

> *The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them.*
>
> Sir William Lawrence Bragg, 1890–1971

Materials chemistry was always a thriving activity at the NCL, largely due to the researches of A. P. B. Sinha, right from the days of his association with Finch (see Chapter 6, Finch's regime). The effort picked up momentum during 1980–90 with the work in the Physical Chemistry Division to develop ceramic superconducting oxide thin films by Sinha and his team, magnetic oxides by M. N. S. Murthy and his group, many electronic materials, and many semi-conducting electrode materials for harnessing solar energy through photo-electrochemical processes. During this period many new high temperature superconducting phases corresponding to perovskite structures were developed and the NCL became known outside for its skills in ceramic synthesis.

Then came the period 1990–2000, which saw an interesting shift towards more soft (instead of hard ceramic-based materials) and organo-inorganic materials with several fundamental changes in the selection of materials. Some of the thrust areas where the NCL developed interesting materials include:

- **Ceramic Humidity and Gas Sensors** Many novel ceramic materials were developed for sensing humidity and a US patent was granted for developing a new composition of humidity sensing phase of lithium stannate doped with several transition metal cations. A comparison of the sensitivity and temperature coefficient values demonstrated several crucial advantages in humidity sensing between 20 and 90% relative humidity and the optimum composition was determined for making a device after incorporating the necessary circuit. Although a prototype was developed and the linearity in this range was superior compared to similar features in existing materials used in Japanese patents (like Ti-doped magnesium chromate), about 4% piece-to-piece variation in resistance thwarted commercialization attempts.

Materials for several other conductimetric sensors were also developed for the detection of impurities at ppm levels in many gases like CO, hydrocarbon, hydrogen, etc., based on a new concept of surface functionalization of tin oxide using ruthenium to control sensitivity facilitating selective detection.

- **Electro-catalysis using Zeolite Modified Electrodes** Since the catalytic properties of zeolites were extensively investigated by several groups in the NCL, some work to explore their electro-catalytic properties for a variety of electrochemical reactions of technological significance were started during 1992. For example, the catalytic and electro-catalytic oxidation of aniline to nitrobenzene over vanadium silicate molecular sieves was investigated at this time, and more importantly the redox properties of some of the Ti and V containing zeolites were also investigated as a function of solution environment.
- **Langmuir Blodgett Films** The Langmuir-Blodgett (LB) film is a set of monolayers, or layers of organic material 1 molecule thick, deposited on a solid substrate. It was recognized to have many potential applications in molecular electronics, nonlinear optics and sensors, and fundamental investigations were carried out on unraveling major issues like the spontaneous reorganization of LB films and spontaneous self-organization and ion exchange in LB films. The discovery that films of amphiphiles can be obtained through self-reorganization without the agency of a condensed solid-phase Langmuir monolayer opens up exciting new possibilities in materials synthesis. An interesting aspect of the LB deposition technique realized at that time was that the super-lattice structure could easily be grown. However, it was also found that considerable reorganization of alternating layers of fatty acid films with different cation and different chain length molecules was occuring. Similarly, vacuum- deposited films of fatty acids or long chain amines, when dipped into suitable electrolyte solutions, displayed ion-exchange and molecular organization phenomena. Most importantly, these studies have resulted in the deposition of nanoparticles of titanium dioxide, which can be employed in harvesting solar energy.

Nanoscience and Technology

The soul of immensity dwells in minutiae.
And in narrowest limits no limit in here.
What joy to discern the minute in infinity!
The vast to perceive in the small, what divinity!

Jacques Bernoulli
Quoted by Quankin, 2004

INTRODUCTION

Nanoscience is an interdisciplinary area of research that focuses on the synthesis, assembly and property measurements of materials that are restricted in their size to a nanometer level, at least in one of the dimensions. Nanotechnology is then the production and use of these structures/materials for various applications. The application potential of these materials has catapulted them to the top-most level in the eyes and minds of funding agencies, to the point where the very word “nano” seems to work wonders in attracting funds in practically all countries of the world. Already several consumer products have found their way into the market place that claim to use nanomaterials in at least one component of their products (http://www.nanotechproject.org/index.php?id = 44).

Richard Feynman is considered by many as the father of nanotechnology. In what is considered as a visionary talk, given at a meeting of the American Physical Society at the California Institute of Technology, titled. “There’s plenty of room at the bottom,” he articulated the possibility of arranging the atoms the way we want and thus controlling the way we can read and write structures and patterns by using them. In fact, he said, if we can arrange the atoms the way we want, the very atoms, all the way down! (then we can) write the entire 24 volumes of the Encyclopedia Britannica on a pinhead. This all happened in 1959 and Feynman did not use the term "nano" anywhere during his talk. Then, in 1974, Norio Taniguchi from Japan coined the term *nanotechnology* to describe production methods with precision in the nanometer range.

Obviously nanoscience or nanotechnology is not new, nor was it unknown till 1974. All the biologically important systems, proteins, enzymes and DNA have their sizes in the nanodimensions. Scientists working in the area of catalysis have been working on making smaller and smaller catalytic particles so as to increase the surface area and enhance their catalytic properties, albeit without again using the terms "nanoscience" or "nanotechnology." However, several happenings in basic sciences around 1980s have propelled the interest of many scientists in this area of research. First, Kroto, Curl and Smalley discovered the fullerenes in 1985, which ultimately paved the way for the discovery of carbon nanotubes by Sumio Iijima in 1991. Carbon nanotubes are considered to be at the forefront of applications of nanomaterials.

NANOSCIENCE AT THE NCL

The NCL was one of the few places where there was a strong research program on nano-particles even before the whole world became obsessed with the unusual properties of nanodimensional particles and materials. For example, the NCL got a US patent (*US Patent* No. 5,643,508 dated July 1, 1997) for making nanodimensional particles of oxides and sulfides based on the work initiated in 1992, and there was a strong research program to make 2–10 nm sized particles of transition metal oxides to exploit their size-dependent catalytic properties. Some of the important applications of these materials as high-energy density cathodes were also investigated.

There were also several other research activities related to rare earth and zirconia-based ceramics, soft and hard ferrites for their magnetic properties, amorphous silicon thin films (tetrahydrally coordinated and hydrogenated amorphous Si-C alloys with widely ranging band gaps of 1.7–2.8 eV), and the development of multi-nuclear and multi-dimensional NMR techniques and their application to the elucidation of the structure and dynamical properties of polymers, zeolites and other solid-state materials.

One very important aspect of the research in nanoscience is that it is highly interdiscip-linary and has seen the participation of engineers, biochemists, chemists, and physicists with the same enthusiasm and interest. It is therefore not surprising that the NCL, with so many well-established scientists belonging to the above mentioned fields became a hub for this field of research. In addition to what was mentioned at the beginning, the seeds for nanoscience research at the NCL were sown with the advent of several surface science-related projects as far back as the late 80s and early 90s. Areas such as formation of lipid films at the air-water interface and the formation of ordered films by incorporating metal ions into the thermally evaporated thin films have opened up new routes for the preparation and assembly of nanoparticles. The assembly part was extended to several biologically important materials, which had the potential for preparing a DNA chip for diagnostics. A big project on this is currently operative in the laboratory.

A quantum jump in research in nanoparticle preparation research came with the confluence of biochemists and material scientists and involved the usage of bioorganisms for the synthesis of nanomaterials. The genesis of this approach was the series of papers from Tanja-Klaus' group who reported that bacteria isolated from silver mines were capable of synthesizing silver nanoparticles when exposed to silver ion stress. This indicates that these bacteria have developed a defence mechanism against the metal ion stress that was based on the reduction of the metal ions (more toxic, more soluble form) to the metal atoms (less toxic, lower solubility form) and thus making them precipitate out. Soon after the appearance of this paper, the NCL group, which has access to a vast collection of microorganisms like fungi (see Chapter 5, section on Resources Centers) started screening these for the synthesis of nanomaterials. What was interesting was that while the first reports indicated the formation of nanoparticles within the cell structure of the bacterium, the NCL results showed the extra cellular synthesis of these nanomaterials, making them very attractive from the application point of view. This area has since grown exponentially and it was shown that this particular method of synthesizing nanomaterials using microorganisms is not unique to metal nanoparticles but could be extended to metal oxides, semiconductors and magnetic nanoparticles.

While tremendous growth occurred on the biological synthesis of nanomaterials at the NCL, the chemical synthesis technique was not left behind. Several interesting protocols were developed to effect the synthesis of metals, metal oxides and alloy nanoparticles. Noteworthy among them are the simplification of the Burst-Schiffrin protocol, development of procedures to prepare polymer membranes impregnated *in situ* with nanoparticles, foam-based synthesis of nanomaterials and transmetallation-based methods for the synthesis of alloys, core-shell and hollow nanostructures, measurement of different characteristics of these nanomaterials, preparation of magnetic nanoparticles and the development of sensors based on these nanomaterials. Some of the NCL's results like the formation of nanotriangles of gold by simply mixing gold ions with some leaf extracts has application potential in the treatment of cancer by hyperthermia, optical coatings, etc.

Currently there appears to be a cascading interest in nanoscience from different groups at the NCL, boosted by the fact that the laboratory has been identified for setting up one of the units on Nanoscience and Technology (DST-UNANST) to be funded by DST. The NCL's research has received international commendation, as can be seen from the following two editorial comments referred to in Chapter 5 under 'Supporting Evidence for Excellence: "spicy route to controlling optical properties" in *Nature*, and "Editors' Choice" in *Science*.

Much of the credit for the NCL's strong position in nanoscience must go to Murali Sastry, B. L. V. Prasad and others in the nanoscience group. I learnt that, after several years of stay at the NCL, Murali Sastry recently left the laboratory to join the Tata R & D center in Pune. While this is a great loss to the NCL, Prasad and his colleagues will no doubt continue the great work.

Thermodynamics[11]

It's no good crying over spilt milk
because all the forces of the universe
were bent on spilling it

Somerset Maugham, *Of Human Bondage*, 1915

The NCL is largely concerned with chemical reactions. The feasibility of these reactions and the extent to which they can proceed theoretically, setting a limit to the conversions attainable, are important considerations. Although the NCL did not conduct any research in this area, it had to develop methodologies to calculate the limits of conversion for reactions of varying degrees of complexity.

Knowledge of the physical and physicochemical properties of compounds is essential in research, process development, and design. Many students of Doraiswamy (D. N. Rihani, Prakash Goyal, K. K. Verma, and K. A. Reddy) and a few staff members (M. V. Kunte, S. R. S. Sastry, and Raman Rao) and R. M. Joshi of Polymer Chemistry developed, in the 1960s and 70s, computational methods for estimating some of these properties. Then, in the early 80s, a program of experimental measurement of some of these properties was undertaken in the laboratory. This was established by a committee of the Department of Science and Technology (DST) headed by Doraiswamy, and involved several institutions including IIT (Mumbai) and the NCL and was placed under the charge of Anil Kudchadkar, Professor of Chemical Engineering at IIT (Mumbai). The NCL's part was headed by S. S. Katti of the Physical Chemistry Division. Several properties were measured and a detailed report was prepared. This was a very fine program and I had high hopes of its becoming part of the then ongoing international effort in this important area. Unfortunately, the DST's interest waned at a critical time and the NCL, in spite of its best efforts, could not muster enough funds to update instrument facilities. The program faded — though not barrenly, but with a sense of some accomplishment.

More recently, in the first few years of the present century, experimental work on the estimation of certain thermodynamic properties was revived, thanks mainly to the NCL's upgraded ability to buy more sophisticated instruments for determining such properties (Annual Report, 2005–6).

Polymer Science and Engineering

Man's mind ***stretched*** *to a new idea never goes back to its original dimension.*

Oliver Wendell Holmes, 1841–1935

The polymers, those giant molecules,
Like starch and polyoxymethylene,
Flesh out, as protein serfs and plastic fools,
The kingdom with life's stuff.

John Updike, *The Dance of the Solids*, 1969

EVOLUTION OF POLYMER RESEARCH AT THE NCL

Polymer chemistry has always occupied a central position in the NCL. Its growth from infancy to the present level of maturity portrays, in many ways, the history of the laboratory itself, and is summarized in Box 8.5. Starting from empirical beginnings comprised of small-scale polymer process development combined with unconnected academic-type research, to cutting edge research in polymer science (mostly chemistry) and engineering, spanning two divisions (Polymer Chemistry and Chemical Engineering), polymers have always been a dominant presence at the NCL.

Shyamlal Kapur, a student of Herman Mark, a doyen among polymer chemists of the mid-20th century, was the chief architect of the NCL's entry into this field. His personal interests were mostly centered on studies

Box 8.5: Evolution of polymer research at the NCL

Phase 1

S. L. Kapur joined the NCL as a monomer and soon became a sizeable polymer!' With these words did Venkataraman introduce polymer chemistry to readers of the NCL Silver Jubilee Souvenir volume. This was a symbolic KV-style reference to the enormous growth of polymer chemistry itself by the exciting process of attracting new polymer chemists and those who were not polymer chemists (the so-called monomers of KV's definition). Hermann Mark, the doyen among polymer chemists of the mid-20th century and Kapur's major professor at Brooklyn Polytechnic, thrilled scientists in the NCL auditorium with his display of polymers of various properties, such as the bouncing ball, the sheet of glass-like transparency, etc. Kapur and his colleagues, notably S. Gundiah, N. R. Rajagopal, R. M. Joshi, N. D. Ghatge, published a host of papers and developed processes for relatively low-volume polymers.

Phase 2

From the mid-1970s to late 1980s, steps were taken that revolutionized polymer research at the NCL. Mashelkar was brought in, and soon M. G. Kulkarni, a student of Doraiswamy, was inducted after completing his Ph.D. A small group under Mashelkar named Polymer Science and Engineering (PSE) was formed, but there was no effective collaboration between Kapur's Polymer Chemistry Division and this fledgling group. With the retirement of Kapur and of his successor Ghatge, that division went into a decline, while the PSE group waxed high and strong. Things again changed when S. Sivaram was brought in as Head of the Polymer Chemistry Division. Polymer research at the NCL, with equal emphasis on chemistry and engineering, became one of its most renowned areas of research.

Phase 3

Polymer chemistry and Engineering research reached its peak in the nineties with strong contributions from the groups of Sivaram and Nadkarni. Sivaram initiated a board range of studies in contemporary themes of research, namely, controlled polymerization using living anionic and free radical polymerizations, metal catalyzed polymerization of olefins, surface modifications of polymers and synthesis of high performance polymers using step growth polymerization. Several industrial and academic collaborations were established at NCL. A long-term research relationship with GE Plastics, USA was initiated which lasted for over 15 years. This is one of the longest and sustained research collaborations with an industry in the history of CSIR. NCL also become a preferred destination for students to perform doctoral research. More significantly, the global research alliances established by NCL in the area of polymer science became the stimulus for many multinational companies to locate their R&D Centers in India. These include GE in Bangalore (2000), DuPont in Hyuderabad (2006), Dow Chemicals in Pune (2007), and Solvay in Vododara (2009).

of dilute polymer solutions, a subject of great interest in those years. He was also very adept at developing low-volume polymers of industrial value. He was succeeded by N. D. Ghatge, of a similar background and attitude. For a while in the 1970s, rubber chemistry seems to have hit the high mark, with the appointment of Uma Shankar, a rubber specialist, as a senior scientist, and Sivaramakrishnan, another rubber chemist, at a more junior level. But soon Uma Shankar retired and Sivaramakrishnan left to head the government condom factory in Kerala, and work on rubber ceased as suddenly as it had started. The division then went through a period of uncertainty bordering on disorder till S. Sivaram, of the IPCL's R & D Department, agreed to move to the NCL to lead the polymer effort in the laboratory. Meanwhile, about a decade earlier, Tilak had accepted my strong recommendation and offered a senior position to R. A. Mashelkar, who was then at Salford University in Manchester, to start a school of polymer science and engineering as part of the Division of Chemical Engineering and Process Development (of which I was the head). The arrival of Mashelkar and then of V. M. Nadkarni and Sivaram heralded a new phase in the history of polymer chemistry at the NCL. They brought laurels to the laboratory, and Mashelkar and Sivaram went on to become directors in due time (see Chapters 5 and 6). A few major projects culled out of this continuing area of research are described in Part IV. The rest of the present section is devoted to a brief general description of polymer research at the NCL.

SOME SELECTED EARLY STUDIES

Thermally stable polymers are well known as high-performance polymers because of their excellent thermal properties, electrical insulation, and chemical resistance. One of the well known members of the thermally stable polymer family is polyimide, which is mainly used in the aerospace and electronic industries in the form of film and moldings. Other examples of thermally stable polymers are aromatic polyamides, polyamide-imides, etc. Applications of these thermally stable polymers, however, may be hampered because of their high softening or melting temperatures and their insolubility in common organic solvents.

In order to overcome the processing difficulties, a systematic study spanning over 25 years was undertaken to improve the processability of high performance polymers. The approaches adapted were (1) insertion of flexibilizing linkages in the polymer backbone such as oxyalkylene, ether, sulfone, silane, and (2) incorporation of alky pendent groups via modified monomers. Thus a range of diisocyanates, diamines, diacids, diacid chlorides, dihydrazides incorporating these structural features were synthesized and utilized to synthesize a host of thermally stable polymers such as polyimides, polyamides, polyamideimides, polyoxadiazoles, etc. Significant improvement in the solubility of these polymers was achieved. Detailed structure-solubility-thermal-property relationships were established. A large number of papers were published in the scientific literature based on these findings.

Liquid prepolymers, in particular hydroxyl-terminated polybutadiene, find a variety of applications. The most prominent and versatile application is as a rocket propellant binder. The NCL developed a commercially viable technology for the manufacture of hydroxyl-terminated polybutadiene using the free radical polymerization technique. The polymer synthesized was suitable for rocket propellant binder applications. This development was significant in view of its strategic importance, as the polymer met a special defense requirement. It also was one of the first undertakings to demonstrate the NCL's competence in taking up challenging tasks of strategic importance.

A conceptually new approach was developed for the direct synthesis of isocyanate-terminated polymers for the first time using the free radical polymerization technique. This opened up avenues for synthesis of isocyanate-terminated polymers without use of free diisocyanates, which are toxic and dangerous to handle. Isocyanate-terminated polymers, viz., polybutadienes, polyisoprenes, polystyrenes, represent interesting intermediates for the synthesis of a variety of block copolymers.

Cashew nut shell liquid (CNSL) is a by-product of the cashew processing industry and is available in abundance in India. It is inexpensive and is considered a versatile raw material of promise for polymer additives and monomers. It is reckoned to be a replacement for petroleum feedstocks in several niche applications. CNSL and its derivatives have been employed as starting materials for the synthesis of phenolic resins, PVC plasticizers, silane coupling agents, rubber curing agents, anti-static additives, and high-value added monomers, such as, bisphenols, diamines, free radically polymerizable monomers such as substituted acrylates and acrylamides. Thus a large variety of useful products were derived from a once considered agro-waste. Although, there has been no commercial exploitation of any of these products/processes, there is a great potential for them when petroleum feedstocks become scarce or unaffordable.

Jaipur Foot

Special rehabilitation aids are necessary for the physically handicapped, mainly in India and many of the developing countries of the world. This is largely due to the contrast in the lifestyles in these countries characterized by "floor sitting," as opposed to "chair sitting" in western countries.

The conventional Jaipur Foot, which had provided consumer acceptability for over 20 years, needed improvement. The hitherto known process for making the Jaipur foot is highly labor intensive, uses hand-crafted technology, and utilizes wood and rubber. It essentially comprises an ankle-block made of wood, and fore foot and hind foot components made out of microcellular rubber. These are tied together using a nylon tyre cord and the whole structure is encased in a rubber outer shell. Failures occur depending on the way a handicapped person uses this foot and the skill of the technician who prepared the foot, as the shape of the components and the methodology of tying the components become critical. No two samples made by two different technicians would be the same as the skills differ from individual to individual. A uniform product with accelerated production was not possible. Increasing demand made it necessary to seriously view alternative materials/method of preparation of the foot so that the process would offer a product with uniform quality, superior aesthetic appearance, lighter weight, and ease of large-scale production.

Polyurethane materials offered several advantages and were found to be ideal to replace both wood and rubber (microcellular for inserts and rubber outer shell) used in the conventional Jaipur foot. The process standardized at the NCL offers a single insert as against the three insert pieces used in the conventional Jaipur foot. The outer shell of the foot in the conventional foot is made of vulcanized rubber and this was also replaced by polyurethane elastomer. Patient trials using the foot made by the NCL process was carried at the SMS Hospital in Jaipur, and the feedbacks from both patients and doctors were encouraging.

The NCL process offers a less labor-intensive procedure and delivered consistent product quality, as it was no more technician-sensitive. No definitive information was available, but it was reported to be in use in Rajasthan.

Other Process and Product Technologies

Several other technologies emerged from NCL in the area of polymers. Some of them were successfully taken up to a pilot plant level and a few were commercially exploited. These are, acrylonitrile — butadiene rubber (nitrile rubber) by an emulsion polymerization process (commercially produced by Synthetics and Chemicals Ltd., Barielly), Ion Exchange resins (produced by Tulsi Chemicals, Pune), Sulfochlorinated Poly (ethylene)s (developed up to pilot scale at Shri Ram Rayons, Kota) and poly (phenylene sulfide)s (developed up to a pilot scale in Shri Ram Fibers, Chennai). NCL developed the first prototypes of plastic components (rotor fans) for the two wheeler industry (Bajaj Auto), a polyurethane based coatings for the construction industry (Dr. Beck and Co., Pune), a series of products under the name "*Encecaps*" for sustained and controlled release of pesticides for applications in agriculture and a novel approach to nanoporous polymers which found application as ultrafiltration membranes for water purification (Membrane Filters Pvt. Ltd., Pune).

Polymer Chemistry in the Nineties

During the decade of the nineties, the thrust of research in polymer chemistry was focused on two broad themes. These are:

- New chemistry and processed for high performances polymers
- Controlled synthesis of polymers using the principles of "living" polymerization and "catalyst design".

New catalysts are important for the synthesis of high performance polymers. New synthetic methods were devised for high molecular weight aromatic poly (arylcarbonate)s and poly (arylester)s and poly (arylestercarbonate)s. More recently, the scope of solid state polymerization for the preparation of high molecular weight poly (ester)s and poly (carbonate)s were studied extensively. Structure and crystalline morphology of both the precursor oligomers and the final polymer were elucidated. More recently these studies have been extended to the polymerization of L (+)-lactic acid, a bio-degradable polymer produced from a renewable resource.

"Controlled" synthesis of polymers was explored using a variety of polymerization techniques, namely, cationic, anionic, free radical and metal catalyzed polymerizations. The objective of this work was to make functional polymers, that is, polymers which bear functional groups, either at one end or both ends of the chain. A second focus of this research was to explore polymerization of olefins using transition metal catalysts with a view to create new properties in poly (olefin)s.

Some of the significant advances to scientific knowledge to emerge from this research are as follows:

- The discovery of a novel concept of self extinguishable metal free catalysts for carbonate interchanges reactions and its application to the synthesis of ploy (arylcarbonate)s.
- Application of solid state polymerization techniques to predominantly amorphous polymers such as poly (arylcarbonate)s and poly (arylester)s. This involved an in-depth understanding the crystallization kinetics of ploy (aryl carbonate)s, both, under thermal and solvent induced conditions. Out of this study emerged a process for crystallizing poly (carbonate) in less than two minutes using a "novel" crystallization process. Polycarbonates have been notorious in the literature for its very slow rates of crystallization (several hours to days).
- First ever particle forming dispersion polymerization chemistry for polyurethanes. This is the first application of a dispersion polymerization to step growth polymerization chemistry. The method enables nearly monodisperse particles of polyurethane, in the 200 nm to microns range to be prepared directly from the constituent monomers. The key to this process is the design and synthesis of well defined steric stabilizers.
- Functional poly (olefin)s was prepared using metallocene catalysts. Using appropriate precursor monomers, poly (olefin)s with hydroxyl, epoxy and carboxyl and amido functional groups were prepared.
- New synthetic approaches to functionalized acrylic polymers were reported using group transfer and atom transfer radical polymerizations.
- The chemistry of ligated alkyl lithium initators for "living" polymerization of methyl methacrylate was explored. This led to new strategies for "controlled" synthesis of methacrylate polymers.

Chemical Engineering[12]

The NCL's involvement in chemical engineering has mostly been through reaction kinetics in one form or another: CRE, PSE, and process design. Although, whenever needed, other aspects of chemical engineering also came into play (such as some unit operations) for purposes of straightforward design, they never acquired the status of an area, and are therefore not discussed here.

The beginning of the NCL coincided with the beginning of a new area of chemical engineering: applied kinetics. Probably the first to make sustained efforts in this area was Olaf Andraes Hougen, creator of Wisconsin's famous school, with his classical papers of the 1940s co-authored with K. M. Watson (and years later with a third author, Ronald Ragatz) and culminating in Part III, *Catalysis and Applied Kinetics* of the trilogy *Chemical Process Principles (CPP,* as commonly referred to). The first paper in this area from the NCL appeared in *Chemical Engineering Progress* in 1957 (*Selective Chlorination of Ilmenite* by L. K. Doraiswamy, M. V. Kunte, and H. C. Bijawat), about 10 years after Hougen's classical work. Followed by another influential book, *Applied Kinetics* by J. M. Smith of many schools, the two formed the bedrock books of those years. Soon thereafter, this new area was unofficially christened Chemical Reaction Engineering (CRE), its authorship probably belonging to Octave Levenspiel, that multi-faceted educator from Oregon. Papers from LKD's group continued to appear in many prestigious journals. A few years later, a second group, a powerful one led by M. M. Sharma, was nucleating at UDCT in Mumbai. Shortly thereafter, Peter Danckwerts of Cambridge, with whom Sharma had worked for his Ph.D., and Levenspiel visited the NCL. This gave a tremendous boost to

CRE at the laboratory. A few years prior to this, around 1965, LKD was invited by the Pergamon Press to write a book on estimation of thermodynamic properties, an area in which he had contributed widely, and he had begun the task. That was when things took a different turn.

In the midst of the happenings just narrated, and as CRE was taking deep roots at the NCL and UDCT, LKD and Sharma met for the first time at the NCL, the beginning of a life long friendship, to discuss possibilities of collaboration in the field of thermodynamics. They enthusiastically agreed to collaborate but, as it turned out — not in thermodynamics but in CRE! Things then moved swiftly and a contract was signed with John Wiley, New York, marking the beginning of a new era of chemical engineering in India. But it would take 15 long years before it would emerge as a completed work (*Heterogeneous Reactions: Analysis, Examples and Reactor Design*, Volumes I and II, 1984), the first authentic treatise in CRE from India. Several years later, R.V. Chaudhari (a student of LKD) and P. A. Ramachandran (a student of Sharma) wrote another important book — *Multiphase Reactions*. I mention these events in some detail to emphasize the fact that the emergence of CRE in India was just a decade behind its rapid development as a modern engineering science in USA and Europe starting from the 1960s; it also marked its beginning as a continuing area of excellence in India. The NCL and UDCT were not the only places in India to initiate research in this area and foster its fertility, but they were certainly the internationally recognized centers. Some IITs, notably that at Kharagpur under M. N. Rao, a contemporary of mine at Wisconsin, who was already a professor in India before he came to work for Hougen, and IISc where N. R. Kuloor had started extensive studies in applied kinetics with the help, among others, of Rajendra Kumar, who would soon become a bright star in Indian chemical engineering, moved into this emerging field with gusto. Also, younger chemical engineers like Gandhi, Santosh Gupta, B. D. Kulkarni, J. B. Joshi, G. D. Yadav, A. B. Pandit, R. V. Chaudhari, and a few others at the IITs were coming of age and would soon be ranked among the best.

It can be seen that chemical engineering and CRE evolved almost simultaneously in India, except for some sporadic attempts in chemical technology and thermodynamics in the preceding years. Box 8.6 summarizes the evolution of chemical engineering (CRE) at NCL since its inception. Some of the areas found their homes in other divisions, or as separate divisions altogether. They are merely administrative details, and our concern here is only with the areas.

With this general background, I shall now briefly walk through the NCL's accomplishments in CRE, since the publication of the first paper in 1957.

Since time is a major parameter in kinetics (or chemical reaction engineering), I start with the following highly pertinent description of the subject:

> *Time* [kinetics] *is God's way of keeping things from happening all at once.*
>
> Anon.

CLASSICAL CRE

> *There is something fascinating about science. One gets such wholesome returns of conjecture out of such a trifling investment of fact.*[13]
>
> Mark Twain, *Life on the Mississippi*, 1883

Modeling of chemically reacting systems began at the NCL in the late 1950s. It was started by LKD and pursued vigorously by R. A. Mashelkar, B. D. Kulkarni, R. V. Chaudhari, K. Jayaraman, V. Ravi Kumar, and others.[14] Over 150 papers were published touching upon various aspects of CRE during the early years of its growth. A few selected contri-butions are outlined below.

Effectiveness Factors

The basis of most studies was the realization that chemical reactions in heterogeneous systems can be classified under different systems, such as reactions between gas and solid (where the solid can be catalytic or non-catalytic); gas and liquid; liquid and liquid; gas, solid and liquid (catalytic and non-catalytic), etc. Mass transfer (i.e. transport of reactive species) between phases and chemical reaction occur independently or interactively to define the overall mechanism. Elaborate theoretical analyses of these interactions led to the formulation of a variety of models for different systems. A term that commonly appears in such studies is

Box 8.6: Evolution of chemical engineering at the NCL

Phase 1

Chemical engineering was among the earliest divisions created at the NCL. In concept, it was no different from what was then known as chemical engineering: emphasis on unit operations, like distillation, absorption, filtration, drying, etc. Chemical reaction engineering (CRE) in the USA and Europe was just coming of age, even as L. K. Doraiswamy (LKD) joined the NCL in India, fresh out of Wisconsin with a Ph.D. under Olaf Hougen, the doyen of chemical engineering and the founding father of CRE, and the Bird-Stewart-Lightfoot era of analysis and transport phenomena (again from Wisconsin) was changing the course of chemical engineering the world over. Harish Bijawat, who was head of Chemical Engineering at the NCL, gave much encouragement to LKD. The priority of the division in those years was to spend Rs. 18 lakhs ($250,000) that had been made available to buy a host of pilot plant and unit operations equipment. There was no explicit chemical engineering component to a project, and each division had its own project, with or without (mostly without) chemical engineering. These were fairly unremarkable years for the Chemical Engineering Division — steady, unexciting, and no quick turnarounds. Then, with the retirement of Finch, followed almost immediately by the resignation of Bijawat, and an organic chemist K. Venkataraman poised to take over the stewardship of the NCL, *the end of the beginning* (to slightly misquote Sir Winston Churchill) seemed to have arrived for chemical engineering in the laboratory, and an uncertain period loomed.

Phase 2

Had KV been a typical Indian professor of organic chemistry, with no appreciation of the need, or even the importance, of chemical engineering, it might have been a very different story. As things were, he was beyond petty professional priorities. He promoted M. U. Pai, the senior most scientist in Chemical Engineering, to head the division. But he was a shrewd man and was quick to surmise that what he saw in the NCL was not the kind of chemical engineering that would take the laboratory to the top. He initiated the changes that later would give his successor Tilak the tools he would need to take bold and far-reaching decisions. Thus he created a new Division of Organic Intermediates and Dyes to specialize in unit processes such as oxidation, nitration, sulfonation, amination, reduction, etc. (with Shreve's Chemical Technology as the model) and promoted Doraiswamy as head of the division. Tilak combined this division with Chemical Engineering to create a new Division of Chemical Engineering and Process Development (CEPD) and placed it under the charge of LKD. Thus began the new (modern) phase in chemical engineering.

Phase 3

CEPD was reorganized to reflect the new priorities and vision. The CRE and PSE groups were considerably strengthened, a process design group was set up with computer aided facilities (although CSIR's offer to fund a full-fledged project engineering cell was not accepted). The CRE group grew over the years, and in 1984 announced its arrival in no uncertain terms through the first major international conference (International Chemical Reaction Engineering Conference, ICREC 1) which was widely acclaimed all over the world. Similar conferences in other areas followed, and soon the NCL's scientific announcements were no longer confined to the printed paper but were also made through personal presentations before internationl audiences, often within the NCL campus. PSE became increasingly a part of the polymer program. As for CEPD, it became a highly visible symbol of the NCL's evolution, alternating between speciation and coalescence, and as of this writing it was going through the second coalescence phase.

effectiveness factor, i.e. the extent to which a pure chemical reaction between components in different phases is influenced (usually but not always diminished) by the resistance to mass transfer of these components between phases. The converse, where mass transfer is influenced (usually enhanced) by chemical reaction is called the enhancement factor. Spurred by the classical papers of Rutherford Aris from Minnesota and Peter Danckwerts from Cambridge, interaction between mass transfer and chemical reaction, i.e. between the physical and chemical steps involved in a reaction, became a major area of study at the NCL. Some selected aspects of these studies are briefly summarized below followed by brief references to a few more areas of CRE.

It was felt that there was no need for two opposite measures of the role of diffusion (mass transfer) in modifying a chemical reaction: effectiveness factor and enhancement factor, as used, respectively, for reactions between a gas (or liquid) and solid, and between a gas and liquid. A unified approach was formulated. But it is difficult to dismantle entrenched practices, and as Max Planck (see his autobiography, 1950) has said in a loftier context:

> *A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it.*[15]

And the two separate approaches continue.

In some important situations, ε is a function of time and it becomes necessary to estimate this varying dependence as the reaction progresses. A new parameter called 'characteristic time' was defined and a compact graphical representation was developed for the effectiveness factor as a function of two diffusional parameters (expressed in terms of the so-called Thiele modulus and the Biot number, one for diffusion of a gaseous component from its homogeneous external environment on to the surface of a solid catalyst and the other for further diffusion of this component within the internal voids of the solid.

Many industrial catalysts are made by compacting porous catalysts into larger pellets. As a result, in addition to the normal porosity variation (referred to as pore-size distribution) of the porous particles, there is a second distribution arising from porosity variations between these particles within the compacted pellet. This so-called bimodal distribution creates its own problems in estimating the role of diffusion in a reaction occurring within the pellets. When to this complication is added the complexity arising from the nonlinear behavior of reactions (i.e. the reaction is no longer a simple linear function of the reactant concentration) and the possibility of temperature variations within the pellet, not to mention such other factors as declining catalytic activity, the situation gets several fold compounded. To put this mathematically, one is confronted with what mathematicians call a 2-point coupled boundary value problem which cannot be solved easily. Two methods were used at the NCL to solve such problems: one based on the so-called collocation theory, and the other by using a trick (transformations) by which the complicating second boundary condition is eliminated and the problem becomes much easier to solve. These transformations are specific to the rate form of the concerned reaction, and were defined for a number of forms — from the simple to the highly complex. Use of such transformations is common, but not always superior to the conventional numerical techniques, which require considerable trial and error with no certainty of obtaining the desired solution.

Multiplicities and Instabilities in Chemically Reacting Systems

> *Propagating spirals emerge in chemical reactions from sheared target patterns. Rather than annihilating one another, interacting waves pattern and condition each other. They have been observed in phenomena as diverse as the aggregation of cellular slime mold, calcium release, chemical oscillators, and traveling wave patterns.*
>
> Epstein, 1991[16]

It is well known that a chemical reaction proceeding smoothly under certain conditions can jump from one steady state of operation to another. If one of the steady states corresponds to quench conditions, the reaction abruptly ceases. The basic requirement for multiplicity and instability is feedback of energy or species. Feedback of energy (temperature) is normally referred to as thermal feedback and has been extensively studied. On the other hand, there was much that was unknown about these due to species feedback in the 1960s, such as intrinsic kinetics on the surface, transformations among adsorbed species, and autocatalysis. The NCL's CRE group contributed substantially to the understanding of some of these situations.

For example, autocatalysis, which is a form of feedback, can explain unsteady behavior, but cannot by itself explain chaotic behavior. For this we have to fall back on that much-used workhorse of chemical reactors, the stirred pot. Indeed, to put it in Shakespeare's words (in *Macbeth*):[17]

> Yet who would have thought the old man to have had so much *blood in him. (Act 5, Scene 1)*

Doraiswamy and his collaborators invoked the coupling of reaction centers (stirred pots) to explain chaos, a behavior characterized by aperiodic oscillations. Thus, the chaotic behavior of a reaction on a catalyst surface can be explained by the coupling action of so-called homotattic patches of different activities, each acting as a stirred pot. Similarly, a fixed-bed reactor can be modeled as a collection of an infinite number of stirred pots and chaos explained by the coupling action of two or more such stirred pots. It was shown by the NCL scientists that by appropriate manipulation of the interaction or coupling co-efficient, it is possible to upgrade the operation of a reactor to the desired steady state, i.e. the higher stable state (with the higher conversion), whereas under uncoupled conditions it would have operated at the lower steady state. It was also shown that a heterogeneous surface, by its very nature, can lead to chaotic behavior of a reaction occurring on it. Loss of active sites due to deactivation can also lead to transitions between stable and unstable states.

The Role of Stochasticity (or Probabilistic Theories) in CRE

> *While writing my book* [Stochastic Processes, Wiley, 1953], *I had an argument with Feller. He asserted that everyone said "random variable," and I asserted that everyone said "chance variable." We obviously had to use the same name in our books, so we decided the issue by a stochastic procedure. That is, we tossed for it and he won.*
>
> Interview with Doob by Laurie Snell
> quoted in *Statistical Science*, 1997

It is now fairly well recognized that the laws of nature are probabilistic rather than deterministic, notwithstanding Einstein's oft quoted statement; *God does not play dice*. that characterized his declining years. This became firmly implanted in modern science following the groundbreaking studies of Nobel Laureates Niels Bohr, P. A. M. Dirac and others in the earlier years of the last century. Chemical engineers were rather late in recognizing this fact, but within a few years of this happening the NCL jumped into the fray with a series of papers culminating in 1987, in perhaps the first reaction engineering book in this area: *Analysis of Chemically Reacting Systems: A Stochastic Approach*, by L. K. Doraiswamy and B. D. Kulkarni.

The modeling of chemically reacting systems rests on the application of the macroscopic laws of physics which while adequate for most engineering purposes can lead to inaccurate results under certain circumstances. This is particularly true with regard to the stability of reacting systems, where the use of averaged values, as in any deterministic analysis, can lead to wrong qualitative/quantitative estimations. A formalism employing probabilistic arguments to restructure these cases was developed and applied to a number of cases of practical importance. For example, for a general reaction scheme on a catalyst surface that generates multiple solutions (i.e. many states can exist, some stable, some unstable), stochastic analysis (i.e. incorporation of fluctuations) shows that multiplicity can appear where none was predicted by the classical approach, and also result in transition to a new stable state. When fluctuations are allowed for at these transition points, also known as bifurcation points, some finer effects, hitherto unnoticed, are revealed.

Mention was made of stable steady states but this is entirely a deterministic concept. Stochastic analysis only calculates the probability of attaining a state, and typical multi-stationarity in deterministic systems shows up as peaks in a probability distribution curve. The maxima and minima of this distribution then correspond to the stable and unsteady states of the deterministic analysis. The time required for transition from one state to another is an important design parameter and a methodology for calculating this transition time was proposed by the NCL's CRE group. Many other unique features were also found and all these are discussed in LKD and Kulkarni's book.

Studies in Adsorption

Adsorption of a fluid (let us say a gas) on a solid is a complex phenomenon and is a necessary precursor to catalytic conversion of the adsorbed species to a desired product. In most analyses of the kinetics of reactions on a solid surface, it is assumed that the surface is ideal, that is, all reactive centers are equally active and are uninfluenced by the neighborhood. In fact, the effectiveness factors mentioned earlier were all defined for an ideal surface. To formulate any model for reaction on a solid surface, the concentration of the reactant on the surface must be known. This is rarely experimentally possible and hence it is estimated using one of many so-called isotherms. The usual practice is to assume an ideal surface for using these isotherms. It is possible to mathematically introduce non-ideal isotherms for purposes of calculation, and the resulting equation is known as the adsorption integral equation. Prasad and LKD were the first to solve this equation using practical limits of behavior expressed in terms of finite values of the heat of adsorption (which is a measure of non-ideality), instead of the ideal and practically meaningless values of plus and minus infinity, as was done in all earlier studies. They also analyzed several other situations of practical interest, all of which are fully explained by LKD in a publication by the journal, *Progress in Surface Science* (1991) as a single volume of several numbers.

Some Other Systems

In addition to the many contributions in gas-solid catalytic reactions, some of which were mentioned above, mention may be made of the following firsts by the NCL's CRE group:

- **Gas-solid non-catalytic reactions**: Discovery of a reaction that starts at the center of the solid and spreads outward (contrary to the usual case of starting at the surface, and thus presenting for the first time a practical example of the so-called rotten apple model, so named because the apple rots from the center), use of solid diluents to enhance conversion limits; and discovery of a unique reaction, an auto-catalytic gas-solid reaction involved in the preparation of chlorosilanes, used in the production of a variety of useful chemicals known as silicones.
- **Solid-solid reactions**: Reaction between solids, such as in the preparation of thermistors and certain types of catalysts, has been steadily gaining in importance but, strangely enough, but for a paper by J. M. Smith, there was hardly any interest among chemical engineers in these reactions. Following the first review of the subject with an engineering bias by Tamhankar and Doraiswamy (1982), an analysis of these reactions formed, for the first time, a full chapter of a book in CRE, that by Doraiswamy and Sharma (1984) mentioned earlier. This provided the initial basis for designing reactors for solid-solid reactions.
- **Gas-liquid reactions using homogeneous catalysts**: Unlike in reactions on a solid surface, here the catalyst is homogeneously dissolved in a liquid phase and facilitates reaction of a reactant in that phase with another in the gas phase. The most important reactions of this class are carbonylation (carbon monoxide in the gas phase) and hydroformylation (carbon monoxide and hydrogen in the gas phase), both resulting in extensively used industrial chemicals. Modeling of such reactions was done for the first time by R. V. Chaudhari and collaborators.

MODERN CRE

> *This book* (The Book of Nature) *is written in the mathematical language, and the symbols are triangles, circles, and other geometrical figures, without whose help it is humanly impossible to comprehend a single word of it.*
>
> Galileo *The Assayer*, 1623[18]

The studies by Kulkarni and associates are highly theoretical, and are difficult to explain in words with any degree of brevity. I therefore summarize them below using the language of the theoretician (as I did in the case of theoretical chemistry), in the hope that the reader may obtain some flavor for the kind of work that was, and is being, done in this ever expanding field. I am tempted to use the word jargon in place of language and hide under J. M. Smith's dilemma:

> *I do think jargon is excusable, but I do* [also] *think we have to learn to talk to people without using it, and it isn't easy.*

But I avoid this problem altogether by simply considering them as "emerging scientific terms."

In the 1980s, work on developing and harnessing new mathematical methods for better design was initiated at the NCL. Kulkarni and his associates developed novel approaches to carry out fault diagnosis, process modeling, identification and process control protocols in the absence of complete mathematical models. This approach is based on pattern recognition strategies to relate the input-output behavior in a manner analogous to those in neural networks. Another approach reduces the dimensionality of the available model while retaining the model's predictive abilities in the likelihood of incomplete process state specifications. The applicability of the methods was tested for chaotic behavior of systems, and newer strategies for servo and regulatory control of the chaotic dynamics of nonlinear processes were developed. New methodologies for understanding the behavior of complex systems using contemporary theories in nonlinear dynamics, chaos, fractals and statistical physics were developed. A new wavelet based noise reduction algorithm was proposed. The group has also developed various Artificial Intelligence (AI) paradigms such as neural networks, genetic algorithms, genetic programming and fuzzy logic. These formalisms have been utilized to develop modeling and optimization strategies for a variety of chemical, biological and chemical engineering systems. Recently, two novel hybrid formalisms integrating neural neworks/genetic programming and genetic algorithms were developed. The huge advantage offered by the proposed methodologies is that process modeling and optimization can be performed directly from the process data, even in the absence of detailed knowledge about the physicochemical phenomena (kinetics, thermodynamics, etc.) underlying a process. A new evolutionary optimization technique, ant-colony optimization, was applied for the first time to batch, semi-batch and continuous reactors normally used in the chemical industry. This can efficiently solve (1) the combinatorial optimization problem for the design of multi-product batch scheduling, and (2) the continuous function optimization problem for the design of a multi-product plant with single product campaigns and horizon constraints. Tools such as tabu search and support vector machines were also developed and applied to a number of problems of interest to chemical engineering.

Although the methods mentioned above may not be intelligible to the average reader, I have referred to them briefly in order to emphasize the strides made by the NCL in this important area, from relatively modest beginnings to the most advanced methods of today. The result is that for the first time, methods have been proposed for using complex mathematical tools for solving problems of great interest to the chemical industry. This is also true of other areas. Being experimental, they were easier to describe and hopefully also to follow.

Process Design

> *Algorithmic compressibility…is the transformation of lists of observational data into abbreviated form by the recognition of patterns. The recognition of such a pattern allows the information content of the observed sequence of events to be replaced by a shorthand formula which possesses the same, or almost the same, information content.*
>
> John D. Barrow, *Theories of Everything,* 1991

THE EARLY YEARS

In the early years of the NCL, the Chemical Engineering Division was established with some specific functions, e.g. (1) to supply chemical engineering data and designs for processes developed in the laboratory, (2) to develop processes initiated in the division from the laboratory to the pilot plant stage, and (3) to undertake both experimental and theoretical investigations in basic chemical and process engineering. Since one of the main objects of the NCL is to assist the Indian chemical industry by demonstrating the feasibility of known or new reactions and processes for chemical products, a major activity of the Chemical Engineering Division, within the compass of its process development program, was the design and operation of pilot plants. Basic chemical engineering research was also undertaken to develop capability to design large scale units with no or minimum use of pilot plants ('dropping the pilot' was a phrase popularly used in the 1960s).

In the early years, significant emphasis was placed on pilot plant experiments and the preparation of complete chemical engineering designs, including material and energy balances, equipment and material flow sheets, process equipment designs, piping schedules, instrumentation flow sheets, plant layouts, detailed cost estimates, and operating instructions. A new pilot plant building was set up in 1965. Several different types of reactors including glass-lined and gas-inducing types were installed and operated in this pilot plant building. In later years, second and third pilot plant buildings were added to establish further reactor scale-up facilities. Some of the key facilities for reactor scale-up at the NCL were:

- Single tube, isothermal reactor for vapor phase catalytic reactions
- Adiabatic fixed-bed reactor for catalytic vapor phase reactions

- Tubular, isothermal reactors for liquid-phase, catalytic reactions
- Adiabatic, fixed-bed reactors for liquid-phase, catalytic reactions
- Several high pressure stirred reactors (including gas-induced/glass-lined vessels)

These reactors were built with flexibility, versatility and novelty in mind; they enabled the experimenter to study the influence of relevant process parameters and optimize the final design.

Several processes were investigated on a pilot scale and commercial designs offered on the basis of the results. In a typical example of such processes, preliminary laboratory investigations were used to obtain the necessary process data. Using these laboratory results, a pilot plant was designed and set up. For this purpose, the design of the various auxiliary units comprising the pilot plant was carried out by conventional methods. In many cases, in the absence of adequate rate data, reactors were designed empirically. As a first step, this procedure was considered justifiable since it was anticipated that the data obtained on the pilot plant would be used as the basis for the rational design of a commercial unit.

The design, construction and operation of pilot plant reactors brought the NCL researchers close to real life experience. This turned out to be useful in developing new understanding and computational models. The operation of pilot plants is time consuming and expensive. Gradually emphasis shifted from the traditional experimental approach, involving bench-scale and pilot plant units, to model-based ones which included analysis of gas-solid reactors, gas-liquid reactors, fluidized-bed catalytic/non-catalytic reactors and prediction of multi-component phase behavior. Teams capable of bringing out fundamental aspects of complex systems also contributed to the technology transfer exercise.

While focus was on the development of processes and design and operation of pilot plants, conscious efforts were made to undertake basic studies in chemical engineering science. Right from the early days, NCL scientists made important contributions to chemical engineering science. Significant contributions were made in the areas of chemical engineering thermodynamics, phase equilibrium in process design, fundamentals of chemical kinetics, catalysis, study of catalytic and non-catalytic reactors and transport phenomena in multi-phase systems. The role of kinetics vis-à-vis transport limitations in multi-phase reactor systems, heat transfer in chemical reactors, selectivity and conversion in series/parallel reactions, conversion of batch data to continuous reactor design and finally selection of type and configuration of reactors were investigated at the NCL in the context of process design and scale-up. Unit operations involving all the mass and heat transfer operations, though simple, were studied at the laboratory to establish performance parameters like yield and choosing or specifying the proper equipment.

THE DESIGN CELL

A design cell was established in the mid-1960s. It was created with the object of preparing chemical engineering designs (wherever necessary) for processes offered by the laboratory for commercial exploitation. In the first year of its establishment, chemical engineering designs for the following were prepared:

- Semi-commercial aniline plant, 60 T/annum
- Dibutyl and dioctyl phthalates plant, 10,000 T/annum
- Dimethyl and diethyl phthalates plant, 1,500 T/annum
- Dimethylaniline plant, 600 T/annum

The activity grew over the years. Apart from preparing the basic engineering packages (BEPs), the design cell also worked with several industries to provide consultancy and advice on the design and drawings prepared by project engineering firms. NCL scientists undertook projects for preparing basic engineering packages (including design, engineering and operation manuals) for the processes developed at the laboratory. Care was taken to develop such a BEP as completely as possible to eliminate or to minimize errors in scale-up, be it a reactor or a distillation column. The emphasis was always on providing accurate process data, including dynamic, time-dependent data to mimick the plant operation before one was constructed.

BEYOND THE TRADITIONAL METHODS

A General Description

In recent years, the NCL enhanced its capability to optimize process design and scale-up based on state-of-the-art computational tools. The design teams at the NCL interacted with process chemists to obtain the necessary data on the one hand, and on the other interacted with chemical engineering researchers to implement modern methods of design and simulation. Several new contributions were made in developing new and better methods of design. Some of these were:

> New correlations for latent heats of vaporization, Prandtl number of organic liquids, dependence of fluidized-bed characteristics on relative pressure drops in the grid and the bed; kinetic models for a large number of systems; mass transfer in liquid-liquid extraction (new types of column internals); effect of fines and dilution in fluidized beds.

The NCL teams also made significant contributions to chemical reaction engineering analysis of a large number of chemical systems operating in a wide range of reactors. Several models and methods were developed to establish optimum design and operation strategies. The focus in the early days was on fluidized-and fixed-bed vapor-phase reactors. Several experimental and modeling studies were carried out to test new design concepts and to optimize internals. New contributions in the understanding of diffusion in catalyst and fouling of catalyst were made. New ways of optimizing reactor hardware and operating protocols were developed. Similarly, detailed analysis of gas-liquid reactions was made and a mathematical framework to explain the diffusion-reaction behavior of heterogeneous systems was developed. New insights were obtained by comparing gas-solid and gas-liquid reactions/reactors. In those days (1970s), very little work was available on the modeling of solid-solid reactions. A comprehensive research program on solid-solid reactions was undertaken. The focus was not only on reaction kinetics but also on understanding the influence of diffusion.

In the late 70s, a comprehensive biochemical engineering program was initiated. Engineering studies on immobilized enzyme reactors were carried out. The theoretical framework and efficient methods for developing optimum operating policies (temperature, pH) for deactivating enzyme reactors were developed. The biochemical engineering group has since been involved in a variety of projects which included microbial fermentation (enzymes, organic acids and secondary metabolites), immobilization of enzymes and ligands on polymeric and inorganic matrices for bioconversion of drug intermediates, recovery of antibiotics and enzymes using microfiltration and ultrafiltration, clarification of fruit juice and process development, and beta-carotene synthesis by yeast. It has also been involved in developing applications of membrane separations in chemical and biochemical processes. A separate group was established to develop polymer/ceramic membrane based separations, including membrane development, adsorption separation and reactive separation. The group developed indigenous membranes for a variety of applications including those for drinking water applications.

About the same time, significant programs were started on polymer science and engineering. Comprehensive reaction engineering models and computer programs were developed to simulate polycondensation reactions. These models were used to realize performance enhancements in industry. This framework was later on used to undertake a contract research project from DuPont on developing a new polyethylene terpthalate finisher. The influence of micro-mixing on polymerization reactions was studied. Based on these studies, innovative reactor configurations for styrene acrylonitrile reactors were developed. Models and methods were developed to carry out stability analysis of polymerization reactors. Fundamental studies on kinetic mechanisms of several polymerization reactions were carried out.

While developing these different branches, a comprehensive program to upgrade the capabilities of designing and optimizing separation and distillation trains was undertaken. Computational models and programs were developed for several separations related projects ranging from absorption of CO_2 and H_2S in amines to complex multi-component distillations including azeotropic and extractive distillations. Early work on thermodynamics and equilibrium calculations facilitated in making these programs useful in practice. Later on, NCL scientists started using CHEMCAD and ASPEN to accelerate their studies on process modeling and optimization. Apart from separations, the design cell also developed models and methods for optimizing heat exchanger network. These methods were successfully used in realizing performance enhancements in various industries. The design cell also undertook development of several simulation packages for various industries (for example, naptha reformer, PET reactor, granulator, and so on).

Computational Fluid Dynamics (CFD) and Miniaturization

In the mid-1990s, the development of computational fluid dynamics (CFD) based models was started. In-house CFD codes to simulate dispersed multiphase flows were developed. New models were proposed to simulate gas-liquid, gas-solid and gas-liquid-solid flows. A group called the industrial flow modeling group was established. Based on the strength of work carried out by this group, a leading CFD software vendor, Fluent Inc., USA, signed a partnership agreement with the NCL. The industrial flow modeling group develops and harnesses computational fluid dynamics and other modeling tools to understand, optimize and develop complex industrial processes and products. It has developed multi-scale modeling capabilities (computational/experimental) to address reactor and product engineering issues and has applied these tools creatively to realize performance enhancements in industrial practice. The group has developed new approaches and CFD-based models which have led to new insights into inherently unsteady multiphase flows in a variety of reactors (stirred reactors, bubble-column reactors, trickle-bed reactors, rotary kilns and fluidized-bed reactors). The models and CFD expertise developed at the NCL were used for carrying out several industrial contract research projects from Indian as well as foreign industries. In the early years, most of these assignments were for providing retrofit solutions to reactors existing in industries. In recent years, efforts were made and are being made to develop better products using computational models (for example, spacers for membrane modules, nozzles for FCC riser reactors, micro-reactors and so on). The group's methodology and some case studies were recently published in a book by Ranade (2002), who has been leading the NCL's process design group since around 2000 and has been responsible (with the help of a few bright young entrants, including Amol Kulkarni) for introducing many modern and innovative features.[19]

In the early 90s, a process engineering unit was established at the NCL with the intention of building a team capable of preparing technology packages based on state of the art computational tools and experiments on pilot scales. However, for some reason, the experiment was not very successful. Despite the excellent contributions of different groups within the NCL in advancing the science of design and scale-up, the interaction among different groups was not very synergistic. Better ways of realizing such synergistic interaction might lead to significantly higher benefits to the laboratory/society at large.

More recently, an elaborate program on the use of micro-reactors was started. Typically, these miniaturized process devices include, in addition to micro-reactors, micro-heat exchangers, micro-distillation devices, micro-hydrocyclones, micro-mixers, etc. The research is aimed at the development of design guidelines as well as scale-up strategies based on the use of these tiny process equipment through experimental as well as CFD methods. An industrial consortium on miniaturization has been formed, for the first time in India, on the use of micro-devices for formulating design strategies.

Is The NCL Getting Smart?

Following the advent of Western science, the various fields of chemical science were broadly classified into a few (classical) disciplines, such as inorganic chemistry, organic chemistry, physical chemistry, and biochemistry, to which polymer chemistry was added a few years later. The numbers increased with the years and new areas emerged, largely in accord with the practice outlined in the introduction to this chapter. Somewhere along the line, classification based on end use or starting materials, i.e. functional division of science, such as medicinal chemistry, glass and ceramics, fuels, petroleum chemistry, coal chemistry, plastics, materials science, leather science, food science, aeronautics, plant science, catalysis, natural products chemistry, etc. became popular. On this was superimposed, though not completely, in the early 1990s what has come to be known as “smart science.” For the first time, smartness of the human mind was supplemented (thankfully not fully replaced) by the smartness of the subject of study. The most visible example of this transformation is the emergence of smart particles, known to many before the smart age as nanoscience. The NCL’s nanoscience group is still known by this name, but I suspect it will not be long before the smart invasion subsumes this too. The discovery laboratory suggested later in Chapter 18 could well be called the smart molecules lab! Chemical reaction engineering can lay claim to the imposing name smart reactors, and polymer science and engineering to the name smart macromolecules or something even more flamboyant. In any case, the NCL will not be found wanting in getting aboard the smart wagon. This is perhaps as it should be, because small is getting smaller and the smaller is getting more numerous by the day, with trillions of magical particles — now there, now not there — passing through the earth every second. The *boson*, so named by the legendary Nobel Prize-winning Paul Dirac after Satyen Bose, and dubbed by another Nobel Laureate Leon Lederman (1993) the God particle, is perhaps that controversial particle. Soon the numbers may exceed the human imagination, and a truer, larger infinity may await the grasp of a future mind. (Let us not forget that infinity is not just a huge number, in fact not even a number; the increasing speculative understanding of the universe’s evolution has stayed this march of numbers, and has made infinity a conceptually mind boggling entity, if indeed it were one — for how can something freed of dimensions, small or large, be anything?)

> *The universe is full of magical things patiently waiting for our wits to grow sharper.*
>
> Eden Philpotts, 2004

Selected Important Publications

Chapter 5 listed many points, including some highly visible research publications that justified the quality of excellence attributed to it. It seems logical to conclude the present chapter with a rigorous selection of publications that have placed NCL on a pedestal of its peers’ making. Box 8.7 (on the following page) attempts to do this.

Box 8.7: Research papers that gave the NCL its mammoth moments — and peer esteem round the world

NCL has published over 10,000 papers, many of them in highly prestigious journals as summarized in Box 8.1. The selection given in the present table is based largely on inputs by the concerned scientists or experts in the areas and my personal judgment. NCL has also taken over 2000 patents, national and international (mostly US and European), but they are not considered here.

- **Chemical Biology**

Fluorescent d(CGCGA$_2$T$_2$CGCG): Characterization of major groove polarity and study of minor groove interactions through a major groove semantophore conjugate. Barawkar, D. A. and Ganesh, K. N., *Nucleic Acids Res.*, ***23,*** 159 (1995).

This was the first publication in which experimental approaches to measure local dielectric constants in a macromolecule such as DNA were announced. Dielectric constant is classically described as a bulk property. However in biomacromolecules like DNA which fold into complex structures, the difference between the values in the major and minor grooves was shown to be as high as 30. This observation prompted two famous theoreticians to optimize theoretical methods for computing dielectric constants, and NCL scientists to undertake further investigations.

Synthesis of site-specific oligonucleotide-polyamine conjugates, Barawkar, D. A., Kumar, V. A., and Ganesh, K. N., *BioMed. Chem. Lett*.**,** **4**, 1733 (1994).

The use of DNA and DNA analogues as antisense agents, a radically new concept in medicinal chemistry, had just emerged and generated intense activity in this area in pharma science. However, DNA/analogues cannot enter the cells since their negative charge is repelled by that on the membranes. This highly cited paper proposed a novel and original method for overcoming this problem.

Aminoethylprolyl peptide Nucleic Acids(aepPNA): Chiral PNA analogues that form highly stable DNA:aepPNA$_2$ triplexes, D'Costa, M., Kumar, V. A., and Ganesh, K. N., *Organic Lett.*, **1**, 1513 (1999).

Peptide Nucleic Acids (PNAs) as novel DNA analogues emerged in the 1990s for potential antisense activity. These have no charged backbones and are achiral. These properties made them bind DNA or RNA equally well with high affinity but in both parallel and antiparallel orientations. In approaches to modify them to specifically bind DNA or RNA, in parallel or antiparallel directions, this paper introduced for the first time the simultaneous incorporation of chirality and cationic PNAs in a single modification. This idea was picked up by several researchers leading to a variety of PNA modifications both from the NCL group as well as others.

(SR/RS)-cyclohexanyl PNAs: Conformationally preorganised PNA analogues with unprecedented preference for duplex formation with RNA, Govindaraju, T., Kumar, V. A., and Ganesh, K. N., *J. Am. Chem. Soc.*, **127**, 4144 (2005).

Using the concept mentioned in the previous paper, the NCL group designed and demonstrated a remarkable PNA analogue cyclohexanyl PNA which showed unprecedented affinity to RNA.

Enhanced triple helix stability of collagen peptides with 4R-Aminoprolyl (Amp) residues: role of inductive and hydrogen bonding effects, Babu, R., and Ganesh, K. N., *J. Am. Chem. Soc.*, **121**, 2079 (2001).

Collagen is a protein of great importance (30% of human protein) and is of historic importance to India as G. N. Ramachandran at Madras University was the first to decipher its structure in a seminal paper in *Nature* in 1954 and introduced to the world the concept of coiled coils. In the NCL paper, a method was suggested for modifying the structure by introducing an amino group at a crucial position. These modified collagens will have great applications as the amino groups can crosslink the triplex bundles of the collagen and are being currently developed as potential tissue engineering biocompatible materials.

(*Continued*)

Box 8.7: (*Continued*)

HIV-1 Tat directly binds to NF°B enhancer sequence: Role in viral and cellular gene expression, Dandekar, D. H., Ganesh, K. N., and Mitra, D., *Nucleic Acids Res.*, **32**, 1270 (2004).

This is a highly original and a very novel paper in the area of HIV. The protein Tat is present in virus and was thought to play an important part by binding to TAR RNA and help continue the stalled synthesis of viral RNA. It was demonstrated through a novel experiment using SELEX that the protein also binds to the DNA region and more importantly to the NFkB regulatory region. This would then enable the control of several immunomodulatory properties and thus help explain the many pleiotropic properties. The discovery is now enabling newer directions for discovering HIV drugs with NFkB-Tat interactions as novel targets.

Linear superclusters of gold particles by electrostatic assembly on DNA templates, Kumar, A., Pattarkine, M., Bhadbhade, M., Mandale, A. B., Ganesh, K. N., and Sastry, M., *Adv. Mater.* **13**, 341 (2001).

This paper proposed for the first time the use of polyanionic DNA as a template to organize gold nanoparticles laced on the surface by lysine, a positively charged amino acid. The randomly ordered positively charged gold nanoparticles upon addition of a piece of DNA get ordered on the surface. Such a method of ordering has great potential in developing molecular wires and electronic circuits. This work has attracted several bioelectronic and material scientists to the area, and NCL has also been pursuing the idea to design nanomolecular wires.

- **Plant Microbiology**

Denaturation-reassociation properties of the genome of *Phaseolus vulgaris*, Seshadri, M. and Ranjekar, P. K., *Hoppe-Seylor's Zeitschrift fur Physiol. Chemie*., **361,**1041 (1980).

An unusual pattern of genome organization in two *Phaseolus* plant species, Seshadri, M. and Ranjekar, P. K., *Biochim. Biophys. Acta*, **610,** 211 (1980).

Novel DNA sequence organization in rice genome. Gupta, V. S., Gadre, S. R., and Ranjekar, P. K., *Biochim. Biophys. Acta*, **656(2),** 147 (1981).

Plant molecular biology research was initiated in India in the early 1980s and NCL was at the top in plant genome analysis in important crop plants such as legumes and cereals. This research laid the foundation for further plant biotechnology research at NCL, which was funded by international agencies such as Rockefeller Foundation and McKnight Foundation.

Microsatellite (GATA) reveals sex specific differences in papaya., Parasnis, A. S., Ramakrishna, W., Chowdari, K. V., Gupta, V. S., and Ranjekar, P. K., *Theor Appl. Genet.* **99**, 1047 (1999).

A highly reliable sex diagnostic PCR assay for mass screening of papaya seedlings, Parasnis, A., Gupta, V.S., Tamhankar, S., and Ranjekar, P. K., *Molecular Breeding,* **6**, 337 (2000).

Since half of the papaya plants are male, it is very important to have maximum female fruit bearing papaya plants for the papaya growers. The two papers listed above show how, using DNA markers, the sex of the plants could be identified at the seedling stage enabling the papaya breeders to remove male plants and have mostly female plants, thereby enabling the breeders to double the papaya fruit yield.

- **Heterogeneous Catalysis**

Titanium silicate -2, Reddy, J. S., Kumar, R., and Ratnasamy, P., *Applied catalysis*, **58** (2)L1-L4(1990). Cited 130 times since 1991.

This paper announced the discovery of a new titanosilicate zeolitic material, the first from India.

Direct catalytic hydroxylation of benzene with hydrogen peroxide over titanium silicates zeolites,

(*Continued*)

Box 8.7: (*Continued*)

Thangaraj, A., Kumar, R., and Ratnasamy, P., *Applied Catalysis*, **57** (1), L1-L3 (1990).

This paper announced for the first time a novel process for the direct hydroxylation of benzene in one step to phenol using hydrogen peroxide over a solid catalyst.

Selective oxidation over copper and manganese salens encapsulated in zeolites, Jacob, C. R.,. Verkey, S. P. O., and Ratnasamy, P., *Microporous and Mesoporous Materials*, **22** (1–3), 465 (1998).

Oxidation of cyclohexane over copper pthalocyanines encapsulated in zeolites, Raja, R. and Ratnasamy, P., *Catalysis Letters*, **48** (1–2) (1997).

These papers, which were published only about 7–8 years ago, have already been widely cited.

Note: A paper, published with Helmut Knozinger when Ratnasamy was in IIP, is said to have been cited over 1000 times, and according to colleagues of Prof. J. M. Thomas at Cambridge it is the most cited paper in the catalysis area.

Selective oxidation of methane to CO and H_2 over Ni/MgO at low temperature, Choudhary, V. R., Mamman, A. S., and Sansare, S. D., *Angew. Chem. Int. Ed. Engl.*, **31**, 1189 (1992).

Reported for first time the low temperature (700 ºC) selective partial oxidation of methane to CO and H_2 with high conversion ($>$ 90 %) and selectivity ($>$ 90 % for both CO and H_2) at very low contact time (about 2 milliseconds), using a non-noble metal catalyst.

Coupling of exothermic (heat releasing) oxidative conversion and endothermic (heat absorbing) CO_2 and steam reforming of methane to syngas over NiO-CaO catalyst, Choudhary, V. R., Rajput, A. M., and Prabhakar, B., *Angew. Chem. Int. Ed. Engl.*, **33**, 2104 (1994).

By carrying out, for the first time, the partial oxidation of methane (a heat generating reaction) simultaneously with oxy-steam-CO_2 reforming of methane (a heat absorbing process) over NiO-CaO catalyst, methane could be converted to syngas with high conversion ($>$ 95%) and 100% selectivity for both CO and H_2.

Coupling of endothermic thermal cracking with exothermic non-catalytic oxidative conversion of ethane to ethylene, Choudhary, V. R. and Mulla, S. A. R., *AIChE J.*, **43,** 1545 (1997).

By carrying out the thermal cracking of ethane in presence of limited oxygen, both the highly endothermic (heat absorbing) thermal cracking of ethane and exothermic (heat releasing) oxidation of ethane occur simultaneously, making this process highly energy efficient. This novel process eliminates almost all the drawbacks of the conventional ethane cracking process.

Formation of nanosized zirconia-supported 12-tungstophosphoric acid in mesoporous silica SBA-15: A stable and versatile solid acid catalyst for benzylation of phenol, Dhanashri, P. S., Vinu, A., Jacob, N. E., Lefebvre, F., and Halligudi, S. B., *J. Catalysis*, **235**, 341(2005).

In this study, listed as one of the top 25 published in the journal, zirconia-supported tungstophosphoric acid (TPA) composite was dispersed in nanosize range 3–4 nm on mesoporous silica SBA-15 after calcination at 1123 K. In a remarkable finding, 15%TPA/22.4%ZrO_2/SBA-15 calcined at 1123 K was ten times more active than the neat TPA/ZrO_2 in the liquid phase benzylation of phenol with benzyl, alcohol to give mainly mono benzylphenol.

- **Homogeneous Catalysis**

Enhancement of interfacial catalysis in a biphasic system using catalyst binding ligands, Chaudhary, R. V., Bhanage, B. V., Deshpande, R. M., and Delmas, H., *Nature*, **373**, 501 (1995).

(*Continued*)

Box 8.7: (*Continued*)

A new concept of promoting interfacial catalytic reactions using catalyst binding ligands has been experimentally demonstrated, which leads to 50-100- fold rate enhancements in biphasic hydroformylation reactions. This occurs due to the greatly enhanced concentrations of reactants in the organic phase and the organic-aqueous interface.

Oxidative carbonylation of aniline over palladium/carbon catalyst: Effect of promoters, solvents and reaction conditions, Gupte, S. P. and Chaudhary, R. V., *J. Catalys.*, **114** (2), 246, (1988).

This represents the first detailed study of the catalysis aspects of the oxidative carbonylation reaction, and provides an alternative non-phosgene route for carbamates and isocyanate synthesis.

Pt and Pd nanoparticles immobilized on amine-functionalized zeolite: Excellent catalysts for hydrogenation and heck reactions, Mandal, S., Roy, D., Chaudhari, R.V., and Sastry, M., *Chemistry of Materials,* **16** (19), *371*, (2004).

A new approach to anchoring metal nano-particles has been illustrated to synthesize supported nano metal catalysts with significantly higher activity. The approach has been demonstrated for immobilization of nano size platinum and palladium catalysts including a complete characterization of the catalysts.

- **Natural Products Chemistry**

Organic chemistry has been the largest single area of research at NCL since inception, and has always been among the top few in the country. The group has published several hundred papers, determined the structures of over 150 organic molecules, and discovered a few new molecules. These are largely associated with the names of Venkataraman, Sukh Dev, Bhattacharyya, and Rama Rao, and their associates A. S. Rao, U. R. Nayak, B. A. Nagsampagi, Y. H. Yadav, K. K. Chakraborty, A. S. Gupta, D. N. Bose, S. C. Sethi, and many more. As the number of excellent papers published by the groups (principally those of Venkataraman, Bhattacharyya, Sukh Dev, and Rama Rao) working in this area is very large, the essence of their contributions is conveyed through the following capsule version of their papers. The most cited papers (80–90) are:

Terpinoids. 11. The structure of costunolide, a new sesquiterpenelactone from costus root oil, Rao, A. S., Kelkar, G. R., and Bhattacharya, S. C., T*etrahdron*, **9**, 275 (1960).

Amberlyst 15, a superior catalyst for preparation of enol ethers and acetals, Patwardhan, S. A., and Dev, S., *Synthesis-Stuttgart*, Issue 5, 348 (1974).

Sukh Dev's group is responsible for the isolation, chemical studies and determination of absolute stereostructures of scores of new complex molecules such as: zerumbone, longicyclene, himachalenes and related compounds, mayurone, mustakone, rotundone, cuparenones, lac constituents, hardwickiic acid, mukulol, devadarol and related compounds, cheilanthatriol, malabaricol, bakuchiol, kodocytochalasins, etc (Singh and Srikrishna, 2003). Many of these compounds represent new fundamental types in nature and have been termed classics (C & EN, Sept 1979, p 63). He is also responsible for two general rules in stereochemistry.

- **Synthetic Organic Chemistry**

Methodology for the synthesis of the spiro[4,4]nonane system: An approach for the total synthesis of fredericamycin, Rama Rao, A.V., Reddy, D. R. and Deshpande, V. H., *JCS Chem. Commun.*, 1119 (1984).

Fredericamycin was isolated from streptomycin griseus. It demonstrated anticancer activity that has an entirely novel spiro (4,4) nonane spiro system, which has not been observed in any other type of antibiotic. This paper describes the synthesis of this novel [4,4] spiro nonane system using thermal isomerization of cyclic enol and has been well cited.

(*Continued*)

Box 8.7: (*Continued*)

A stereoconvergent synthesis of (+)-4 demethoxydaunomycin, Rama Rao, A. V., Yadav, J. S., Bal Reddy, K., and Mehendale, A. R., *Tetrahedron*, **40**, 4643.3 (1984).

A steroconvergent synthesis of (+)4-demethyoxydaunomycin, Rama Rao,A. V.; Yadav, J. S.; Bal Reddy, K.; Mahendale, A.R. *JCS Chem. Commun*., 453 (1984).

Anthacyclinone antibiotics are a very important class of antitumor antibiotics isolated from streptomycin spp and have emerged as the most effective treatment for broad spectrum of human cancers. Synthetic analogs (such as 4 methoxy and 11 deoxy analogs of natural products have demonstrated about 10 times more potency than the natural product itself. In addition, enantioselectivity is also very important for superior biological activity.

The above two papers demonstrated a practical enantio selective synthesis of (+) 4 demethoxydaunomycine using Sharpless enantio selective epoxidation.

Synthesis of Lavendamycin, Rama Rao, A.V., Chavan, Subhash P., Sivadasan, Latha, *Tetrahedron*, **42**, 5065 (1986).

Lavandamycin is an antitumor antibiotic isolated from Streptomyces Lavendule has attracted large number of synthetic chemist's attention. This publication described the synthesis of lavendamycin starting from 8-hydroxyquinoline and Indole via Bischer-Napieraski cyclization attracted 28 citations.

A stereoselective synthesis of coriolic acid and dimophecolic acid, Rama Rao, A.V.; Rajarathnam Reddy, E. ; Sharma, G.V.M.; Yadagiri, P.; Yadav, J.S. *Tetrahedron Lett*. 26, 465 (1985).

Coriolic acid and Dimophecolic acids are two Ionophores are derived from heart mitochondria have shown as self defensive substances in rice plant against Rice blast deceases. This interesting activity attracted several synthesis chemist's attention for the total synthesis of these two compounds. Synthesis described in this paper starts from epichlorohydrin has attracted 46 citations.

(Trichloromethyl)-benzene: A versatile reagent for the preparation of substituted benzophenones, Ayyangar, N. R., Lahoti, R. J., Srinivasan, K. V., and Thomas, D., *Synthesis*, 322–23 (1991).

It was found that a variety of industrially important benzophenones can be prepared in high yield, selectivity and purity under mild reaction conditions at room temperature using this benzotrichloride aluminium chloride complex. It is a non-hygroscopic non-lachrymetric reagent and handling of the reagent in large-scale operation is easier. Being the precursor of benzoyl chloride it is cheaper and can be used very effectively.

Exceptionally stable phenyldichlorocarbenium ion as a Friedel-Crafts intermediate: A high-field multinuclear NMR study, Racherla, U. S., Daniel, T., Rajamohanan, P. R., Ayyangar, N. R., *J. Am. Chem. Soc.*, **111** (19), 7659 (1989).

This study demonstrated for the first time that it is possible to obtain exceptionally stable aryl dihalocarbenium ions under milder Friedel-Crafts reaction conditions. A high field NMR study of benzotrichloride–aluminium chloride complex also revealed that it possessed a remarkably higher degree of positive charge compared to the commonly used bezoyl chloride-aluminium chloride complex. and also possessed high stability. Thus it can be used as an off-the-shelf benzoylating agent.

- **Material Chemistry/Nanotechnology**

Bioreduction of AuCl4 ions by the fungus Verticillium sp. and surface trapping of the gold nanoparticles formed, Mukherjee, P., Ahmad, A., Mandal, D., Senapati, S., Sainkar, S. R., Khan, Md. I., Ramani, R., Pasricha, R.,. Ajayakumar, Alam, M., Sastry, M., and Kumar, R., *Angew. Chem. Int. Ed*., **40**, 3586 (2002).

(*Continued*)

Box 8.7: (*Continued*)

In this paper for the first time it was demonstrated that a fungus, *Verticillium sp.* (AAT-TS-4) — an eukaryotic organism — could be utilized in the biological synthesis of noble metal nanoparticles such as gold. This really was the first paper which paved the way for all further biomediated nanoparticle synthesis research at NCL.

Biological synthesis of triangular gold nanoprisms, Shiv Shankar, S., Rai, A., Ankamwar, B., Singh, A., Ahmad, A., and Sastry, M., *Nature Mater.*, **3,** 482 (2004).

This paper reported the discovery that an extract from the lemongrass plant, when reacted with aqueous chloroaurate ions, yields a high percentage of thin, flat, single-crystalline absorption by the particles, and highly anisotropic electron transport in films of the nanotriangles. It was very well received both by the scientific and nonscientific communities.

Keggin Ions as UV-switchable reducing agents in the synthesis of AuCore - AgShell nanoparticles, Mandal, S., Selvakannan, P. R., Pasricha, R., and Sastry, M., *J. Am. Chem. Soc.*, **125**, 8440 (2003).

This paper demonstrated the formation of Au core-Ag shell nanoparticles using photochemically reduced phosphotungstate Keggin ions. The use of Au nanoscale surface-bound switchable reducing agents such as that provided by Keggin ions enables the reduction of Ag + ions only on the surface of the gold particles, thus obviating the possibility of nucleation of fresh Ag nanoparticles in solution. This paper received wide spread attention from the academic community and was highlighted in *Science Editor's Choice.*

Gold nanoparticle networks with photoresponsive interparticle spacings, Sidhaye, D. S., Kashyap, S., Sastry, M., Hotha, S., and Prasad, B. L. V., *Langmuir*, **21**, 7979 (2005).

This paper described the formation of photoresponsive gold nanoparticle networks by functionalizing Au nanoparticles with azobenzene derivatives. It initiated work on functional hybrids of designed organic molecule-nanoparticles that defines a large part of NCL's nanoparticle research presently in progress.

- **Plant Tissue Culture**

Tissue culture of plant trees: Clonal multiplication of *Tectona grandis* Linn. (Teak) plant, Gupta, P. K., Nadgir, A. L., Mascarenhas, A. F., and Jagannathan, V., *Plant Sci. Lett.*, **17**, 259 (1980).

Elites in forest trees often can be identified only in mature trees which are difficult to propagate. This was the first report on multiplication by tissue culture of elite 100 year old teak trees.

Growth of mosaic-virus free sugarcane plants from apical meristems, Hendre, R.R., Mascarenhas, A.F., Nadgir, A.L., Pathak, M. and Jagannathan, V., *Indian Phytopathology* , **28,** 175 (1975).

This is the first report on the elimination of virus from sugarcane by tissue culture. This method is now widely used in India for virus elimination from sugarcane.

- **Enzymology**

Purification and properties of ox brain acetylcholinesterase, Kaplay, S. S. and Jagannathan, V., *Arch. Biochem. Biophys.*, 138, 48 (1970).

This enzyme is important in brain function and was available then only from an exotic source, electric eel. This paper was the first report on obtaining the pure enzyme from ox brain.

Interactions of a novel inhibitor from an extremophilic bacillus sp. with HIV-1 protease: Implications for the mechanism of inactivation, Dash, C. and Rao, M., *J. Biol. Chem.*, **276,** 2487 (1970).

This was the first report on a biologically derived peptidic inhibitor from an alkalothermophilic *Bacillus* species. The inhibitor is active against HIV-1 protease, a key enzyme in the life cycle of HIV, the causative agent of AIDS.

(*Continued*)

Box 8.7: (*Continued*)

Application of cellulases from an alkalothermophilic *Thermomonospora* sp. in biopolishing of denims. Anish R., Rahman, Md. S. and Rao, M., *Biotechnol. Bioeng.*, **96**, 48 (2007).

This paper reports for the first time the application of an alkalistable cellulase from an extremophilic alkalothermophilic *Thermomonospora* sp. in denims finishing replacing pumice stones. The use of enzyme imparts softness to the fabric, reduces hairiness causing fuzz with minimum weight loss and exhibits lower backstaining with high abrasive activity.

High activity alkaline protease production by a *Conidiobolus* sp. , Srinivasan, M. C., Vartak, H. G., Powar, V. K., and Sutar, I. I., **5**, Biotechnology Letters, 285 (1983).

This paper announced the discovery of *Conidiobolus*, a relatively less investigated fungus, as a source of high activity alkaline protease that is compatible with the requirements of the detergent and leather industries, which are the main users of these proteases.

High activity glucose (xylose) isomerase from a Chainia species, Srinivasan, M. C., Vartak, H. G., Powa, V. K., and Khire, J. M., *Biotech. Lett.*, **5**, 611 (1983).

Glucose isomerase is an important enzyme for the commercial manufacture of high fructose syrup. It is mostly an intracellular enzyme (i.e. occurs within the cells) in actinomycetes and bacteria. This paper announced the discovery of this isomerase as an extracellular enzyme (i.e. occurring outside the cells) from the actinomycete CHAINIA. It also reported the differential characterization of the glucose isomerase, as distinct from xylose isomerase in the secreted enzyme complex, and is a milestone contribution to enzyme technology.

Cellulae-free xylanase production from an alkalophilic Bacillus species, Balakrishnan, H., Dutta-Chaudhary, M., Srinivasan, M. C., and Rele, M. V., *World J. Microb. Biotech.*, **8** , 627 (1992).

This paper represents one of a series of papers on NCL's discovery of cellulase-free xylanases from natural populations of bacteria, actinomycetes and fungi, which are unique and pioneering contributions to enzyme technology with commercial application potential.

- **Chemical engineering science**

Instabilities due to surface transformations of adsorbed species: The case of hydrocarbon oxidation, Ravi Kumar, V., Kulkarni, B. D., and Doraiswamy, L. K., *Chem. Eng. Commun.*, **20**, 367 (1983).

Multiplicity and instability in isothermal homogeneous reactions in a CSTR: The case of autocatalysis, Ravi Kumar, V., Kulkarni, B. D., and Doraiswamy, L. K., *AIChE Journal*, **30**, 649 (1984).

On the robust control of nonlinear systems, Ravi Kumar, V., Kulkarni, B. D., and Deshpande, P. B., *Proc. Roy. Soc. Lond. Ser. A*, **433**, 711 (1991).

This paper deals with stabilizing unstable reacting systems by adaptive control and set the tone for considerable further work in NCL in the area of controlling systems with nonlinear dynamics (multiple steady states, oscillations, etc.).

Effects of coupling nonlinear systems with complex dynamics, Badola, P., Ravi Kumar, V., and Kulkarni, B. D., *Phys. Lett A.*, **155**, 365–372 (1991).

This is the first piece of work from NCL using the principles of chaos theory and that studied the role of coupling mechanisms in systems with complex dynamics. It is relevant to note that the study of such coupled systems has interdisciplinary applications in contemporary areas ranging from modeling of reactors to understanding brain function.

Analysis and characterization of complex spatiotemporal patterns in nonlinear reaction-diffusion systems, Parekh, N. Ravi Kumar, V., and Kulkarni, B. D., *Physica A*, **224**, 369–381 (1996).

(*Continued*)

Box 8.7: (*Continued*)

This paper showed that a mathematical model of a chain of CSTRs is an excellent paradigm for studying reaction-diffusion systems exhibiting pattern formation. Relationships of invariants like Lyapunov dimension and entropy that exist in turbulence as a function of its spatial size could be derived. In fact, their availability considerably eases the study of turbulent systems.

Simple denoising algorithm using wavelet transform, Roy, M. Ravi Kumar, V. Kulkarni, B. D., Sanderson, J., Rhodes, M., and van der Stappen. M., *AIChE J.*, **45**, 2461 (1999).

This publication was the first from NCL on wavelet transforms (one of the many, along with the popular Fourier transform, used in the mathematical transformation of signals) to demonstrate their utility in devising useful algorithms and realizing practical applications. The basic principles developed in the publication have been implemented by several interdisciplinary research groups and industries.

Parameter estimation in spatially extended systems: The Karnhunen-Loeve and Galerkin multiple shooting approach, Ghosh, A., Ravi Kumar, V., and Kulkarni, B. D., *Phys. Rev. E.*, **64**, 056222 (2001).

This is a sophisticated algorithm for estimation of all operational and intrinsic parameters in space-time systems exhibiting complex dynamics. It ingeniously circumvents the numerical problem of getting stuck in local minima during optimization, and can efficiently handle experimental data corrupted with noise.

Isometric graphing and multidimensional scaling for reaction-diffusion modeling on regular and fractal surfaces with spatiotemporal pattern recognition, Kuriakose, J., Ghosh, A. Ravi Kumar, V., and Kulkarni, B. D., *J. Chem. Phys*, 120, 5432 (2004).

This unique paper addresses the problem of studying huge databases that contain information/data in reacting systems. Fault detection by correlating chemical plant data (say, data obtained today with data obtained at an earlier date, extending to years) is now made possible by this methodology. The software developed for this has been embedded in an analysis unit of a chemical plant producing yarn and owned by Invista, USA, a multinational company.

- **Theoretical Chemistry**

Exact solution of the adsorption integral equation for a heterogeneous surface, Prasad, S. D. and Doraiswamy, L. K., *Chem. Phys. Lett.*, **108**, 83 (1984).

The adsorption integral equation: A new method of solution, Prasad, S. D. and Doraiswamy, L. K., *Phys. Lett. A*, **60**, 11 (1977).

The adsorption integral equation is a rigorous equation for representing adsorption on a non-ideal catalyst surface. Several solutions have been published over time, but the two cited above are the only ones for integrating the equation between practically observable limits and hence are of much greater practical value.

A constrained variational approach for energy derivatives in Fock-space multireference coupled-cluster theory, Shamasundar, K. R., Asokan, S., and Pal, S., *J. Chem. Phys.*, **120** (14), 6381 (2004).

This is the most complete version of the pioneering formulation of the multireference coupled-cluster theory response that was developed at NCL.

Structural, electronic, and bonding properties of zeolite Sn-beta: A periodic density functional theory study, Shetty, S., Pal, S., Kanhere, D. G., et al., — *European J. Chem.* **12** (2), 518 (2006).

It has been demonstrated that the substitution of tin atoms in the BEA framework (an important aspect of zeolite catalysys) is an endothermic process and hence the incorporation of tin in the BEA is limited. Using theoretical considerations, the significant observation has been made that the T2 site is the most favorable site for the substitution of tin atoms in the BEA framework.

(*Continued*)

Box 8.7: (*Continued*)

Critical study of local reactivity descriptors for weak interactions: Qualitative and quantitative analysis of adsorption of molecules in the zeolite lattice, Pal, S. and Chandrakumar, K. R. S., *J. Am. Chem. Soc.*, **122** (17), 4145 (2000).

The adsorption of gaseous molecules inside a zeolite lattice was studied using, among many descriptors, the Fukui function-based descriptors and the local hard-soft acid-base (HSAB) principle. This represents the first time that the local HSAB principle has been successfully used for quantitative description of weak adsorption cases.

Principle of maximum hardness: An *ab-initio* study, Pal, S., Vaval, N. and Roy, R., *J. Phys. Chem.*, **97**, 4404 (1993).

The important principle of maximum hardness (PMH) was tested through an accurate quantum chemical calculation. Through this most rigorous test yet, it was shown that symmetric stretching does not provide any maximum of hardness, but asymmetric stretching does. It also showed for the first time the importance of keeping the chemical potential constant.

Use of cluster expansion methods in the open shell correlation problem, Mukherjee, D. and Pal, S. *Adv. Quant. Chem.*, **20**, 291 (1989).

This state-of-the-art paper is a comprehensive development in cluster expansion methods to-date, emphasizing the scaling of the methods with size of the system. Valence-universal and state-universal versions of multireference coupled-cluster methods and the utility of these in chemical problems have been highlighted.

- **NMR Spectroscopy**

Promoter induced enhancement of crystallization rates in zeolites and related molecular sieves, Rajiv Kumar, Bhaumik, W., Ahedi, R., and Ganapathy, S., *Nature,* **381,** 298 (1996).

REAPDOR NMR Spectroscopy and location of cations in molecular sieves, Ganapathy, S. and Vega, S., *J. Am. Chem. Soc***. 120**, 1072 (1998).

Triple Quantum Magic Angle Spinning ^{27}Al NMR of Aluminum Hydroxides Damodaran, K., Rajamohanan, P. R., Chakrabarty, D., Uday Racherla, Fernandez, C., Amoureux, J. P., and Ganapathy, S., *J. Am. Chem. Soc* **124**, 3200 (2002).

Identification of distinct Bronsted acidic sites in zeolite mordenite by proton localization and [^{27}Al]-^{1}H REAPDOR NMR, Ganapathy, S., Rajiv Kumar, Delevoye, L., and Amoureux, J. P., *Chemical Communications* **16**, 2076 (2003).

As cited in the four papers above, the focus of research by the NCL NMR group, over the last two decades, was on developing and advancing new methods in Solid State Nuclear Magnetic Resonance and exploring new applications in materials science. Highlights of the published work include: promoter-enhanced crystallization of zeolites, published in *Nature* (ref. 1), development of new NMR structure elucidation tools for advanced porous and layered materials (ref. 2-4), and hydration, rheology and dynamics of polymers (see Polymer Science and Engineering).

- **Polymer Science and Engineering**

Solid state polymerization of aromatic polycarbonates. A facile route to high molecular weight polycarbonates, Iyer, V.S., Sehra, J.C., Ravindranath K and Sivaram S., *Macromolecules*, **26** 1186 (1993).

This paper was one of the first in NCL to follow Mashelkar's call for "patent, publish or perish." This work was granted a US patent 5,266, 659 on November 30, 1993 and published thereafter. This paper and many to follow on this topic led GE Plastics, USA to establish a research partnership with NCL.

(*Continued*)

Box 8.7: (*Continued*)

Tailoring carbonion structures for controlled anionic polymerization of acrylonitrile, Dhal, P.K., Kashikar, S.P., Khisti, R.S., Shinde, B.M., Baskaran, D., and Sivaram, S. *Macromolecules*, **24**, 1967 (1991).

This was the beginning of NCL's forays into the area of controlled anionic polymerization. NCL become a globally recognized center of research in the area of metal free catalytic for anionic polymerization.

Anionic polymerization of alkyl (methacrylate)s using metal free initiators. Effect of ion pairing on initiation equilibria, Baskaran, D., Chakrapani, S., Sivaram, S., Hogen-Esch, T.E., and Muler, A.H.E., *Macromolecules*, **32**, 2865 (1999).

This was definitive paper that came at the end of a decade of research which became the "last word" in this class of polymerization. This paper unequivocally established the mechanism of polymerization, a subject that has provoked many controversies around the world and widely discussed in conferences.

Role of trimethylaluminum in the zirconocene-methylaluminoxane catalyzed polymerization of ethylene, Reddy, S.S., shashidhar, G.V.S., and Sivram, S., *Macromolecules*, **26**, 1180 (1993).

This paper marked the beginning of NCL's activity in the area of olefin polymerization using metallocene and post metallocence catalysts. Subsequent contribution from NCL led to it being recognized as a major center for research in this area.

A new analytical solution of the binary copolymer composite: An equation and suggested procedure for deriving the monomer reactivity ratios, Joshi, R. M. and Joshi, S. G., *J. Macromol. Sci. Chem.*, **A5**, 1329 (1971).

Knowledge of copolymer reactivity ratios is essential in the preparation of copolymers. The formula given in this paper, known as the Joshi-Joshi formula, was the first analytical solution for finding the reactivity ratios of binary copolymerization system. It is included in many textbooks in polymer science.

Proton MASS NMR - A new tool to study thermoreversible transitions in hydrogels, Ganapathy, S., Badiger, M. V., Rajamohanan, P. R., Kulkarni, M. G., and Mashelkar. R. A., *Macromolecules.* **24**, 106 (1991).

Hydration in polymer studied through Magic Angle Spinning Nuclear Magnetic Resonance and heteronuclear ^{13}C- {^{1}H} Overhauser enhancement spectroscopy: Cross-relaxation and location of water in ploy(acrylamide), Ganapathy, S., Rajamohanan, P. R., Ray, S. S., and Mashelkar, R. A., *J. Chem. Phys.*, **103**, 6783 (1995).

In situ Rheo-NMR investigations of shear-dependent ^{1}H spin relaxation in polymer solutions, Badiger, M. V., Rajamohanan, P. R., Ganapathy, S., and Mashelkar, R. A., *Macromolecules*, **35**, 126 (2002).

The three papers cited above represent NCL's original contributions to the elucidation of the structure and behavior of water absorbing polymers since the serendipitous discovery of one such polymer which was later named Jalshakti. Undertaken in collaboration with the NMR group, this led to the development of new NMR structure elucidation tools for advanced porous and layered materials and for the study of the hydration, rheology and dynamics of polymers.

Finishing stages of PET synthesis: A comprehensive model, Ravindranath, K. and Mashelkar, R. A., *AIChE J.*, **30**, 415 (1984).

Thermodynamics of hydrogen bonded polymer gel-solvent systems, Lele, A. K., Hirve, M. M., Badiger, M. V., and Mashelkar, R. A., *Chem. Eng. Sci.*, 5**0** (22), 3535 (1995).

Energetically crosslinked transient network (ECTN) model: Implications in transient, Lele, A. K. and Mashelkar, R. A., *J. Non-Newtonian Fluid Mechanics*, **75** (1), 99 (1998).

Switching biomimetric hydrogels, Kamalkar, R. N., Premnath, V., Kulkarni, M. G., and Mashelkar, R. A., *Proc. Roy. Soc.*, **456,** 1305 (2000).

(*Continued*)

Box 8.7: (*Continued*)

The challenge in designing synthetic enzyme mimics has been to replicate the specificity and reactivity of the natural enzymes. This paper describes a novel synthetic approach that exploits the concept of molecular imprinting to design a chymotrypsin mimic. The paper further demonstrates how the activity of mimics can be switched on/off in response to specific stimuli such as light and pH.

Designing a self-associated cationic polymer for enhanced compatibility palatability and gastric release of cefuroxime axetil., Menjoge, A. R. and Kulkarni, M. G., *Biomacromolecules*, **8**, 532 (2007).

This investigation demonstrated how the self-associations within the new reverse enteric polymer (NREP) eliminate adverse drug-polymer interactions, and leads to enhanced drug bioavailability. The rigidity conferred by the choice of 4 vinyl pyridine and self-associations enhance thermal stability and lower adhesion to cell line enhancing biocompatibility.

Formation of linear polymers with pendant vinyl groups via inclusion complex mediated polymerization of divinyl monomers,. Satav, S. S., Karmalkar, R. N., Kulkarni, M. G., Mulpuri, N., and Sastry, G. N., *J. Am. Chem. Soc.*, **128**, 7752 (2006).

Supra molecular chemistry is an emerging multi-disciplinary research area that has potential applications in diverse fields. This paper shows how inclusion complexes of cyclodextrin (well known in organic chemistry) with divinyl monomers enables selective polymerization of divinyl monomers. These polymers find wide ranging applications in drug delivery, optical wave guides, as selective adsorbents, etc.

A Rheological Study on the Kinetics of Hybrid Formation of Polypropylene Nanocomposites, Galgali, G.; Ramesh, C. and Lele, A. K., *Macromolecules*, **34**, 852 (2001).

This paper reported for the first time careful creep rheological studies on melt compounded polypropylene organo-clay composites and showed that such materials exhibit an engineering yield stress and that their “solid-like” response is actually the manifestation of a high viscosity Newtonian liquid state. The presence of a yield stress is relevant to industrial polymer processing operations. This paper has already been cited over 200 times.

Flexible Ring Polymers in a Obstacle Environment: Molecular Theory of Linear Viscoelasticity, Iyer, B. V. S, Juvekar, V. A., and Lele, A. K., *Physical Review E*, *021805*, 1 (2006).

In this paper, which has already begun to receive wide attention, a rigorous theory was proposed to understand the dynamics of an interesting class of polymer chains, viz. endless or ring polymers, which are placed in a topologically confining environment such as in a 3D gel. This problem is of interest in separation of plasmid DNA using gel electrophoresis. It is also of fundamental interest in understanding how endless polymers can escape out of a topologically confining field. The dynamical model was further used to derive a constitutive equation for a melt of ring polymers. The predictions of the model compared well with one of the few sets of experimental viscoelastic data available on pure ring polymers.

- **Chemical Reaction Engineering**

An initial value approach to reaction-diffusion problems, Namjoshi, A., Kulkarni, B. D., and Doraiswamy, L. K., *AIChE Journal*, **30**, 915 (1984).

By reducing the diffusion-reaction problem in a solid catalyst from its intrinsic boundary value nature to an initial value problem, the solution has been greatly simplified and made much more useful.

Gas-solid reactions: An unusual observation in the disproportionation of potassium benzoate to terephthalate, Gokhale, M. V. Naik, A. T., and Doraiswamy, L. K., *Chem. Eng. Sci.*, **30**, 1409 (1975).

Gas-solid reactions: Experimental evaluation of the zone model, Prasannan, P. C. and Doraiswamy, L. K., *Chem. Eng. Sci.*, **37**, 925 (1982).

(*Continued*)

Box 8.7: (*Continued*)

NCL's work on gas-solid reactions has been widely recognized. The first paper reports for the first time a reaction in which it starts at the center of the solid, unlike the common case of starting at the surface and moving to the center. The second verifies for the first time the three-zone model by experimental determination of reactant profile in the three zones by electron probe measurement studies.

Solid-solid reactions: Diffusion and reaction in pellet-pellet systems, Tamhankar, S. S. and Doraiswamy, L. K., *Ind. Eng. Chem./Fundam.*, **17**, 84 (1978).

Studies in solid-solid reactions — Autocatalysis in the reduction of cuprous chloride by silicon, Tamhankar, S. S., Gokarn, A. N., and Doraiswamy, L. K., *Chem. Eng. Sci.*, **36**, 1365 (1981).

NCL was among the first research centers to work on the engineering science of solid-solid reactions. In addition to a rigorous theoretical model of such a reaction proposed in the first paper, NCL scientists were also the first to identify in the second paper listed above an autocatalytic reaction for a very useful industrial process. The autocatalytic nature of the reaction was verified from experimental kinetic data, and a rate equation was proposed that represented the data with remarkable accuracy.

Phase-transfer catalysis: Chemistry and engineering, Naik, S. D. and Doraiswamy, L.K., *AIChE J.*, **44**, 612 (1998).

- **Thermodynamic and Transport Properties**

A generalized method for estimating heats of vaporization, Kunte. M. V. and Doraiswamy, L. K., *Chem. Eng. Sci.*, **12**, 1 (1960).

Estimation of heats of formation of organic compounds, Verma, K. K. and Doraiswamy, L. K. *Ind. Eng. Chem./Fundam.*, **4**(4), 389 (1965).

Estimation of the heat capacity of organic compounds from group contributions, Rihani, D. N. and Doraiswamy, L. K., *Ind. Eng. Chem./Fundam.*, **4**(1), 17 (1965).

Estimating liquid diffusivities, Reddy, K. A. and. Doraiswamy, L. K., *Ind. Eng. Chem./Fundam.*, **6**, 77 (1967).

The first of the above four papers was the first to propose a generalized chart based on reduced coordinates (temperature and pressure) for estimating heats of vaporization. The second and third were the most comprehensive and accurate at the time for estimating the heat capacities and heats of formation of organic compounds, and were included in every book on the subject as being among the methods of choice. The fourth was also widely referred and used but to a lesser extent.

- **Papers with over 100 citations (all areas)[†]**

Sonochemistry: science and engineering, Thompson, L. H. and Doraiswamy, L. K., *I&EC Research*, **38**, 1215 (1999), has become a classic. It is the 5th most-cited paper published in *Industrial & Engineering Chemistry Research* over the past 10 years, and one of the most cited in the history of the journal.

Phase transfer catalysis: chemistry and engineering, Naik, S. D. and Doraiswamy, L. K., *AIChE J*, **44**, 612 (1998) was declared paper of the month by *Chem. Eng. Prog.*, and was among the 5 most downloaded papers of *AIChE J* in 2004.

An inspection of the domain between putative tata box and translation start site in 79 plant genes , Joshi, C. P., *NucleicAcids Research*, **15** (16), 6643 (1987).

Putative polyadenylation signals in nuclear genes of higher plants — a compilation and analysis, Joshi, C. P., *Nucleic Acids Research*, **15** (23), 9627 (1987).

Organic carbonates, Shaikh, A. A. G., and Sivaram, S., *Chemical Reviews*, **96** (3): 951 (1996).

Molecular and biotechnological aspects of microbial proteases, Rao, M. B., Tanksle, A. M., Ghatge, M. S., and Deshpande, V .V., *Microbiology and Molecular Biology Reviews*, **62** (3), 597 (1998).

(*Continued*)

Box 8.7: (*Continued*)

A rheological study on the kinetics of hybrid formation in polypropylene nanocomposites source, Galgali, G., Ramesh, C. and Lele, A., *Macromolecules*, **34** (4): 852 (2001).

Titanium silicalite-2-synthesis, characterization and catalytic properties, Reddy, J. S., Kumar, R. and Ratnasamy, P., *Applied catalysis*, **58** (2), 11 (1990).

Cyclic sulfites and cyclic sulfates-epoxide like synthons source, Lohray, B. B., *synthesis-stuttgart*, (11), 1035 (1992).

Catalytic properties of crystalline titanium silicalites -1: synthesis and characterization of titaniumrich zeolites with mfi structure, Thangaraj, A., Kumar, R., Miraijkar, S. P., Ratnasamy P. *J. Catal.*, **130**, 1 (1991).

Molecular and biotechnological aspects of xylanases source, Kulkarni, N., Shendye, A., and Rao, M., *Fems Microbiology Rev*., **23**, 411 (1999).

Use of cluster-expansion methods in the open-shell correlation-problem, Mukherjee, D. and Pal, S., *Adv. quantum chem*., 2**0**, 291 (1989). times cited: 158.

Photoconductive CDS fims by a chemical bath deposition process , Pavaskar, N. R., Menezies, C. A., and Sinha, A. P. B. J. Electrochem. Soc., **124**, 743 (1977).

Estimation of the heat capacity of organic compounds from group contributions, Rihani, D. N. and Doraiswamy, L. K. *Ind. Eng. Chem./Fundam*., **4**(1), 17 (1965).

Modeling of noncatalytic gas-solid reactions, Ramachandran, P. A. and Doraiswamy, L. K., *AIChE J.*, **28**, 898 (1982).

On the structure of some manganites, Sinha, A. P. B., Sanjana, N. R., and Biswas, A. B., Acta Crystallographica, 1**0**, 439 (1957).

† 100 is a generally accepted measure of high citation. Papers in biology, organic chemistry, materials science, etc. are far more numerous than in engineering/technology journals. In the absence of any quantitative way of normalizing the figures, I have used this number as a “blockbuster” measure in preparing the list. It is likely that some really good papers have been missed out, and I apologize to the concerned authors for this possible lapse.

Note: Some of these papers are also included under the different areas.

To put all the explanations given by the scientists in writing would be an effort in itself and not germane to this book. Hence I simply list the papers along with a few explanatory sentences, unfortunately not at the freshman level as required by Feynman but, hopefully, intelligible enough to the average reader.

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9

WALKING THROUGH WHAT IS TO COME
THE WORLD OF INDUSTRIAL RESEARCH

No, a thousand times no; there does not exist a category of science to which one can give the name applied science. There are science and the applications of science, bound together as the fruit to the tree which bears it.

Louis Pasteur, 1871

Categories of Process Development

Developing a chemical process either by itself or in association with the industry, and working out mechanisms for its commercialization, were the bedrocks on which the NCL was founded. We saw in Chapters 7 and 8 how the laboratory came of age by establishing a strong basic research foundation and working in a variety of challenging areas. In this chapter, we will discuss the NCL's philosophy of process development and its association with the chemical industry.

For a number of years following its inception, projects on which the NCL worked were only those selected by the laboratory. Till about 1955, this selection was left entirely to the individual scientists. Being completely unconnected with the industry's requirements, their choices were arbitrary, based as much on individual fancy as on easy availability of published information. Then came the committees, starting from the Executive Committee to the divisional committees. The divisional committees disappeared somewhere along the way (probably in the early 1990s). In between, the CSIR created the Technology Assessment Boards (TABs), one for each of the five groups of laboratories into which the CSIR was divided, the so-called Coordination Councils. The chemicals group consisted of five laboratories, of which the NCL was one. To what extent they were useful is open to debate. My personal view is that they would not have been missed had they never existed. In any case, nothing much could be expected from this changing pattern of project selection and monitoring. The best period was when the divisional committees were active and each meeting of a committee was preceded by a comprehensive meeting of all scientists of a division with the director in a free-for-all discussion from which many good things emerged. For instance, certain projects were dropped, some were extended for a short period, and some new ones were taken up. This practice was followed from the mid-1960s to the end of the 1980s.

As described in Chapter 7, the NCL had a number of collaborative programs with universities and government agencies from many countries. It had a much larger number of contractual programs with industrial organizations from within and outside India.

In general, programs with universities and government agencies were not subject to any uniform contractual protocol and were undertaken on a case-by-case basis. On the other hand, cooperative programs with the industry were governed by strict contractual agreements.

No exact figure is available on the number of processes developed by the NCL. A large part of the uncertainty arises from the laboratory's changing perception of a 'completed' process. Even such complicated processes as citric acid and transfusion gelatin were declared as complete, based on some rudimentary laboratory experiments carried out by a single scientist on a laboratory scale with not a shred of accompanying engineering data (see Chapter 10). A list of personal selections, with a less generous view of completeness, is given in Box 9.1.

Box 9.1: A personal selection of NCL projects over the years (out of many)

Licensed Projects

No.	*Title*	*Name of First Licencee*
1	Acetanilide	Hindustan Organic Chemicals, Rasayani
2	Phthalates — dioctyl and dibutyl	Alta Laboratories Ltd., Khopoli
3	Monochloro acetic acid	HICO Products Ltd., Mumbai
4	Terpineol	Dujodwala Industries Ltd., Mumbai
5	70% Sorbitol from dextrose monohydrate	Maize Products, Divn, Sayaji Mills Ltd., Kathawada
6	β-Ionone	S. H. Kelkar & Co. Ltd., Mumbai
7	Monoethylaniline	Atul Products Ltd., Atul 396
8	Nitrile rubber	Synthetics and Chemicals Ltd., Bareilly
9	Ethylenediamine	Diamines & Chemicals Ltd., Kalol
10	Sorbitol	Hindustan Antibiotics Ltd., Pune
11	Vitamin B6	Lupin Laboratories Ltd., Mumbai
12	Endosulfan	Bharat Pulverising Mills Pvt. Ltd., Mumbai
13	Dimethoate	Mico Farm Chemicals Ltd., Chennai
14	Ethephon	Vasudha Biotek Pvt. Ltd., Hyderabad
15	Ethion	Shaw Wallace & Co. Ltd., Kolkata
16	Butenediol	Hindustan Organic Chemicals Ltd., Rasayani
17	Sodium/Potassium ferrocyanides	Hindustan Development Corporation Ltd., New Delhi
18	Albene Process	Hindustan Polymers, Vishakhapatnam
19	Encilium Process	Dhampur Sugar Mills Ltd., Bareilly
20	Catalyst for conversion of methanol to formaldehyde	International Catalysts Ltd., Pune
21	Homobrassinolides	Bahar Agrochem & Feeds Private Ltd., Ratnagiri
22	Ultrafiltration Membranes	Membrane Filters (India) Pvt. Ltd., Pune
23	Biotin Intermediate	Erythro Pharma Pvt. Ltd., Hyderabad
24	Famciclovir	USV Limited, Mumbai
25	S(-) Amlodipine besylate and S(-) Pantaprazole	Emcure Pharmaceuticals Ltd., Pune
26	Sorbic acid	Somaiya Organo Chemicals Ltd., Mumbai
27	THPE Technology	GE Plastics, USA/Excel Industries Ltd., Roha
28	Fractionation of Bagasse	Godavari Biorefineries Ltd., Mumbai
29	Epichlorohydrin	Aditya Birla Group, Thailand
30	ATBS	Vinati Organic Chemicals Ltd., Mumbai
31	Solid Catalysts for Biodiesel	Benefuel Inc., USA

Note: Some of these were partly sponsored at later stages in their development.

Exact figures are also not available for the number of contractual programs undertaken with the industry.

It is difficult to classify the kind of work done under the broad sub-heading "process development." To call it applied science would be an affront to Louis Pasteur. Some of it was not even applied research. It was largely the intelligent use of available information to fashion processes that could be used by the industry. A few such are described in Chapter 10. State-of-the-art processes were also developed and Chapter 11 describes some of these.

The processes covered under those discussed so far largely did not involve association with the industry during development. What was conceived to be a completed process was passed on to the industry and its shortcomings were addressed, if at all, during the operation of the commercial plant. On the other hand, a number of processes were developed for the industry through a contractual agreement right from the beginning. Several modes of contract research were formulated by the CSIR and are outlined below.

Contracts with Industry

EARLY ASSOCIATION

Historically, the NCL has laid great store by its association with the industry. Unfortunately, this was not possible in the very early years of its existence, largely because of the absence of mutual recognition. Actually, this non-recognition was mostly on the part of the industry. The reasons for this are evident (see chapter 4). Except for a few large complexes, the chemical industry was no more than a bunch of small or medium-scale manufacturers or sales agencies for imported products. Those who did manufacture restricted themselves to single-step processes for which they imported the penultimate intermediate of a multi-step process and completed the last step in the country. Alternatively, the process itself was a simple one involving a simple single step or perhaps two steps. Their mindset did not extend beyond these simple operations. Hence the concept of association with a research organization was beyond their grasp. At the most, they were prepared to invest a small amount against which they usually demanded a process demonstrated on a large pilot plant, which they expected the laboratory to have or to put up, with all guarantees on ultimate commercial production. This really was not their fault, because there were many in responsible positions who also held the view that the NCL should be a complex of multi-purpose pilot plants, whatever that meant, which could be used for developing and demonstrating processes to the industry. In a sense, therefore, for many years after independence, the mindset in the country precluded any association in the true sense of the word.

It was not until the CSIR stepped into the picture that the situation changed. It defined the many ways in which research laboratories and the industry could join forces to develop a technology. Collaboration, sponsorship and other forms of association were formally defined. The National Research and Development Corporation (NRDC) was also created around the same time to participate, whenever needed, in such associative efforts, but largely to assist in and to formalize transfer of technology from laboratory to industry.

DIFFERENT FORMS OF CONTRACT

The CSIR defined the following forms of contractual association between laboratory and industry in its office memoranda of 1999 (Guidelines for Technology Transfer & Utilization of Knowledge Base): sponsorship, collaboration, grant-in-aid, and composite. In addition, consultancy services could also be offered either institutionally or by individual scientists. The guidelines for these projects/services were clearly defined as below:

- **Sponsored projects:** Projects wholly funded by the client with specified R & D objectives and well-defined expected project output/results, generally culminating in generation of intellectual property. Exception to full funding by the sponsor could be made, with the approval of competent authority, for specific nationally relevant projects related to defense, social welfare, and the like. Sponsored projects could also be multi-client, with two or more sponsors sharing the project funding and research outputs.
- **Collaborative projects:** Projects partially funded by the client and supplemented by provision of inputs such as expert manpower, engineering, production/fabrication of product in bulk for testing/trials, infrastructure facilities or other inputs. Collaborative projects could be for upscaling/improving laboratory level know-how, technology development, generation of intellectual property, etc. Like sponsored projects, the expected project output/results are well defined.
- **Grant-in-aid projects:** Projects involving grants by way of financial inputs, either in full or in part, assistance in kind such as equipment, training, etc. to supplement the laboratory's efforts in ongoing or new R & D projects or for creating new capabilities/facilities. Generally the laboratory seeks or requests grant-in-aid support/funding from government departments/agencies or international bodies. Thus these projects are normally for supporting basic or exploratory R & D/surveys, for maintaining large/nationally important R & D groups, or testing/infrastructural facilities.
- **Composite projects:** Some projects are composite in nature and envisage diverse inputs, which in CSIR terminology may be termed as contract R & D, consultancy, technical services, etc. Such types of projects could, for purposes of CSIR costing/accounting, be split into appropriate contract research, consultancy and technical services components; and approval of competent authority had to be obtained for each component indicating the overall project profile. The contract for and the charge to the client may be as for a single composite project.
- **Consultancy services:** All consultancy services are institutional and fall under two categories: advisory and general. Advisory consultancy comprises scientific, technical, engineering or any other professional advice provided to a client, based entirely on available knowledge or experience of individual(s) without envisaging the use of any laboratory facility, including experimental, informational, computational, etc., and not involving any kind of survey or report writing. General consultancy involves all the above, plus the minimal use of laboratory facilities and also preparation of surveys, state-of-the-art technology source listings, interpretation or validation

of test results, risk and hazard analysis, design engineering, assistance in plant erection and commissioning, trouble-shooting, waste management, technology assessment, etc.

The terms and conditions for all these forms of contractual work have undergone changes from time to time. In the case of the first three, the changes were marginal. In the case of consultancy, benefits to the individual scientists underwent substantial changes. From a paltry few thousands at the beginning to Rs. 50,000 in the 1980s to limitless at the beginning of this century.

THE NCL'S GROWING INVOLVEMENT

The first major sponsorship was ethylene oxide by chlorohydrin route from HICO Products Ltd., the first major collaborative project was on chloromethanes with Standard Alkali and the first institutional consultancy was from Hindustan Organic Chemicals Ltd. The total number of such projects up to 1955 was probably less than 10 (no records exists of these earlier years). With these meager beginnings, the figures rose steadily up to 1990. After 1990, the entire economic philosophy of the country changed. The NCL's approach is briefly outlined below, and its performance in this new era is described in Chapter 12.

To capture the scope and quality of the sponsorship and other types of contractual projects undertaken for the industry, a list of the important projects up to 1990 is given in Box 9.2 and a few selected ones are described in Chapter 10.

Box 9.2: Personal selection of contract projects (out of many) till the advent of the global era at the NCL

No.	*Title*	*Client*
Collaborative Projects		
1	Vitamin C	Hindustan Antibiotics Ltd., Pimpri, Pune
2	Chloromethanes	Standard Alkali Chemicals, Mumbai
3	Methyl chlorosilane	HICO Products Ltd., Mumbai
4	Metal replacement by polymer composites in two wheelers	Bajaj Auto Ltd., Pune
5	Water proofing system for Beck Bond PU22	Dr.Beck & Co., Pune
Sponsored Projects		
1.	Perfumery products based on longifolene (capinone)	Caphor & Allied Products Ltd., Dist. Bareilly
2.	Chlorobenzenes (MCB)	Hindustan Organic Chemicals Ltd., Rasayani
3.	Dimethylaniline	Sahyadri Dyestuffs and Chemicals P. Ltd., Pune
4.	Acrylic acid/Acrylates from acrylonitrile	Indian Petrochemicals Corpn. Ltd., Vadodara
5.	Nitrile rubber	Synthetics and Chemicals Ltd., Mumbai
6.	Theophylline, aminophylline and caffeine	Pefco Foundry & Chemicals Ltd., Mumbai
7.	Vinblastin sulphate BP/USP and Vincristine sulphate BP/USP	CIPLA Ltd., Mumbai

BUSINESS DEVELOPMENT IN THE GLOBAL ERA

The NCL adopted several new approaches for generating business in line with the changing times. Before exploring this major issue, I would like to set the international stage by briefly recapturing the way the USA, the major driver of globalization, cut strings and increased international involvement, primarily to cut costs (joint inventions would come later, if at all, but were far from consideration when this new trend began). Outsourcing of some activities was the first step, and India offered a fertile source. But things moved so rapidly in India that by 2007, the Tata Group had acquired a major American out-sourcer, and was on the verge of outsourcing some of its own activities as well. This may or may not indicate a permanent shift, but it does suggest a possible dramatic turn-around in business flow in the years ahead.

Some figures given in *Science and Engineering Indicators* (2004) for the years 1991–2001 are instructive. US companies participated in more than 4,600 research and technology alliances worldwide, and about 80% of the alliances involved the US, European, Japanese, and emerging-market companies. Activity was particularly strong in IT and biotechnology. In addition, US Federal agencies participated in more than 3,600 Co-operative R & D Agreements (CRADAs) with industrial and non-profit organizations in 2001, although new CRADAs have been stable at about 1,000 annually since 1997. In the manufacturing industry, the overall ratio of expenditures for contract R & D to expenditures for R & D performed in-house steadily rose in the 1990s to 3.6% in 2001. The proportion was higher for chemicals manufacturing at 11.7% (and pharmaceuticals manufacturing at 18.7%). Within non-manufacturing industries, the contract R & D ratio for the information sector was 3.3%, while that for the professional, scientific, and technical services sector was 7.4%. Most notably, within the latter industry, the proportion of R & D services contracted out amounted to 12% of the $10.9 billion in internal company-funded R & D expenditures. Clearly, outsourcing had come to stay.

Outsourcing within a country is quite different from doing so internationally. In the case of the USA, for instance, outsourcing to foreign agencies by alliances that included a Federal laboratory was considerably higher than for alliances in which there was no federal participation. From 1991 to 2001, there were close to 6,000 new technology alliances formed worldwide in six major sectors: information technology (IT), biotechnology, advanced materials, aerospace and defense, automotive, and (non-biotech) chemicals. Of these, IT and biotechnology were the top technology sectors of the alliances (Hagedoorn, 2001). In addition to technology transfers through alliances, many universities in the USA have facilitated joint innovations and transfers through the creation of science parks (also known as technology or innovation parks). The first of these was formed by Stanford University in 1951 and was called Stanford Research Park at Stanford, California. This was followed in 1959 by the Research Triangle Park at Research Triangle, North Carolina. The Cambridge Science Park (Trinity College) in England and the Zhongguoncunb Science Park in China were among the many more that followed, including the University of Pune Research Park at Pune and the Iowa State University Research Park at Ames. Usually a university is the main participant in a science park, with offers of land, but that is not necessary. There are several with no academic involvement.

Based on the concepts of cooperative research outlined above, the NCL constantly reorganized and re-energized its cooperative efforts over the years, particularly since the advent of globalization in the 1990s, as indicated below:

- **Licensing of Intellectual Property Rights (IPR):** In order to commercially exploit the IP generated within the organization, the laboratory is free to license it. Licensing IP means granting the licensee the right to further develop it or to utilize it to make the resulting product either for commercial/captive purpose or as otherwise agreed to. The NCL has different models with regard to ownership and sharing of benefits of IPRs arising out of contract research. Each model is customized to suit the needs of the customers. The NCL exhibits a high degree of flexibility in exploring different options with the customers, such as, on the basis of exclusivity, as per different geographical territories, or jointly shared.

  Periodically, the NCL reviews the exploiable IP portfolio available, in order to build and maintain a relevant and active roster. All non-exploitable IP is eliminated from the portfolio after the assessment of each case on an individual basis in terms of its commercialization potential.
- **Engagement of technical and business development consultants:** In order to access global markets, the NCL engages consultants for a fixed period and assigns them specific and specialized tasks such as tying up with design and engineering consultants/companies, financial institutions and other agencies for packaging the laboratory's knowledge base, identifying and developing markets/clients for the IP/knowledge base and international marketing of IP/knowledge base.
- **Consortium approach:** In this model, several companies join together and form a consortium in an area of common interest. While the NCL gets the opportunity to access the generic knowledge of a particular industry, the members of the consortia are able to share the possible benefits from R & D and the associated research costs. A consortium on Microreactor Technologies has been successfully functioning at the NCL since 2008.
- **Public-private partnership:** I understand that the NCL is exploring the possibility of setting up Special Purpose Vehicles (SPV) in association with the private sector using joint investment in infrastructure and equipment in areas of synergy.
- **Technology business incubator:** The NCL has set up a business incubator at its premises (with funding from the Department of Science and Technology as part of its larger incubation program) for promoting the development of knowledge led enterprises and entrepreneurships. The incubator offers space and shared facilities to entrepreneurs and leverages the infrastructure facilities as well as technical expertise of the NCL and also enables scientists to take a Sweat Equity in the new high technology ventures.

Fruits of Research

As a late-comer to the NCL, much against its charter, real industrial research made its firm debut in the laboratory through the well-tested acetanilide process commercialized in an unprecedented (till then) mix of industry's reluctance to accept Indian technology and the NCL's forceful attempts to have one of its technologies in place in the country's industrial landscape through the unrelenting efforts of a combative Director (B. D. Tilak). The details of this and other projects are described in Part IV and a closing statement is included at the end of that part. I would like to end this chapter by being the prophet of the obvious, an unremarkable quality, if at all. Research, just to advance knowledge (i.e. purportedly "useless research," see Statement of Context), yields results useful to humankind in ways unsuspected and undreamed of. The following statement is a profound reminder of this truism (see neutron research under References) to fund-giving organizations in India that take pride in not wasting people's money on useless research:

> *The quality and range of consumer products have improved steadily since the 1970s. One of the reasons: neutron research. The fruits of neutron research were publicly proclaimed in the mid-1980s by the Exxon Chemical Company in a two page advertisement that appeared in Science. The ad included an artist's impression of Argon National Research Laboratory's George Wignall standing next to a High Flux Isotope Reactor.*

I mention this here to emphasize the link between Parts III and IV.

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Part IV
The Bridge to Industry

The Indian industrialists do not easily accept indigenous technology, however original. You must learn to be evangelical in dealing with them.

Indira Gandhi, NCL Silver Jubilee Address, 1975

INTRODUCTION

This part deals essentially with projects, as distinct from areas, specifically meant for in-dustrial exploitation. In the course of transferring technologie s to the chemical industry during 1960–90, the NCL encountered a number of situations. They can roughly be categorized as those

- that radically changed the industry's perception of the NCL;
- that ushered in the era of state-of-the-art technology at the NCL;
- where the technology succeeded but shifts in government policy/commercial environment led to plant shutdown;
- where the transfer was contentious resulting in under-performing plants;
- where there was a recall to excellence following unfortunate attempts to pass on text book technology;
- where a chance observation (serendipity) led to a new product and a new area of research in the NCL.

Then, around the end of 1980, India came under the influence of an all-sweeping era of globalization. This period was marked by the NCL's contractual relationships with major companies round the world. Technology development in collaboration with these companies became the focus. Facilities were also sought to be provided to smaller companies through the establishment of an Innovation Park to encourage innovative technology development outside the multinational sphere. Traditional technology transfer had had its day at the NCL and was no longer to be its forte. Part IV ends with a brief description of this aspect of the NCL.

10

THE AGONY AND THE ECSTASY
BRUSH WITH REALITY

The test of a vocation is the love of the drudgery it involves.

L. P. Smith, 1931

We should be careful to get out of an experience only the wisdom that is in it — and stop there; lest we be like the cat that sits down on a hot stove-lid. She will never sit down on a hot stove-lid again — and that is well. But also she will never sit down on a cold one anymore.

Mark Twain, *Following the Equator*, 1897

Naiveté or Oversell?

What is a completed technology? What, for that matter, is a technology completed on a pilot plant scale?

In the years immediately following the inception of the NCL, the answers to these questions were never sought as an expert view but were left to the individual scientists, sometimes chemical engineers (but more often chemists), to provide. Indeed, the questions were often never even asked. The scientists were merely requested to provide a list of "completed" projects. They did, often all too willingly, based on their own concept of completeness, sometimes as an exaggerated claim, and often as a result of "*active ignorance*."[1,2]

As a result, some of the NCL's claims must have looked almost ridiculous to the industry. For example, in the *Science in the Service of Industry* exhibition organized in New Delhi in 1956 (within a few years of the laboratory's effective functioning) at which a large number of institutions were represented, many new and completed projects were claimed by the participating institutions. The NCL was no exception to this display of ignorance, naiveté, oversell, or combinations thereof. It claimed a process for the fermentative production of citric acid using a new strain of Aspergillus niger isolated by it; a novel process for transfusion gelatin for use as plasma substitute in blood transfusion; a process for nicotine sulfate from tobacco waste; the setting up of a pilot plant for PVC; processes for certain types of phosphate and nitrogenous fertilizers; processes for musk and civet; an ion-exchange resin for softening tap water; molding compositions based on indigenous asbestos for fabricating battery containers; and many more.

It is obvious that many of these processes required sustained studies including investigations on pilot plants of sufficient scale, which could never have been carried out at the laboratory. Thus, if the NCL's word was suspect in the eyes of the industry, the mistrust was quite understandable. The energy barrier to be crossed to redeem the situation (known to chemists as activation energy) was indeed high. The story of how this affected technology transfer in later years when the laboratory was more cognizant of its responsibilities while offering processes to the industry is told in the rest of the chapter. It was not easy. Genuine responsibility not unmixed with a dash of bravado seemed necessary in the initial stages. This is exactly what Tilak used and, after a period of trial and travail, the laboratory scaled the barrier to reach a level of acceptance from where it never looked back.

The NCL had different kinds of experience in transferring technologies to the industry. Also, these technologies evoked different kinds of reaction from the industry. All these and a few more may be classified as follows:

- Projects that changed the industry's perception of NCL
- Contentious technology transfers
- A sound beginning to new technologies: catalytic processes

Projects that Changed the Industry's Perception of the NCL

When nothing seems to help, I go and look at a stonecutter hammering away at his rock perhaps a hundred times without as much as a crack showing in it. Yet at the hundred and first blow it will split in two, and I know it was not that blow that did it, but all that had gone before.

Robert Frost, 1874–1963

The NCL had no more than a nominal rapport with the industry till the early 1960s. In fact, the industry by and large ignored the NCL, except in a few cases where the scientists themselves were directly involved. This was in many ways an unspoken disapproval of the laboratory's unwillingness to reach out to them. If the industry came to the laboratory, well and good. If it did not, that was fine as well. This sort of attitude generated a dangerous trend which, if unchecked, had the potential to permanently ruin the NCL's relationship with the industry. It was at this stage in this worsening relationship that Tilak stepped in. With characteristic determination laced with his own brand of bravado, not entirely disturbed by the incompleteness of a technology, and somehow certain that he and his colleagues would deliver the 101st blow of Robert Frost's stonecutter, he took on major assignments and made commitments his detractors might be tempted to call reckless. This was one of the greatest blows struck in favor of the NCL, and forever changed the industry's perception of the laboratory. Had Tilak not been Tilak and waited to comply with all the management dicta of the day, NCL might still be struggling to find its industrial feet. A few examples of the history of the major projects undertaken during his regime should bring home this point.

ACETANILIDE: ADVENT OF THE TURN-KEY ERA AT THE NCL

As already mentioned in Chapter 4, acetanilide was the first product to be manufactured by the Indian chemical industry using the NCL's technology, perhaps any CSIR technology. It was also the first instance of a turn-key offer by a national laboratory. While the NCL was created to serve the Indian chemical industry, its efforts and direction were not reflected in the kind of competence that was being created and staff that was being assembled. There was criticism all round of the distance from any meaningful industrial research. Eduljee, a well known chemical engineer of the 1960s, 70s and 80s, who was associated with the NCL for a number of years as a member of its many committees, once wrote to Tilak complaining of the laboratory's formlessness. Kane was even more vocal of this deficiency, seen by him as a deliberate policy of the NCL. Shanti Palit, another member of the NCL's top committees and a leading academic, while appreciative of laboratory's work, was unhappy at its academic pursuits cutting into the university's province, due to its relative monetary strength. In short, the NCL was under attack both from the industry and academia, each for its own reasons.

It was in this climate of uncertainty and self-doubt that some bold initiatives were taken in the mid-1960s that set the tone for the next 15–20 years. The Hindustan Organic Chemicals (HOC) had just been commissioned at Panvel in Maharashtra, about 60 miles from Pune, and was fertile territory for these initiatives. K. Venkataraman (KV) and Tilak were both associated with it in a major way right from its inception and took the opportunity to include the NCL in the picture in no uncertain terms. KV was then the Director but, by special arrangement with the CSIR, had brought in Tilak as Additional Director, a one-time position that was never again created in the CSIR. There was a tacit understanding between him and the Director-General, Hussain Zaheer, that Tilak would succeed him as Director, again the first and only instance of such a pre-arranged selection in the CSIR.

HOC's tenders for acetanilide were soon to be sent to the press. Tilak wanted the NCL to make a bid. He called me and gave me six months to develop the technology with unrestricted access to staff and facilities. I assembled a team of scientists including G. R. Venkitakrishnan (GRV), S. M. Abhyankar (the main scientist involved), R. K. Sen, and a few assistants. We went to work and soon came out with the outlines of a process using existing information. At this point, Tilak brought in the project engineering firm of R. L. Dalal and Co. (RLDC) of Mumbai who deputed R. Jaishankar, an IIT Kharagpur chemical engineering graduate, to lead their engineering effort. The days that followed were among the busiest at the NCL, with the team working almost round the clock. Tilak would frequently drop in with words of encouragement and assure me that if we failed, he would take the full responsibility and no blame would be attached to me or to my team. I would not have allowed this to happen but it spoke volumes for the man. To cut a long story short, a process package was soon prepared, based on which RLDC submitted their bid, with all guarantees and penalties included. The NCL itself was not structured to offer these but RLDC was. Hence the basic requirement of any client was met. Kane and the Managing Director of HOC, G. S. Kasbekar, were skeptical about these guarantees and did not conceal their view, but were legally helpless.

Then came the period when Tilak, who was still the Additional Director to whom Venkataraman had handed over the full responsibility for this project, was at his fighting best. In my own mind, I knew that the technology needed much polishing but I had no doubt that we would succeed (after some on-site modifications). Based entirely on this confidence, I promised Tilak that we would not fail. Buoyed by this confident assurance, Tilak made up his mind to go all the way, even if it meant displeasing many higher-ups in Delhi. The day arrived when tenders were opened, and within days there was a prompt letter from G. S. Kasbekar to KV listing a whole lot of points where the NCL technology did not meet the requirements. KV summoned an urgent meeting in his office at which Tilak, Ramesh Dalal (Managing Director of RLDC) and I were present. We disagreed with many of the points mentioned by Kasbekar, and after a considerable amount of discussion, Tilak was asked to come back with a rejoinder. This he did in record time and took the massive document personally to KV. Cautious to a fault in language and gentle in manner, KV was aghast to read "This is a lie," written by Tilak in his report, against my advice. He however agreed with the substance of the report but directed Tilak to tone down the language. Tilak, who used to address KV as Doctor, said "Yes, Doctor" and we left. He edited the report and he and I were back in KV's office within a few days. As KV read through the modified report, I could sense a feeling of shocked disbelief creeping on his face. Yes, Tilak had modified the offending sentence, which now read "It is a damn lie!"

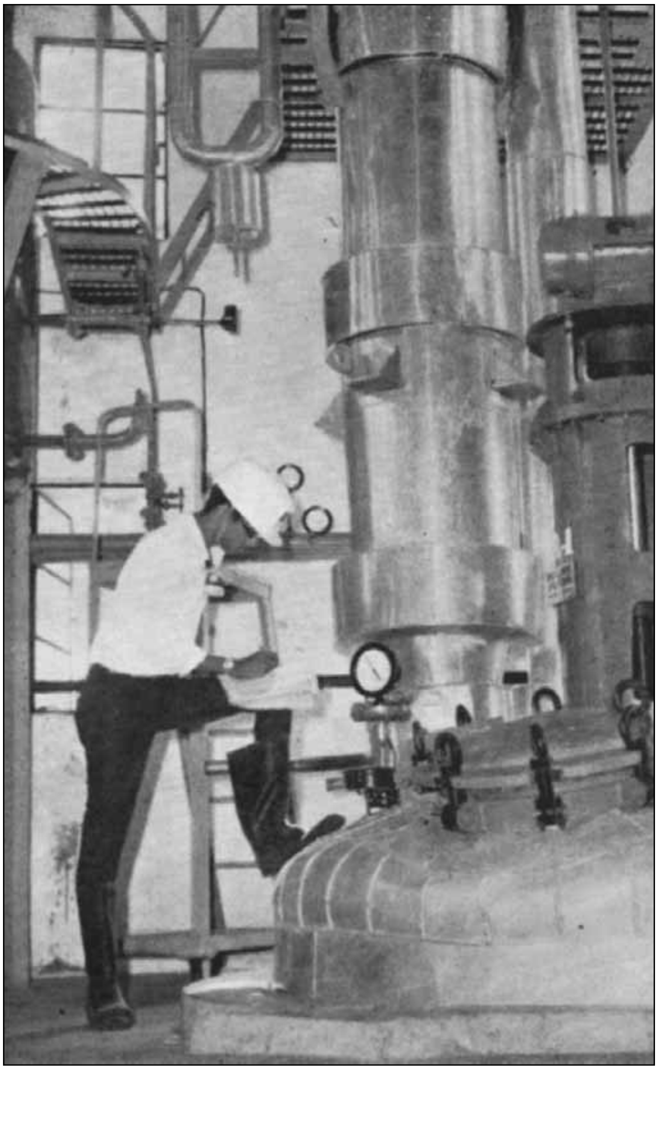
After one more lecture from KV on the virtues of politeness, a rejoinder with more diplomatic language was crafted and sent out. I record all this in some detail because Tilak took this project very seriously and was determined to have an Indian technology in place at HOC, even if it meant staking the full prestige and reputation of the NCL in the process. He had by then become the Director and was no longer tied down by the more traditional methods of KV. His wife once remarked at a dinner that acetanilide and Kasbekar had become an obsession with him! I could not have agreed more!

At this point the story took a somewhat comic turn that relieved the tension that was building up within the NCL and between the NCL and HOC. The central character in all this was the works manager of HOC, a tall, imposing figure, well-meaning and friendly. He was deputed along with a team of chemical engineers to witness the demonstration of the process at the NCL. He carefully studied the demonstration protocol and appeared satisfied — except for a lingering question: why did the NCL choose a batch size of 62 kg? Why not 75? He seemed at a loss. He nonetheless accepted the size with some reluctance and the demonstration proceeded. When the batch was done and time came for weighing the finished product, he said to me excitedly, *Doctor sahib, stop, I want to examine the balance and test it out personally*.

He then promptly stepped on the scale and announced that there could be an error of 1–2 kg based on his own weight, which he claimed was standard! Anyway, the demonstration was completed and, after a couple of weeks, he submitted a predictably ambiguous report. After one more demonstration and much explaining, the process was eventually declared workable, and HOC formally accepted the tender. This was done against strong competition from Germany's Udhe and many other equally reputable firms. Tilak had scored!

Then in 1968, HOC formally inaugurated the acetanilide plant (see Figure 10.1), its first in a series of over 20 plants established since, and the NCL's first commercial success. The euphoria was short-lived, for the months following were even more tense for the NCL than those preceding the acceptance of our tender. The product had to be of pharmaceutical grade and this could not be achieved in continuous commercial production; the process of flaking the product also ran into much operational trouble. These difficulties were overcome within a few months during which the entire acetanilide team remained at HOC, took control of the plant, and succeeded in delivering the product in the required quantity and quality. Another instance of comic proportions occurred in one of the many joint

Figure 10.1: Photograph of the first plant to go on stream based on the NCL technology — The acetanilide plant at HOC



meetings of the NCL, RLDC and HOC scientists and engineers during this period. RLDC had placed an order for a number of non-return valves.[3] When it was found that many of them were not required, the HOC works manager was annoyed that RLDC was indulging in such wasteful expenditure. When Jaishankar responded that it was a simple enough matter to return the valves, the annoyed HOC representative remarked — with a sneering smile: *Jaishankar, have you forgotten that these are non-return valves*?

Weak with suppressed laughter, we barely managed a straight face. But I did blurt out a timorous response that it would not hurt to try – and in any case, I assured him, HOC will not have to pay.

Thus began a long period of association with HOC, with the NCL acting as their institutional consultants for over 25 years. During this period, among other things, the acetanilide plant capacity and efficiency were further improved. Then, in 1995, HOC decided to fully revamp the plant and increase its capacity by 50%. The task this time was assigned to the NCL with no RLDC involvement. The revamped plant was commissioned successfully and the non-binding guarantees were fully met.

The acetanilide experience was a milestone in the NCL's history. It taught many lessons, not the least important being the need for continuous association with the processes developed with the object of offering improvements to the clients from time to time.

CHLOROBENZENES: THE FIRST ENCOUNTER WITH "SIMPLE" REALITY

The NCL is preparing chlorobenzenes?

That was the question some NCL scientists, particularly organic chemists, asked me in stunned disbelief when I announced to an informal group that we had decided to work on the process with the intention of offering it to HOC. This is first year chemistry, they complained, and first year engineering — if there is any engineering in it at all. Every beginner knows that reaction between benzene and chlorine is the simplest example of a consecutive reaction, leading to an array of chlorobenzenes. And separation? It is no more than a first lesson in distillation! I am no apologist for developing textbook technology, but considering the context (there was need to prove to ourselves that we could do big things, even if not original things to start with, and that acetanilide was not just a fluke) and Voltaire's famous words,

> *The instruction we find in books is like fire. We fetch it from our neighbor's, kindle it at home, communicate it to others, and it becomes the property of all….*

it was entirely justifiable for the time, even if Voltaire's remarks did not specifically endorse claims of imitative technology development as a major achievement.

All this is true, but when one starts developing a process, the perceived simplicity quickly vanishes, and one is faced with some real problems, particularly when one is doing it for the first time, with no help from established manufacturers. But jibes continued to flow. Some called it reinventing the wheel.[4] Perhaps it was, but when the material of the wheel is a crucial factor and when the wheel has to perform tricks during its motion, such as churning out graded materials in pure form from the ground at different rates, it is a different matter altogether — particularly when you want to do it all on your own, without recourse to the chronicles of world producers. And they were soon all silenced. We had come face to face with problems we had never encountered before: a photochemical reaction (one triggered by light) with severe corrosion issues, and a strategy for separation involving liquids of the slightest difference in boiling points and a solid with appreciable solubility in its liquid co-products, which must (the tender insisted) additionally accommodate reactor effluents of different compositions (depending on product pattern demands).

The problems of the process were far more challenging than its simple chemistry would indicate. Solutions were not novel, but had to be optimal, flexible, and profitable. How the NCL produced them is an interesting story, which also says something about the industrial environment of the time in India, and the building of confidence in our engineering (forget the chemistry of the process, so uninteresting and mundane).

The main product of benzene chlorination is monochlorobenzene (MCB), used in the manufacture of a variety of end products. In the 1960s, when HOC included MCB in its product spectrum, there were only two plants operating in India for DDT and many more for dyes and drugs. At this point, Tilak again decided to make a turn-key bid through RLDC, now renamed Dalal Consultants and Engineers Private Ltd. (DCEP), based on the pilot plant work that had already been commenced in the laboratory. I was again asked to lead a team of scientists, the other members being: G.R. Venkitakrishnan (GRV), S.P. Mukherjee (SPM), and N. Sadasivan. As the NCL was offering a continuous process for the first time, one that also involved the possibility of severe corrosion, it was decided to run a semi-commercial unit at an industrial site, with all operational protocols fully defined. Tilak managed to persuade Excel Industries, a Mumbai firm devoted to indigenous technology development, to put up the desired semi-commercial unit by offering a share of the profits. The plant was constructed and became fully operational in record time, and soon thereafter, the NCL team set up camp at the site to run the unit and collect design data.

Although I had spent several days at a time at HOC previously, this was a particularly difficult experience. The company did not have the safety, control, or other means to deal with chlorine leaks. To add to this, there was the alarming sight of a series of open flasks with chlorine bubbling into the liquid placed in them to produce chlorinated paraffins. The large quantity of gas that leaked out was allowed to be freely inhaled by one and all in the adjacent MCB unit! When I complained to the management, their unsmiling response was: *Welcome to the real world of chemicals, doctor*! or words to that effect. They gave us large quantities of bananas which, they said, should ease the breathing problem. In an incredible turnaround in later years, Excel greatly modernized their safety standards and even won national awards for safety. When on a later occasion I remarked to K. G. Shroff, the Managing Director of the company, that I wished he had these safety protocols in place when my colleagues and I were struggling to breathe at their site several years before, his smile was seraphic! This progressive sophistication of medium sized entrepreneurial ventures has been a significant feature of India's industrial growth. Instances of this are not wanting from practically any sector of the industry. The NCL has played no small part in bringing about this change in the chemical industry. This was done by including safety protocols in its process packages, particularly to smaller companies who have often demonstrated a remarkable propensity for sidestepping this issue, and insisting on compliance. Surprisingly, its own safety procedures did little to inspire confidence among scientists and industrialists. This situation was remedied by Ratnasamy and later, more effectively, by Sivaram. The entire matter of safety at the NCL will resurface as a coalesced issue in Chapter 14.

The Dalal tender was accepted, with the usual doubts expressed by the HOC management. The plant gave the NCL more than its share of headaches but eventually it was brought under control and began to run to specifications.

The chlorobenzene story is more than just a successful technology transfer. It led a once skeptical organization to retain the NCL as its institutional consultant and, after 25 years, entrust the task of setting up a new chlorobenzenes facility for double the original capacity. This time, the NCL's methods were highly sophisticated, with computer-aided design at every stage and implementation according to a tighter and state-of-the-art protocol. Thus, the history of the chlorobenzenes facility at HOC is a history of the NCL's silent growth, from a fledging laboratory struggling to find its design feet to one of a sophisticated center of design (largely for its own projects).

ACRYLIC ESTERS: FINALIZING/IMPLEMENTING A MULTINATIONAL DESIGN AND EXTENDING IT TO OTHER PRODUCTS

In the 1970s, when the synthetic fibers industry in India was being greatly expanded (following its beginnings with Nylon manufacture at Kalyan in Mumbai), the IPCL had plans to set up manufacturing facilities for acrylic fibers, a copolymer acrylonitrile of methyl acrylate at Baroda (renamed Vadodara) in Gujarat. The esters of commercial importance are methyl and ethyl acrylates, as well as the butyl and 2-ethyl hexyl acrylates. The methyl esters is required as co-monomer in the manufacture of the fiber. As the requirement of these esters was small compared to the other claimants for acrylonitrile as raw material, the IPCL decided to set up this plant using surplus acrylonitrile and indigenously developed technology. Predictably, the NCL was soon in the picture. Tilak in the earlier years and later, I, were on the Board of the IPCL, and each in his own way and time made strong presentations to the laboratory on this subject.

The acrylic fibre plant was established by Asahi of Japan. As part of the contract with Asahi, the IPCL was asked by the government to include a clause that would enable them to share the information with a national laboratory for a technology for the manufacture of methyl acrylate, a comonomer needed for the manufacture of acrylic fibre. Incidentally, this brought up for the first time the question of technology absorption, on which I was later asked by the IPCL Board to prepare a comprehensive report (see Chapter 13). Asahi had also supplied a brief know-how package for the methyl and ethyl esters of acrylic acid, and a much briefer one for the higher acrylates. The IPCL invoked the new clause in the contract to pass on this incomplete package to the NCL to initiate pilot plant studies on the esters and complete the packages in every respect. It had already taken a decision to put up an esters plant using the Asahi package as modified/completed by the NCL.

The processes involved reaction followed by distillation with troublesome azeotropes (mixtures that greatly complicate the isolation of pure fractions). A team of several scientists, including GRV and M. V. Gokhale (the principal chemical engineer on the project) with me as the team leader, was entrusted with this task with a strict timeline. This group collected exhaustive data both on the reaction and distillation steps, including kinetics, azeotropic distillation, and other physicochemical data. All this was done in collaboration with Engineers India Ltd., a public sector project engineering firm commissioned by the IPCL to do the engineering of the plant.

The project was implemented in two stages: stage 1 for the lower methyl and ethyl esters, and stage 2 for the higher butyl and 2-ethyl hexyl esters. After minor start-up problems, the plant for the lower esters was stabilized and became commercially operational. On the other hand, considerable difficulties were encountered in the production of the higher esters, both in the reaction and distillation sections. The NCL team spent considerable time at the IPCL and worked in full collaboration with the IPCL and EIL teams to solve these problems. Gokhale from the NCL showed himself to be a particularly innovative chemical engineer (his later untimely death in a motorcycle accident was a very sad event), and remained at the IPCL for days in a stretch to be personally available to solve problems that seemed to be cropping up with alarming regularity.

The success of this project was widely hailed in the industrial circles and pushed the NCL up by several notches in the scale of acceptance and in upholding the NCL's claim that its earlier successes were no random specks but firm points on a rising curve. This was amply demonstrated by the Indian Chemical Manufacturers' Association's recognition of the effort by its awarding the prestigious Acharya P. C. Ray Award for Development of Technology Indigenously in 1990 to the IPCL.

A lesson that emerged strongly from this project was that for any horizontal technology transfer to be successful, it is not enough that the top management of the receiving organization is cooperative. It is even more important that the staff at the working level are fully committed. Both these happened in this particular case, thanks mainly to R. Sethuraman, the Production Manager, and the project succeeded. The problem arises when the organization as a whole is asked by a higher authority in Delhi to cooperate with what they believe to be against their better judgment. It also arises when working-level staff are directed by the management to cooperate. The NCL has experienced both these situations and the projects suffered as a result. Before ending this quick walk through the acrylic fibers project, a reference to the NCL's involvement in a parallel effort with the same company is necessary.

Ammoxidation of propylene to acrylonitrile: As mentioned previously, acrylonitile is the primary raw material for the production of acrylic fibers. The Sohio package given to the IPCL contained extensive information on the process minus some vital design details such as a viable model for the reaction between acrylonitrile, ammonia and oxygen, known as ammoxidation, carried out in a fluidized-bed reactor. As this was a vital item of information in any future design of an ammoxidation reactor, I suggested to the IPCL chairman to sponsor a project at the NCL to model the reactor. He readily agreed and the task was assigned to B. D. Kulkarni. Soon Kulkarni came up with a fine mathematical model based on a sound physical postulation and the IPCL agreed to validate it from data to be collected from the commercial unit. However, the production people were reluctant to divert staff and resources to this task and consequently risk production loss. The IPCL's R & D group, and even the chairman, considered it desirable to validate the model, but the production lobby prevailed and the effort was soon history. Contrary to the NCL's experience with the acrylates project in the same company, lack of internal cooperation in this case killed the project.

ETHYLENEDIAMINE: A HELPING HAND BY GOVERNMENT

The government's attitude towards indigenous technology was variable and unpredictable, routinely explained away by the ever handy excuse: each case on its own merits. In the case of ethylenedimaine (EDA), however, the process would never have sold without the government's helping hand in the initial stages. But we are jumping the cart here. Let us see how it all began and progressed.

Starting from the early 1960s, the NCL had been actively involved in research on chemicals for agriculture, mostly insecticides and pesticides. Since EDA is a chemical that is largely used in the manufacture of agrochemicals and textile intermediates, the NCL examined the feasibility of an indigenous technology for this product. An issue was the rather low demand (less than 1,000 tons per annum as against the lowest production capacity of 10,000 tons per annum for similar plants the world over). Notwithstanding this discrepancy, the NCL decided to go ahead with the development in the hope that it could make the process economical enough to attract a customer.

The route used was amination of ethylene dichloride with aqueous ammonia, and the reactor selected was a long tube in a compact setting. The reaction that occurs is a complex one involving many amines that must be optimized for maximum selectivity for the diamine (EDA) or any other required combination of amines. Amines contain nitrogen with its great fertilizer value that is retained through subsequent conversions to the final product used in agriculture. EDA is a particularly effective amine in this regard. Additional features of this reaction are the use of an elevated pressure (about 70 atmospheres) and a large ratio of utilities to raw material costs, which makes optimum energy utilization a key factor. This was a challenging task for the NCL which had not handled such a complex reaction earlier. The challenge was accepted and soon the major details of a process were worked out in the laboratory. At this stage, unlike in the other projects mentioned previously, there was no urgency.

Soon two companies appeared on the scene as possible customers for a plant of one ton per day capacity, with the object of collecting data on all aspects of the process to enable scale-up to commercial scale. A unique feature of the arrangement reached with one of the companies, Bharat Vijay Mills (BVM), was that a scientist from the NCL was deputed to BVM to fully assist in setting up and operating the plant. This was successfully accomplished in about two years and subsequent market acceptability trials of the product were also satisfactory.

At this stage, the task of detailed engineering and construction of the commercial plant was assigned to Metallurgical Consultants and Engineers Private Ltd., New Delhi. This engineering firm, headed by T. K. Roy, an Sc.D. from MIT and a leading chemical engineer of the country, enjoyed a fine reputation and the NCL was pleased that its recommendation to appoint them as project engineers was accepted by BVM. Now, for various reasons, BVM decided to float a new company, Diamines and Chemicals Ltd., to implement this project. Then, for financial and contractual reasons, a special arrangement was worked out, freeing the NCL from financial obligations. I mention this in some detail because the laboratory was no longer a simple R & D organization but one with mounting commercial obligations that had to be worked into an institution not structured for it. On the advice of the NCL, BVM approached the Industrial Development Board of India (IDBI) for a loan. After a satisfactory technical presentation to the IDBI by NCL scientists, the question of performance guarantees with built-in penalties came up. As the NCL/CSIR was not in a position to offer such guarantees, I persuaded the National Research and Development Corporation (NRDC) to provide them for an additional fee in the interest of implementing an indigenous technology. The liability was to be restricted to the amount of additional payment made by the company. This was a four-way arrangement worked out for the first time, and was based on a combination of the NCL's reputation, the firm's willingness to water down the contract, the IDBI's willingness to accept the NCL's laboratory scale guarantees, and the NRDC's readiness to legally own the contractual responsibilities. At the insistence of the IDBI, it was stipulated that the NCL will provide all the technical expertise till the successful completion of the project.

The plant was successfully commissioned in 1974. However, as the product cost was higher than in the international market, and continued to be higher even after further optimization with the NCL's help, the laboratory sought and obtained government protection by way of customs duty on imported product for a limited period. Meanwhile, the demand for the higher amines rose, and the NCL was able to obtain the required data both through experiment and computer simulation to produce the amines in the required proportions in a suitably modified plant. This joint effort of the DACL and NCL was hailed by the Indian chemical industry as a major success and the former was given the ICMA's prestigious Acharya P. C. Ray Award for the Development of Technology Indigenously in 1985.

But the story did not end there. The DACL decided to produce the higher amine diethylenetriamine (DETA) for the export market, using a separation technology offered by Sulzer. As the DACL's consultant, the NCL informed them of the inadequacy of the Sulzer design. The DACL went ahead just the same, but had to come back to the NCL later to redesign the unit. After this was done, the DACL was able to export DETA to Europe. Soon after, however, for various reasons, it was unable to sustain production and sold the plant to Alkyl Amines and Chemical Ltd. of Mumbai, who were manufacturing the amines at their Patalganga plant, about 100 km from Pune, till the writing of this book.

This project marked an important milestone in the NCL's development. From a research laboratory to an institution that for the first time established a plant on a turn-key basis, it had now become an active player in the industrial politics of the country. The effort thenceforward would be to sustain this new found integrated role of the laboratory.

Contentious Technology Transfers

One cause is good until the other's understood.

Anon: see *Poor Robin's Almanac*, 1731

Considering the very nature of horizontal technology transfer, it is not surprising that a number of transfers were contentious. One can list several projects in this category, many of them relatively minor. Recounted below are the stories of two major technologies that were particularly contentious. These drew the attention alike of government and industry and generated much controversy.

OPIUM ALKALOIDS: THE STORY OF A CONTENTIOUS LEGACY

A good process (new at the time), average engineering, customer hostility, the nationalistic decision of a powerful bureaucrat, these were the ingredients of the tortured history of this project whose memory still lives in an under-performing plant at Neemuch in Madhya Pradesh, a plant that was launched with great fanfare and optimism. It all started with Sukh Dev's interest in natural products chemistry and ended in the Neemuch plant just mentioned, and its checkered history is part of the NCL saga. Neither a peg on which to hang a success story, nor one on which to hang a story of failure, it certainly is a story of mixed outcomes and many lessons. In its own way, it was a success of sorts, for it was far superior to the technology it replaced. On the other hand, it was an under-performing plant in the sense that the yields claimed by the NCL could not be achieved.

Large quantities of opium are produced in India, one of the few countries that grow poppy plants that produce this popular narcotic, most of which was exported to Western countries. The principal alkaloids, morphine and codeine, were then extracted from this opium and exported back to India! This was an unacceptable practice in independent India and, as the Government of India handled the cultivation and export of opium, they decided in the early 60s to put an end to the export. It was at this stage that Sukh Dev's work at the NCL caught the eye of the Ministry of Finance, which operated an outdated plant for the extraction of alkaloids from Indian opium at the government Opium Alkaloids Factory at Ghazipur in Uttar Pradesh. There were several visits to the NCL by the Chief Chemist, Dr. Suri, of the Central Revenues, and the Narcotics Commissioner, Government of India, to discuss the possibility of using Sukh Dev's process at Ghazipur. (It was a matter of interesting coincidence that Suri, who was an assistant to my uncle S. S. Iyer, the first Indian Chief Chemist of Central Revenues in New Delhi, had succeeded him just a few years earlier. The stories we exchanged were perhaps the only few personally satisfying and humorous moments in an otherwise dull and tense relationship between the Ministry and the NCL.)

The government had taken the decision to set up a modern plant to process the raw opium to the get the individual alkaloids for medicinal use in India, and probably for export as well. As the first logical option, they approached several Western countries for tenders. Although many of them offered their technologies, the cost was prohibitive and the collaborators usually wanted to buy the raw opium from India at a favorable price for an extended period of time, a condition not acceptable to the government.

It was at this stage that the casual eyeing of the NCL process by the Ministry of Finance gelled into a distinct possibility and then into an action plan. It was decided that the NCL would pursue this project seriously (as it was a national endeavor, no fee was to be paid) and that a chemist from Ghazipur would be deputed from time to time to work at the NCL, particularly to assist in chemical analysis according to government standards. It was also decided by KV, who was then the Director, that process development work would be done as a collaborative effort between the organic chemistry group headed by Sukh Dev with C. G. Joshi as the principal chemist and the chemical engineering group headed by me with GRV and SPM as the principal chemical engineers. This team continued for the entire duration of over 10 tortured years of this project. During this period there were a number of changes in the Ministry, but the persons the NCL had to deal with most were the Narcotics Commissioner, Asthana, the Chief Chemist, S. Ramanathan, and a senior deputy secretary to the government.

Finally, after the process was developed on a laboratory scale and successfully demonstrated to the GOAF, it was decided to validate it on a pilot plant scale. The NCL had close contacts with the Indian Drugs and Pharmaceutical Ltd. (IDPL) at Hyderabad. Their sprawling facility, much of it only partly used, was established through an agreement between the Government of India and the then USSR (see Chapter 4). I was a member of its Board of Directors for several years and both KV and Tilak had also close contacts with them. There was therefore no great difficulty in persuading the IDPL to extend all facilities of equipment and some floor level staff to the NCL to conduct pilot plant trials. The Ministry also accepted the NCL's recommendation to appoint the National Industrial Development Corporation (NIDC) as project engineers for setting up a plant for treating 80 TPA of opium to give all the principal alkaloids, namely morphine, codeine, narcotine, and thebaine, at internationally specified levels of purity. In spite of the NCL's superior facilities, the purity specifications had to be confirmed by the chief analytical chemist of the GOAF.

The Moisture Diviner with the "Touchometer!"

A question then arose: who was the chief analytical chemist of the GOAF? And herein lay an amazing story. There was a strict specification on the moisture content of morphine. The NCL always checked the value with a high degree of precision to ensure that it really and truly met the strict specification. However, while GOAF chemists accepted this value with grave politeness, they wanted this to be confirmed by their moisture man. I am not sure of his education but he certainly had a way with moisture. He was from the village of Ghazipur and had lived with morphine all his life — not taking it but handling it.

He perhaps knew something of chemistry but I am not sure. His analytical procedure was simple. He would take the morphine powder in his hand, half close his eyes, and run his fingers through the powder. In less than a minute, almost oracularly, he would announce a value. And to our astonishment, he would be very close to the NCL value. In the rare case of a disparity, GOAP chemists would accept his value over NCL's — reluctantly of course! Spectrometry or touchometry, take your pick![5] Although the demonstration was successful, there was no little hesitation on the part of the Ministry officials to finally accept the process, for the pressures from the European lobbies and their propagandists in Delhi were heavy. Around this time, with the permission of Tilak, who was still the Director, I went to Delhi and personally invited Mr. Banerjee, an Additional Secretary to the Government of India, who was also in charge of the Ministry of Revenue and Expenditure. He immediately agreed to visit the NCL. At over 300 pounds, he was a veritable power in the Ministry, both in build and voice. His word was seldom questioned. A staunch nationalistic bureaucrat, he was visibly pleased to see the work in progress at the NCL on the opium project. Proudly looking at the morphine powder held by a scientist in his hands, he declared with transparent joy:

> *If my Indian scientists can produce this drug as efficiently as the technologists from Europe, or even slightly less so, I will face any difficulty and put up a plant based on the work of these enthusiastic young scientists here at the NCL.*

And so the decision was made. There was no going back now. But I am not sure the other officials of the Ministry, the retinue that followed him, were as pleased!

A Successful "Jailbreak!"

Getting back to the alkaloids plant: Banerjee had spoken, the pilot plant trials at the IDPL had been successful, the NIDC had completed their designs, a site adjacent to the place where opium was sun dried was selected, and construction was about to begin. At this point there was an intrusion so serious that the whole project stood to suffer irretrievably, and yet it had a bizarre humor of its own. It was Banerjee again, this time not as a favorable force but an unconscious hindrance! He had just vetoed the choice of site and wanted the factory to be located in an existing cellar-type stone-built jail — for reasons of security! I received several frantic phone calls and telegrams from Delhi and Neemuch to immediately intervene. It was a measure of their confidence in the NCL, despite their dislike of it, that they turned to the laboratory to organize the jailbreak. I contacted Banerjee and he agreed to visit Neemuch jointly with me, GRV and SPM. We spent several hours at the jail when I explained to him how it was impossible to house a modern chemical plant in a structure of 3 foot thick stone walls and less than 7 foot ceiling. Obviously I told him nothing his own staff had not, and yet he agreed without demur, admonishing them in his loud voice — Why didn't you tell me all this before, instead of wasting the doctor sahib's time?

His staff stood still, grave and unsmiling, taken aback by this abrupt turnaround but distinctly relieved, not daring to tell him that they had already said it all![6] And so the crisis passed and there were no further hindrances from the Ministry.

Banerjee's goodwill and high spirits notwithstanding, the relationship between the NCL and GOAF was often tense though outwardly always calm, particularly with Ramanathan, who was an expert in alkaloids chemistry and often clashed with Sukh Dev. But he was in awe of the famous NCL chemist. At the working level, the deceptive veneer of calmness also slipped at times, and working together was not always easy. There was a cultural clash between those who felt that an untried local technology was being hoisted on them at the expense of a smoothly working imported technology and those who were keen on fully indigenizing this critical area of production with all its uncertainties and frustrations (economic and socio-political implications).

The NCL overcame all these problems and plant construction proceeded smoothly. There was considerable discussion on the design of the factory building itself. Banerjee clearly wanted two levels of security, an outer one with armed guards, and an inner one through which the workers had to pass without their clothes in single file to ensure that no narcotic was slipped out. The plant was finally inaugurated in 1980.

Resistance from Workers to Closed Drying of Morphine thus Preventing those Wonderful Particles from Wafting into Them!

One more aspect of plant location conveyed a distinctly Indian touch to this project. The opium from the poppy plants cultivated in the Neemuch area was sun dried on concrete slabs constructed in a guarded enclosure with no ceiling. The modern factory was constructed as an extension of the same site but with no change in the drying procedure. The government was particularly careful not to interfere with the existing method of manual drying of the opium, as this was a very sensitive issue with the local labor force. But the drying of the finished alkaloid was modernized. In the old process at Ghazipur, morphine was dried on heated pans. The workers loved this since it allowed them to breathe in fine particles of the narcotic. There was an understandable uproar when this practice was replaced by one with closed drying. The workers resented the withdrawal of the continuous soothing narcotic effect of the older method!

The Second Modernization Phase

Then came the second phase when the plant was to be further modernized with the latest imported equipment and an improved process for converting morphine to codeine, largely by N. R. Ayyangar. The codeine process was successful and is to this day working well giving the specified yields and purities. On the other hand, the modernization exercise marked one of the worst experiences of the NCL in its history of technology transfer. The NCL failed to recognize its inability to specify equipment without personally handling it for the kind of gummy material involved in the process. Although two engineers from the NCL (GRV and SPM) accompanied officials of the Ministry to examine the equipment offered by many European countries, the recommendations of the team were faulty and the equipment failed to perform. An unsavory outcome of this failure was that the Ministry instituted an enquiry into possible irregularities in the purchase procedures.

Although many technical lessons were learned from this long drawn project, the most important was with respect to management. The lesson the NCL passed on to the Ministry in the most unmistakable terms was that the government was not structured to deal with industrial production. Public sector units perhaps, but never the government directly. The administrative bureaucracy had not a clue about managing a production unit. They changed managers at will and with distressing frequency, gave them no powers, retained stratified procedures, imposed bureaucratic rules, and on top of it all, expected profits! There was no technical audit, no recognition of outstanding work (except through obsolete rules), and none of the things that any normal factory would have. Factories of this type have no future unless they are fully taken out of government hands. As the materials involved are narcotic, appropriate safeguards must be mandated, but they must be managed by private or autonomous bodies. Nowhere in the developed world does the government take upon itself the production of medicinal drugs just because they are narcotic. I rather suspect that these recommendations are safely stowed away in some basement of the Ministry.

If this project was only moderately successful, there is enough blame to go around. There is much to be learnt for any such future effort, particularly for the NCL, because it might well face similar situations in the years ahead in its dealings with the government.

ENDOSULFAN: FAILURE TRUMPS SUCCESS

We now come to a project of mixed outcomes, success and perceived failure vying with each other to define it. It has already been noted that pesticides/insecticides constituted an important component of the NCL's research program. Processes for several of these were developed and transferred to industry, but none on the scale of Endosulfan, a broad spectrum insecticide used in common crops like rice, wheat, cotton, and fruits. It was being imported from manufacturers in the USA and Germany and formulated and sold in India by a number of companies. Hindustan Insecticides Ltd. (HIL), a public sector undertaking, proposed to manufacture it in India through a foreign collaboration.

At this stage, Tilak decided that the NCL should offer a competitive technology and wanted the laboratory's organic chemists to develop a process along the lines of a two-step process reported in the literature, in which three main raw materials are used: hexachlorocyclopentadiene (HCCP) and thionyl chloride (both corrosive and hazardous) and butene diol, all imported. The NCL developed a laboratory scale process with results that indicated a lower cost of production than by the three-step process offered by HIL's proposed collaborator. This was done by a team of organic chemists headed by R. B. Mitra, with the assistance of a team of chemical engineers — GRV, N. Sadasivan (NS), and Doraiswamy.

This was a controversial project right from the start. The technology was riddled with separation, recycle, purity, equipment, safety, and corrosion problems, all of which needed considerable plant scale experience to be addressed effectively, preceded by studies on a fully integrated pilot plant. The chemical engineering group cautioned Tilak to go slow, and even withdraw any involvement, but he had made up his mind. The entire group soon became so committed that Endosulfan became the NCL's priority project. For Tilak's part, it was another acetanilide, another fight to put the NCL on India's industrial map, but the challenge this time was greater, the stakes higher, and my advice to Tilak was different.

The tenders were in the papers and time was running out. So, much against better sense, the NCL decided to make the offer without any integrated pilot plant trials, an unavoidable step for a process of such complexity. “Dropping the pilot” was just a term on paper from the academia even for relatively simple processes, and the NCL was perhaps one of only a few laboratories to have dared to attempt it. Not that Tilak did not know that. He was a very shrewd man, but his enthusiasm and spirit of nationalism proved stronger than his judgment, and the NCL jumped into the fray. It was back again to DCEP and a turnkey offer by them to HIL. The key equipment were to be imported based on tests in prototype units.

While HIL were evaluating all offers, the NCL made one of its most tactical moves in technology transfer that in time was to offset the gathering negative fallout from the HIL experience. Bharat Pulverlizing Mills (BPM), a privately owned company that was engaged in formulating and selling pesticides, developed a great interest in manufacturing some of the pesticides it was formulating, and had carried out some initial experiments on Endosulfan. The NCL hurriedly locked in an agreement with BPM for establishing a plant in the quickest possible time using the NCL’s process. The laboratory had rightly calculated that BPM, unencumbered by red tape and other procedural deterrents to speed, could accomplish this, and dropped all holds to assist them in every way possible. The plant was set up and commissioned in record time, a tribute indeed to the NCL and BPM engineers. The task was made easier when one of the members of the NCL Endosulfan team, N. Sadasivan, decided to join BPM. Sadasivan was an unusually smart chemical engineer with no formal education in the field save a diploma from the Indian Institute of Chemical Engineers. His practical sense proved to be a great asset to the NCL on many occasions, and his departure was a loss to the laboratory’s chemical engineering group.

Soon after the successful running of the BPM plant, the HIL plant was also ready for operation. Unfortunately, the runs were not successful. The stipulated capacity and purity were not achieved and a number of operational problems were encountered. These setbacks prompted HIL to discontinue further inputs and matters came to a tense standstill. Never was a disconnect between the NCL and its client so painfully real. The stalemate was broken when the NCL took an initiative, perhaps the only one of its kind in the history of CSIR, and offered a two-stage solution. (1) It offered to modify the process and demonstrate it at the NCL on a pilot plant scale in a number of runs; HIL would be invited to physically participate in the runs and convince themselves fully on every point of doubt. (2) Then came the telling offer. The NCL would take over the HIL plant and operate it at its expense till HIL was satisfied with the process. This step taken by me (I had by then succeeded Tilak as the Director of NCL) clinched the issue since HIL could not possibly turn it down. The offer was accepted, the NCL ran the plant successfully with the operating personnel of HIL and achieved the stipulated results. HIL accepted the plant, its justifiable anger notwithstanding, and continued to run it. It was not a particularly happy ending, but the NCL got out of it gracefully enough leaving a plant behind that is reported to be still running.

In retrospect, what rescued the NCL was the decision to fully take over the plant, operate it, and hand over a running unit to HIL. But what stands out most strikingly is the CSIR’s unreserved confidence in the NCL and its readiness to underwrite all expenses connected with modifying and operating the plant. Never before had a director-general done this. G. S. Sidhu, the then Director-General of the CSIR, earned the NCL’s lasting gratitude for his optimism, unwavering support, and resolve. Indeed, twice he accompanied me on my visits to the Vice President of CSIR (the Prime Minister is President) and Minister of State for Cultural Affairs, Professor Nurul Hassan, to apprise him of the situation in case there were questions in Parliament.

It is unfortunate that the HIL story seems to grab attention in the country's industrial circles, while BPM's success story is rarely mentioned. But we will leave Endosulfan here, with a disquieting story told in full and a successful one narrated in lesser detail (almost sneaked in, as it were, to buttress the positive features of the larger HIL plant).

ENCILIUM TECHNOLOGY FOR ALCOHOL: AGAIN A CASE OF DIFFERENT PARTIES, DIFFERENT OUTCOMES

Cellulose to alcohol has, over the years, attracted the attention of practically all countries. Several proposals involving various levels of pilot plant operation were submitted and reviewed from time to time by the concerned ministries of the Government of India. On a somewhat smaller scale, an attempt was made at the NCL, based on the results obtained from a UNDP project (described in a later section), to undertake pilot plant studies using a special strain of yeast prepared by the Biochemistry Division. This strain formed agglomerates leading to heavier particles settling at the bottom of the fermenter. It could therefore be easily separated from the main liquor, behaving like immobilized yeast without the need for immobilization. The process based on this yeast was christened the *Encilium process*. After its successful operation on a pilot plant, the news was conveyed to the alcohol industry. This attracted several enquiries, including one from the Dhampur Sugar Mills Ltd., Dhampur (DSM). This firm readily agreed to carry out further developmental work in a pilot plant of 5000 L capacity. After successful operation of the pilot plant for three months, the DSM offered to demonstrate this fully validated *Encilium process* to parties interested in it.

At this stage trouble began to brew. A couple of parties conducted trials at their sites and seem to have been satisfied, but for various reasons did not proceed with commercial implementation. On the other hand, Buckau Wolf of Pune and a few distilleries under Cooperative Sugar Mills were not satisfied with the technology. Declaring the process a failure, Buckau Wolf initiated legal proceedings against the NCL. The matter was settled out of court by refunding the fee to the company. This is perhaps the only instance of legal proceedings against the NCL in its entire history.

The DSM declared the process a success and clearly mentioned this in its annual report for 2004–5. The companies which bought the process from the DSM declared it a failure. The politics of it all is difficult to unscramble. To my knowledge, the DSM was using the *Encilium process* till 2008.

VITAMIN C: AN ILL FATED UNDERTAKING

Here was a process that was riddled with a curious mixture of cooperation and conflict, that was declared by KV as successfully developed by the NCL, but whose fate was never openly declared by the user, Hindustan Antibiotics Ltd. (HAL). Vitamin C lingered on for over two decades, till its troubles and technical novelties, shared by the NCL and HAL for the better part of its duration, were entirely unburdened on HAL almost as a matter of course. It was one of the first major processes in which chemical engineers were brought into the picture, though rather late in the day, and taught the NCL the absurdity of offering such a technology without any chemical engineering inputs in the first place. Although chemical engineering inputs, such as they were, were late and severely wanting, there was for the first time an inter-divisional cooperation of sorts within the NCL, and then between the NCL and HAL. To that extent, this was a step in the right direction in the NCL's learning process, though unintentionally so, and at heavy cost both to process developer and user.

As the process progressed from a single-scientist (S. S. Subramanian) undertaking to the divisional level (Biochemistry), then to the inter-divisional level (Biochemistry and Chemical Engineering), and finally to the joint trouble shooting level involving Jagannathan, LKD, M. V. Kunte and GRV from the NCL and S. Ramachandran (who would later become Secretary of the newly formed Department of Biotechnology in the Ministry of Science and Technology in New Delhi), and the chief of R & D and others from HAL. It was a genuine effort that restored the plant to an operational level. It was not, however, good enough to fully resurrect the technology to deliver the anticipated level of performance.

Early Catalytic Processes: A Springboard for Excellence in Process Development

Do not go where the path may lead, go instead where there is no path and leave a trail.

Ralph Waldo Emerson, 1803–82

The NCL's excellence in process development began with its efforts in the 1960s and 70s in the area of catalytic processes. Starting from this sound base, its accomplishments in catalyst development and catalytic reactor design reached a very high order of excellence in the 1980s. We begin by narrating its sound beginning in this section and defer its crossing into excellence to the next chapter. The narration in both the chapters is restricted to catalyst development, and to catalytic reactor design by simple empirical methods. A fuller discussion of its excellence in catalytic reaction engineering was already presented in Chapter 8.

HEXACHLOROETHANE (FROZEN CHLORINE): THE NCL'S FIRST PILOT PLANT PROJECT

Chronologically, this was the first process developed and operated by the NCL on a pilot plant scale. It was also the first process based on a catalyst. This was done even as the fledgling Chemical Engineering Division was struggling to define itself, first under Harish Bijawat and then under M. U. Pai. In terms of impact, this project was not in the same class as those described previously. If it had a lesson at all, it was that continuous operation of a chemical process even on a pilot plant scale had to be done in a different cultural environment and the NCL was not the place for it. It will be seen later that, in spite of this limitation, the NCL did manage to operate, after years of experience, pilot plants over a period of 2–3 days at a time. Around 1960, as the Indo–Pakistan war raged furiously, Venkataraman was approached by the Defense Ministry to quickly develop a process for hexachloroethane (HCE) and produce adequate quantities for use in the war. The chemical composition of HCE is such that it contains approximately 10 parts by weight of chlorine for every part of carbon. Thus it is essentially frozen chlorine that can be released at any selected location to serve as smoke screen.

KV entrusted the task to LKD with GRV, Mukherjee and Sadasivan to assist him. The team quickly developed a process (by no means optimal, considering the urgency) that involved chlorination of ethylene (with chlorine) over a catalyst in a fluidized-bed reactor. A pilot plant was set up (Figure 10.2) and operated continuously. But not before inhaling huge quantities of chlorine over long periods of time, making numerous changes to the pilot plant, and spending continuously over two days at a time in the laboratory on several occasions. The team had also to endure jibes and questions such as "How is the chlorination of NCL going?" There were also some finer moments, such as the conduct of Arthur Lobo, the mechanic assigned to the project, whose optimism was exceeded only by his self-confidence and his self-confidence by his commitment. On one particular occasion, when GRV and I spent the night at the pilot plant and things were going surprisingly smoothly, we decided to take a nap. Lobo volunteered to take on the full

Figure 10.2: The NCL's first pilot plant, the only one that was also used as a production unit to supply the product, hexachloroethane, to the Ministry of Defense

responsibility! We gave him appropriate instructions and asked him to make sure that the temperatures and pressures were periodically recorded (no recorder had been installed!). In the morning, when we went back to the site, he proudly presented his record book. He had meticulously recorded readings every minute for over three hours and had scrupulously cleaned the plant area!

The project was a success. Immediately thereafter, there was a development that was in keeping with the Defense Ministry's general procedure — discarding a project the moment it ceased to be of interest. The quantities supplied by the NCL were useful but no more was needed. Thus ended the NCL's first encounter with a pilot plant project.

THE PRELUDE TO EXCELLENCE IN CATALYSIS

Ever since its inception, the NCL had an interest in catalysis. For the most part, this interest was manifested in the form of research papers and there was hardly any major project involving catalysis. The first signs of project-based interest in catalysis were discernible in the M.Sc. work of D. N. Rihani on the kinetics of hydrogenation of nitrobenzene to aniline under the supervision of LKD. This interest spilled into commercial potential when the NCL undertook a project for HOC to improve the catalyst of their aniline plant. The Managing Director of HOC, N. K. Gharpure, was personally keen on the project since he was interested in pursuing a Ph.D. project under the supervision of LKD. Although that did not materialize, his interest in the project continued and the NCL went far into it. Details are given below under the section *Aniline*. A few other projects were also taken up, such as toluidines, monomethylaniline, and dimethylaniline (DMA), all of which helped establish the NCL as a center of research and development in the field of catalysis. But the effort did not go beyond the use of conventional catalysts, except in the case of DMA, which is considered in the next chapter. Hence these serious excursions into process development may be regarded as a prelude to sustained excellence that was launched around 1980. The area of catalysis gave the lead.

Aniline

The reduction of nitrobenzene to aniline using a copper-supported silica gel catalyst was a common process for aniline in the 1960s and 1970s. One such process, by Sumitomo of Japan, was being used by HOC. The NCL also undertook a project to develop a catalyst for aniline that involved the incorporation of nickel, chromium, zinc, etc. as promoters, in the hope of offering it to HOC. It is necessary to go into some detail regarding this effort as it illustrates the many strategies the NCL had to adopt to sell a process.

The NCL team tested over 100 compositions before arriving at a suitable composition for the conversion. Then, in order to develop confidence for making an offer to HOC, the installation of a multi-tubular (seven tubes) reactor assembly and demonstration of the process in this reactor assembly was considered desirable. The process demonstration was arranged to the staff of HOC and the project engineering firm of Engineers India Ltd. through whom the offer was to be made. At this stage, a tragic event interrupted the process. There was a huge earthquake in Koyna that stopped the supply of electricity to Pune. The standby generator could supply the electricity for the pilot plant, but the hydrogen supply (M/s. Sandvik Asia) could not be resumed.

In view of the requirements of HOC before accepting the process and the NCL's difficulties of running a pilot plant reactor on a 24 hr basis, a joint development program with HOC was signed and a single-tube-reactor pilot plant was established at the site of HOC. The joint development effort continued and a stage was reached when the reactor was found to give the expected conversion and selectivity. But as it did not satisfy the requirement of low pressure drop in the reactor, further work was continued to develop a pelleted catalyst similar to the one in use at HOC. Although this catalyst met all the performance and operational requirements, it did not have the adequate strength. It was at this stage that the NCL got together with the ACC, a catalyst manufacturer, to supply the catalyst. HOC wanted to have guarantees of performance and the ACC was not agreeable to offer any guarantees as the composition was developed by the NCL. The NCL also was not in a position to give financial guarantees and the matter rested there.

HOC was continuing to get the catalyst from the plant suppliers — Sumitomo — but the supplier soon intimated that they might discontinue the supply of catalyst as they were considering a change of technology. The NCL had, by this time, acquired some experience in the design of large fluidized-bed reactors. HOC agreed to invest on a pilot plant fluidized-bed reactor of one ton day capacity. The reactor was integrated with the existing commercial reactor for utilities and product recovery. The NCL prepared the required amount of catalyst — copper impregnated on silica gel — and the pilot plant reactor was run for a few days. The key feature of this reactor design was that the exothermic heat of reaction was removed as steam by locating a boiler inside the reactor.

In the meantime, Sumitomo reversed their earlier decision and agreed to resume catalyst supply. The NCL too had continued its efforts to develop a catalyst in pellet form and carry out the life test in its laboratory scale units. Most importantly, it also showed that the spent catalyst could be regenerated by burning off the deposited carbon. HOC then implemented this method of *in situ* regeneration of the catalyst, thus reducing the requirement of catalyst for aniline manufacture.

This entire cycle of operations beginning with the development of a catalyst for HOC's aniline plant and ending with the implementation of a much less ambitious scheme, that for *in situ* catalyst regeneration, is of historical importance. It demonstrates how the NCL adopted different strategies for somehow getting involved with HOC's aniline plant in order to announce its entry into the field of catalysis and catalytic reactor development. Although this effort met only with partial success, it served a more important purpose. It had whetted the NCL's appetite for catalysis that strengthened its determination for raising the bar and developing state-of-the-art catalysts and catalytic processes. The story of how it did this and succeeded in developing many such processes is told in the next chapter. A few other, not so original, attempts described below contributed to this transformation.

Toluidines

Sudarshan Chemical Industries (SCI) had been manufacturing toluidines, important intermediates in dyes and drugs manufacture, from nitrotoluene by the conventional iron/HCl reduction process. The NCL suggested to them that a vapor phase catalytic process, which would dispense with the need for disposing of large quantities of environmentally harmful iron sludge, would be cleaner and cheaper. They convinced SCI that they could develop a catalytic process for toluidines based on their experience in developing a very similar process for aniline. The NCL then prepared the full design of a plant for toluidines, based on which SCI fabricated and commissioned the plant expeditiously. They operated the plant using a catalyst prepared as per the procedure outlined by the NCL. After several years of operation, SCI could no longer procure the silica gel support of the required purity and strength (for preparing the pellets) in India. They thus decided to import the catalyst in the final pellet form and continued to operate the plant successfully.

Monoethylaniline

The Government of India needed monoethylaniline for defense purposes. The NCL had developed details of the well known liquid phase process where the mono and dialkyl products were generated in equal quantities. In view of the exclusive requirement of the monoalkyl product, catalyst development work was initiated where natural bauxite was found to give a high degree of selectivity to the desired product in a fluidized-bed reactor.

M/s. ATUL products Ltd., Bulsar, showed considerable interest in this project. I had several discussions with their Marketing Manager Daddy Patel, who pushed the project hard from the ATUL side. An integrated pilot plant reactor assembly was fabricated and the process was demonstrated to the company using the bauxite catalyst purified by the NCL, and the product of the required high level of purity was obtained. A commercial plant was then installed by ATUL that was successfully commissioned and operated by the company. As ATUL experienced difficulty in getting bauxite of the required reproducible composition for the process, they procured an equivalent alumina from the ACC and ran the plant successfully.

Butadiene

Synthetics and Chemicals Ltd., Bareilly, had a plant to manufacture butadiene starting from ethanol. It was the only plant in the world manufacturing butadiene by this process and they had difficulty in procuring a catalyst for this process. The NCL successfully developed a catalyst to fully satisfy their requirements.

Projects that Failed or Just Faded Away

> *Results! Why, man, I have gotten a lot of results. I know several thousand things that won't work.*
>
> Thomas Alva Edison, 1847–1931

WATER EVAPORATION CONTROL: A PROJECT THAT PERISHED FOR WANT OF A PERSISTENT CHAMPION (THE CSIR'S WATER MANAGEMENT MISSION)

Large areas of India are arid or semi-arid. The situation is compounded by the loss of water stored in lakes and reservoirs for irrigation and domestic use by evaporation during the summer months. This loss is perennial and enormous, and it is possible to save 25–30%

of this loss by use of evaporation retardants. The pressures of growing population and expanding agricultural and industrial uses of water greatly aggravate the problem. Thus the importance of preventing loss of water due to evaporation from various stored stretches of water as a means of alleviating the problem cannot be overemphasized.

It has been established the world over, in Australia in particular, that normal long chain organic compounds such as cetyl and steryl alcohols, when spread over a water surface as a monomolecular layer, are effective in reducing the loss of water due to evaporation. A project to study this problem in depth was commenced at the NCL within 10 years of its founding (1958) and lasted for over 20 years till 1979, with varying degrees of support from the directors. The immediate objective was to develop compounds with retardant properties superior to those of cetyl and steryl alcohols. The initial findings led to the hope that by extending the polar group of the alcohols and other long chain compounds, better retardants could be prepared. Several detailed experiments confirmed this finding. These compounds, called long-chain alkoxy ethanols, thus became the focal point of further studies. The project was now given a more important status and pursued in three phases:

Phase 1: Synthesis of alkoxy ethanols and determination of their monolayer properties in suitably designed laboratory equipment and experiments.
Phase 2: Semi-field trials on selected compounds in evaporimeter pans.
Phase 3: Large-scale trials in lakes.

The monolayer properties that determine the performance of an evaporation retardant are rate of spreading, equilibrium spreading pressure, film pressure-area relationships, specific resistance to evaporation, surface viscosity, and surface potential. Using these properties as determinants, studies in Phases 1 and 2 clearly established the superior performance of normal alkoxy ethanols over normal alcohols. They brought about a reduction in evaporation of 65–70% as against 45–50% by the corresponding alcohols. A two-step method for their preparation was standardized: first for the preparation of normal long chain fatty alcohols from cotton seed and other oils, and the second for the direct condensation of ethylene oxide with various alcohols to get ethylene oxide condensates. It is noteworthy that normal alkoxy ethanols manufactured by direct ethylene oxide condensation were utilized for the first time in India for large-scale trials. Earlier, only ceto-stearyl alcohols and their various blends were used for this purpose.

One critical observation was that beyond wind velocities of 15 km/hr, the films tended to rupture thus exposing new surfaces for evaporation. Even with this basic limitation of poor wind velocity resistance, large-scale experiments were undertaken to get a feel for the performance of the alkoxy compounds as evaporation retardants. The most important of these was a trial on Indira tank in Maharashtra, at which Tilak, Mrs. Sashikala Tilak, LKD, S. S. Katte, S. H. Iqbal, and several members of the group were present. The photograph in Figure 10.3 shows Mrs. Tilak spreading the compound. The results confirmed the inadequacy of the compounds at wind velocities higher than 15 km/hr. One method of improving wind velocity resistance is to form monolayers of mixtures of the alkoxy ethanols with suitable polymers. Application of the retardants in the form of powders can also lead to better wind resistance. All this required sustained effort and continuous funding, in addition to cooperation from various departments of the state government as well as the CSIR. None of this was forthcoming in the desired measure. Hence the NCL decided to drop the project in 1979 — an unfortunate end to a project that had known it all: normal recognition, neglect, and high priority — and that had now become irretrievably unimportant.

ETHYLENE OXIDE: A PROJECT THAT COULD HAVE SUCCEEDED WITH THE RIGHT KIND OF RESOURCES

This project was taken up as a collaborative venture between the NCL and Engineers India Ltd. (EIL) with the ambitious objective of developing a better than the best EO technology available at the time. It was decided that EIL would provide the funds required for the pilot plant work and the NCL would take care of laboratory scale studies on catalyst and process development. A feature common to many studies is the unavailability of raw materials. In this case it meant the continuous preparation of ethylene from alcohol and its purification. Almost 50% of the team's effort went into this routine job. This, combined with poor experimental facilities, contributed to an enormous delay in developing the required catalyst. Finally, after over three years of sustained effort, a catalyst with the desired

Figure 10.3: Mrs. Sashikala Tilak spreading the water evaporation control agent on lake Indira in Rajgurrunagar, near Pune, in December 1976

activity/selectivity (80% EO selectivity at 15% alcohol conversion) was developed. It took a further 2–3 years to get the pilot plant ready for catalyst testing. Continuous running of the pilot plant was beset with a whole lot of problems, bringing once again to the fore the unwisdom of undertaking pilot plant studies of this nature in a research laboratory like the NCL that is basically ill equipped to run a pilot plant continuously for an extended period of time. Even so, the pilot plant was run for over two weeks and the laboratory scale results were fully validated. An appreciative message was received from Subroto Ganguly, the CMD of the IPCL, the company that was to commercialize the NCL's catalyst.

Then the bombshell came, as it did in many other cases in different ways. Scientific Design and Co. announced an improved technology with 1.5% higher EO selectivity. In a large volume production such as that of EO, this was the proverbial death knell for any technology that performed even marginally less. It would require a few more years of the NCL's time to match this figure, and even if it did there was no certainty that a still higher demand would not be made. The NCL therefore had no option but to call a halt to this genuinely fine effort, wrongly conceived, plagued by delays, scientifically brilliantly executed but at the end of it all, with no future. The credit for the scientific achievements of this project goes largely to V. R. Choudhary for catalyst development and process development studies and to R. V. Naik for pilot plant studies (under Choudhary's leadership).

The main reasons for the failure of the EO project may be summarized as follows:

- The EO technology was continuously updated by the multinationals and their inputs for this purpose were high. This is true of most major processes and the NCL, by its very nature, could not do this for any of its technologies. The consequences for xylofining and other NCL technologies were not severe but were particularly disastrous for the EO technology, for they struck even before it could be commercialized. NCL had underestimated the possibility of such quick absolescence.
- The user industry was not involved, as in the case of xylene isomerization.
- The NCL was not the right place for continuous running of a pilot plant.
- It is difficult to compete with multinationals, particularly for developing a known technology in the high technology area. The case is different for a new technology.

FINE CHEMICALS PROJECT: A SQUARE PEG IN A ROUND HOLE THAT INEVITABLY PERISHED

In the early years of the NCL, scientists of the laboratory (largely organic chemists) were often frustrated by the long delays in procuring much-needed laboratory chemicals from abroad. In addition to the normal delays in importing items from overseas, there was also a great deal of paperwork involved in processing any overseas purchase order. The costs of these bottled chemicals were 10 times those of bulk chemicals and the duty also higher. Venkataraman overcame this problem by establishing a group, under V. P. Fernandez, fully equipped to prepare such chemicals. As many other institutions in the country also experienced similar difficulties, the NCL undertook to supply fine chemicals to them also. Since the NCL was not organized for such tasks, which involved production management, the project did not last long. However, it served the laboratory's interests for several years. This was a case of the NCL taking on commercial type of work that was not supported by its structure for short-term gains. It was like a square peg in a round hole and extracted its own price. It is to the credit of the NCL that it did not attempt to justify the project to avoid a perception of failure by those benefiting from it (a common habit of government agencies), but was decisive enough to scrap it completely. Other projects were allowed to lapse by indifference or calculated neglect (by slow freezing of funds), but this was the first instance in the NCL, and one of the few in its entire history, of a major project being officially dropped.

HIGH TEMPERATURE PROCESSES

The NCL has had a long history of very good work in high temperature inorganic chemistry, though unfortunately with results in no way commensurate with the quality and scope of the work done. Like the chlorosilanes project described in considerable detail in the next chapter, many of these were victims of government policy and the reluctance on their part, perhaps justifiably so in these cases, to commit huge sums of money to untried, complicated technologies. Many senior scientists, including J. Gupta, M. Damodharan, V. V. Dadape, A. B. Bastawde, D. N. Sen, D. Chakrabarty, S. H. Iqbal, and, in particular, V. G. Neurgaonkar, were key players in this effort. Neurgaonkar's well-planned researches came closer to industry's expectations than anyone else's in this group. A few selected high temperature projects are briefly discussed below.

Enrichment of Titanium Dioxide in Ilmenite

In view of the availability of ilmenite, a rich source of titanium, in the state of Kerala, efforts were not wanting at the Indian Institute of Science and the Bhabha Atomic Energy Center to develop processes for isolating titanium dioxide, perhaps the best available constituent of white pigment, Not surprisingly, the NCL too was soon in the picture. The first major kinetic analysis of the process was published by LKD and co-workers in 1958 (see Chapter 8), but it was left to Neurgaonkar and his collaborators to undertake process development and pilot plant studies. The first effort was triggered by a sponsorship from Travancore Chemicals Ltd., but this was abandoned due to scale-up difficulties. Later, a fluidized-bed technology was developed and validated on a scale of 20 kg/hr. Then, in the early 1980s, a meeting was called by the Industrial Development Bank of India (IDBI) to consider a proposal submitted by Kerala Mines and Minerals Ltd. for a plant of 2000 tons/annum capacity, at which representatives of about 20 international companies made presentations. Neurgaonkar made a powerful case for the NCL process, but the IDBI selected an American firm for a process similar to the NCL's. Mr. Panja, the Managing Director of the IDBI, and his technical experts were fully satisfied with the NCL technology, but, for reasons all too familiar by now (absence of a working plant), he had no option but to set it aside. My personal intervention was also of no avail — beyond firmer assertions of faith in the NCL's capability to deliver!

Fumed Silica

Another high temperature project, handled by Chakrabarty, Bastawade and Neurgaonkar, was on fumed silica (fluffy silica with an average particle size of 12 micron) used in automobile tire manufacture, sponsored by Century Rayons, Kalyan.

The process involved hydrolysis of silicon tetrachloride in a specially designed multi-nozzled rosette type burner in a hydrogen/air mixture at 950 to 1000°C. The silicon dioxide produced in the flame was agglomerated in a tube to a particle size of 12 micron and then was separated from the hydrochloric acid in a cyclone separator. The hydrochloric acid gas was absorbed in a scrubber, producing the liquid acid. The fumed silica met the standards of M-5 grade of Cab-O-Sil produced by Degussa, Germany. The firm eventually decided to import the material, rather than make it.

High Grade Silicon

The electronics industry in India was coming of age and the production of high grade (ultra pure) silicon jumped into the fore as an issue of national debate. A. P. B. Sinha, a distinguished scientist of the NCL and an early winner of the prestigious Bhatnagar award, introduced the NCL into the picture by undertaking a serious research program on the production of this material. The Department of Electronics under Ashok Partasarathi was keen on speed and independence from uncertainties associated with any indigenous technology on which work had just begun, notably at the NCL and IISc. Circumstances were ripe for a political free-for-all! Had the NCL unanimously chosen to offer a technology along lines earlier adopted by Tilak for acetanilide, it might have been a different story. As things were, I was not keen on tying up huge chunks of the NCL's resources on a project of this magnitude where, as a chemical engineer, I saw failure as the dominant probability. However, although my support was lukewarm and top priority was not assigned to the project, nothing was denied. A complete pilot plant building was placed at Sinha's disposal and a site was selected adjoining the MERADO building to construct a semi-commercial plant with CSIR assistance. But I was not prepared to stake the NCL's reputation by making a turn-key offer with all guarantees, even though a major manufacturing company, Mettur Chemicals, was brought into the picture for help. An interesting story of how Director-General Sidhu offered his fullest support has been told elsewhere in this book. Fortunately, the waiting and political game was soon over and, rightly or wrongly, the government decided to entrust the job to an American firm. Sinha was convinced that lack of complete support from me killed the project. I for one, was happy the ordeal had ended, the outcome notwithstanding.[7]

A few other processes were also worked out by the high temperature group, such as: chlorination of bauxite sludge, a waste product of the Bayer process, by V. Damodharan and Neurgaonkar, and chlorination of enriched ilmenite by Neurgaonkar and associates. Excellent results were obtained in small pilot reactors, but for various reasons, the work did not proceed further.

OTHER PROJECTS THAT WERE GIVEN UP OR TRANSFERRED

In a laboratory of the size and scope of the NCL, it would be surprising if more than a few projects did not fly and had to be given up for various reasons, including lapse of rationale. They are not to be regarded as failures in the sense that they were taken to a fairly advanced stage and then given up or failed as commercial units (as in the cases mentioned above). Such projects included: high temperature chemistry, organometallic chemistry (later assimilated in the homogeneous catalysis group), technology for imprinting microcircuits on chips (later transferred to Government of India, Department of Electronics' new unit in Pune, along with the concerned scientist, S. Setty), oils and fats chemistry (later transferred to the Regional Research Laboratory in Hyderabad — known now as the Indian Institute of Chemical Technology, along with the project leader A. K. Aggarwala), ion-exchange technology (most of it transferred to the Central Salt and Marine Chemicals Research Institute in Bhavanagar, along with the project leader, N. Krishnaswamy).

It is amusing to note that, although many projects were dropped or allowed to die, they somehow seem to have continued — in a different garb! This was done by the scientists who already had portions of them in their Ph.D. projects, or by astute conversion. This was entirely legitimate since all directors had distanced themselves from such projects.

Rayon Grade Pulp

This project (as distinct from an area) of over 20 years' duration had perhaps the longest and most checkered career in the NCL's history. Started by KV and going all the way into the early years of Mashelkar's stewardship, it had its share of ups and downs, till finally it vanished rather quietly with a legacy marked neither by industrial impact nor academic contribution. The manufacture of rayon in India was based entirely on the right kind of pulp imported from the USA or Europe. It seemed most appropriate therefore to investigate the suitability of different kinds of indigenous biomass to produce rayon-grade pulp. With sporadic support from industry, and mostly with CSIR funds, the NCL set up an integrated pilot plant that occupied almost half the main pilot plant building (named PPI). G. M. Vyas, with his vast experience (including a stint at the US Forest Products Laboratory in Madison, Wisconsin) and then D. S. Bendale, were in charge of this project. Although pulp of the required specifications was obtained, for various reasons (including cost effectiveness), the NCL was unable to commercialize the process.

Bendale was a competent individual but difficult to handle. No director was comfortable with him, and he has the distinction of organizing an open revolt against the NCL, which came to a head during my time when he held a meeting at the main gate to embarrass me as I walked home, but the effort fizzled out (see Chapter 6).

Rural Development (Annual Report, 1976–77)

> *Science to be science must afford the fullest scope for satisfying the hunger of body, mind and soul.*
>
> Mahatma Gandhi, 1869–1948

> This statement best captures the philosophy of rural development, but is in no way restricted to it. The average village dweller in India not only needs scientific inputs to give him food and shelter, but also craves for peace of mind — not through the urban tools of luxury but through simple facilities to practice his faith and discharge his duties.

During the second half of his tenure as the Director of the NCL, Tilak shifted his interest and focus from industrial development to rural development. He was convinced that the NCL's stated objective of working for the good of the people had not been fulfilled to any extent. Considering the fact that over 80% of India's population lived in rural areas, most of them below the poverty line, the research programs of the laboratory had not been oriented to reflect this reality. He therefore became as ardent an enthusiast of rural development as he had been of industrial development in the earlier years of his stewardship of the NCL. While he did not fully lose his interest or connection with industrial projects, his conviction of their near futility in the huge task of improving the lives of village dwellers lent an almost different personality to him — that of a nationalist reformer. He would travel to the remotest parts of Maharashtra, meet the local poor and their leaders and try to see how best the NCL could be involved in their overall betterment. Some scientists were fully with him in his new vision for the NCL but many were not. So the years that followed were marked by an increased delegation of power to project leaders handling some major projects of the NCL that had earlier been taken up to help the Indian chemical industry. Projects in which he had evinced no great interest such as the water evaporation control project now received his personal attention. The work on plant tissue culture, which he had once relegated to the back burner as not appropriate to the NCL's program, now received his enthusiastic support. These and a few other NCL projects were earmarked as crucial to his vision of rural development and were pursued with characteristic determination. It was acetanilide all over again with a new zeal in a different direction.

I mention Tilak's role in the NCL's rural development program in some detail because it is historically important, but more so because it was almost a one-man effort with a handful of senior scientists, mainly A. M. Lele (then head of DTS) and J. V. Rajan (the NCL's finest economist-scientist), and a very devoted secretary, R. Nagarajan, fully involved in it. His second in command, LKD, did not evince any great interest, which both irritated and saddened Tilak, and was most unfortunate because LKD had the highest regard for him and greatly appreciated his continued support.

As the NCL mulled different ways of getting actively involved in rural development, more than merely declaring some existing projects as being important in that regard, the then Director-General of CSIR, Y. Nayudama, announced a concrete beginning at the CSIR level by "adopting" the Karimnagar district, a backward area of Andhra Pradesh, as a model for integrated development through intensive application of science and technology. His plan envisaged the participation of a large number of CSIR laboratories with their wide variety of expertise brought to bear in this national effort. Tilak soon caught on to this idea and wished to adopt a village in Maharashtra for integrated development but downscaled it by restricting the effort to the NCL. So, instead of a CSIR adoption, it was to be an NCL adoption. In pursuing this decision, the NCL had several discussions with appropriate authorities of the Maharashtra government and other social and economic research organizations in and around Pune to select an area in Maharashtra for such an effort. Based on these discussions, the Chandrapur district in Maharashtra was considered suitable. To start with, NCL scientists prepared a tentative basic document containing some ideas on the formulation of an ecosystem development plan for Chandrapur. This document attempted a departure from the usual normative approach of sectorial development and emphasized the need for an ecological approach, with the common man as the central figure and as the main beneficiary of the development efforts. After several deliberations on the methodology and approach with Maharashtra government authorities, the Government of Maharashtra created four task forces, viz., forestry, agriculture, mining and mineral based industries, and infrastructure to study in depth the problems of development and prepare appropriate schemes for implementation. This resulted in a report containing a detailed plan of action.

The coordinating scientists at the NCL made a consolidated review of all the recommended schemes taking into consideration the pertinent experts' comments. Special emphasis was laid on identifying areas where the induction of scientific and technological capability would make a sizeable social and economic impact on generation of added value for the people living in the region, most of whom were backward and belonged to *adivasi* communities.[8] Specifically, a floristic account of the Chanda District of Maharashtra State was prepared. Out of 800 different species available in the various forest reserves of Chandrapur, over 120 were identified as useful medicinal species. But due to reasons mentioned below, the entire work on rural development at the NCL was discontinued.

As part of the rural development program at the NCL, which was pursued intensively between 1974 and 1978, collaboration with the Government of Maharashtra and its field agencies such as the Directorate of Irrigation and Forest Development Corporation Limited (FDC Ltd.) for the implementation of some of the R & D projects forming part of the ecosystem development plan was continued. The program of work specifically related to the areas of water evaporation control experiments at Indira and Kondhapuri tanks in the Pune district, Aundha Naganath tank (Parbhani district) and Kedarpur Tank (Nagpur district). Work on tissue culture for the propagation of teak, which was already a part of the NCL's program (see Chapter 8) was now sponsored by the FDC to identify it more closely with rural development. An ambitious scheme for the utilization of the forest resources of Chandrapur district was also initiated. The District Planning and Development Council for Chandrapur district approved the installation of water treatment plants for treatment of water in the iron-ore belt in that area. Another project suggested by the NCL for the installation of a mechanized charcoal production unit in Chandrapur was approved by the FDC Ltd.

Center for Application of Science and Technology for Rural Development (CASTFORD): With the background experience gained during the course of their work and the approvals obtained from the concerned authorities connected with the formulation of an ecosystem development plan for Chandrapur, the director of the NCL and his colleagues felt that there was a need for the establishment of a separate unit which would be exclusively concerned with the identification, transfer and implementation of technologies specifically suited for rural development. With this end in view, a proposal for establishing a Center for the Application of Science and Technology for Rural Development (CASTFORD) was submitted to the CSIR. After the usual round of expert comments and other formalities the center was established in 1978, a few months before Tilak's retirement. Hardly 2–3 objectives of the center involved research and development. The rest were all exercises in technology transfer to rural areas, study of rural problems, motivation of scientists for rural development, and organization of cooperative effort. Furthermore, the annual report on rural development studies at the NCL for the year 1976–77 lists over a dozen objectives of the center, all of them based on the NCL's full involvement on a permanent basis. Tilak hoped that the center which will form a constituent part of NCL's activities, will open a new chapter not only for the NCL but will also catalyze a new movement in India to mobilize the country's scientific and technological expertise for achieving rural development through innovative inputs of science and technology.

In late 1978, when LKD took over as Director, he examined *de novo* the extent of the NCL's involvement in the proposed center and found that it depended almost entirely on NCL for its scientific inputs. Further, a scheme for motivating NCL scientists to work for the center was also envisaged. This was in conflict with his concept of building scientific excellence at the laboratory and bringing it in line with similar laboratories the world over. LKD was fully supportive of rural development but not at the expense of scientific excellence at the NCL. When Tilak was told about this, he moved the center to another location in Pune. But as it was heavily dependent on the NCL, and for other reasons, it did not survive long. Tilak's death in 1998 ended his dream, for there was no one else with his commitment, drive, single-mindedness, and contacts to continue the effort. LKD's decision in 1980 to relegate rural development at the NCL to a relatively low level of priority (as there were other places much more suited for it) will remain a matter of debate, as a few other major decisions by other directors also will. In any case, in a laboratory like the NCL, it would not have survived the onset of globalization around 1990.

Small Scale Industries Cell (SSIC)[9]

A bedfellow of rural development was small-scale industry, but with a difference: it had an industrial bias and a profit motive. The NCL formed a special Cell in 1982 under the leadership of S. M. Abhayankar to extend assistance to small-scale industries in Maharashtra. The assistance could be of any one of the types described in Chapter 9, broadly: sponsorship, collaboration, and consultancy. Considering the limited financial capability of the small-scale industries, these services were made available at a very reasonable charge. The objective of the cell was to assist these chemical industries with the scientific/technical expertise of the NCL, mostly on the basis of institutional consultancy. It received a number of enquiries which could be classified as

- those relating to trouble shooting
- those from parties that had identified their projects and needed assistance
- those from parties seeking suggestions for starting new chemical industries

The cell was able to solve the problems of numerous SSI units. In consultation with various government and financial agencies concerned with the development of small-scale chemical industries, it was decided that the following approaches should be adopted for providing assistance to the small scale sector.

- rendering help/advice/consultancy in solving in-plant technological problems
- providing assistance in the assessment of know-how from the technological point of view
- assisting in the development of know-how on a short-term sponsorship basis
- maintaining a data bank and liaison with the industry
- monitoring the assistance rendered
- organizing short-term courses, lectures and seminars for the benefit of small scale manufacturers

Special visits were made to MITCON, MSFC, MIDC, WMDC, Maratha Chamber and Federation of Association of Small Scale Industries to discuss SS sector problems and arrange meetings with entrepreneurs. A comprehensive list of small-scale manufacturers and of government departments, public institutions and allied organizations dealing with the SS sector was prepared and correspondence was initiated with them. In order to assist SSI units in project identification, work on the preparation of directories on specialty chemicals project profiles was continued.

Many enquiries needed experimental work to be carried out at the NCL. The Cell undertook experimental/developmental work for many SSI units. It worked well but was soon consumed in the sea swell of globalization.

READY-TO-USE KITS AT THE BEHEST OF THE GOVERNMENT OF INDIA

The NCL prepared two kits for the Government of India, one that worked for a while and the other whose fate was never known.

Narcotics Detection Kit

Prime Minister Rajiv Gandhi had visited China and Pakistan in the late 1980s. An issue on which there was agreement between the heads of the three states was the urgent need to control narcotics traffic. The PM consulted the Narcotics Department and the Ministry of Finance on ways of achieving this and noted that one of the difficult problems was the quick detection of narcotics. It was necessary to analyze any confiscated material and be quickly sure that it was indeed a narcotic and not a harmless substance. Speed was of the essence in order to avoid arresting innocent people. The PM then made attempts to obtain the kits from UN agencies. The UN had already supplied a few kits to India and they could supply no more. It was necessary to have them developed in India, and it occurred to him that the laboratory best equipped to do this was the NCL. The PM's secretary got in touch with LKD, who in turn asked N. R. Ayyangar to take up the challenge and complete the job within three months, as required by the PM's office. Ayyangar immediately started the work with his group and the kit was ready within three months. LKD then approached Hindustan Antibiotics Ltd. (HAL) along with Mr. B.V. Kumar, a senior official of the Department of Revenue, Ministry of Finance, to manufacture the kit. The managing director of HAL willingly took up the task and produced the kits and supplied them to the Ministry as planned. Each kit was priced at Rs. 2000. HAL made some commercial gain out of this venture.

Tamper-Proof Sealing Kit

The Prime Minister's office approached LKD to develop a tamper-proof sealant for sealing envelopes that could contain highly sensitive information for them. This task was assigned to A. J. Varma, who successfully produced an innovative customized adhesive sealing system during 1983–85. Varma then set up the laboratory-scale unit at the Ministry's technical office. A kit containing the sealant and its application device was prepared for ease of carrying by senior government officials (it resembled a doctor's kit). There were reports that it was being used but there was no official confirmation. There was also no further communication from the PM's office or from the concerned Ministry. Enquiries did not elicit any response.

Contract Research[10]

We saw in Chapter 9 how contract research has been a major part of NCL's applied research program. Contract research was fairly lackluster till about 1990, with a few exceptions, after which, with the advent of the free market era, it was lifted to a different plane altogether. To capture the scope of the contract research projects undertaken for the industry till about 1990, a few selected ones were listed in Box 9.2, of which some that were particularly significant are described below. Because of its different character, contract research after 1990 is described in Chapter 12.

CHEMAPRENE: NITRILE RUBBER

The history of the NCL would not be complete without a strong expression of what it owes to the captains of industry who pushed hard — even staking their reputations — to commercialize indigenous technology. The commercial plant for nitrile rubber in Bareilly is a glowing example of such leadership by one who was a sound technologist, the managing director of a major private company, a fearless spokesman for *Swadeshi* technology both in the private and public sectors of the Indian industry, and a member of many top committees of the CSIR and NCL: D. M. Trivedi.[11] He needed no prodding from Tilak or Kapur in the earlier years and later from me to persuade the Kilachand group to accept the NCL's technology. It was a great day indeed when the joint efforts of Trivedi and the NCL received a clear green signal from the company's board.

Processes were developed for the manufacture of three different grades (viz, low, medium, and high nitrile content) of nitrile rubber, which are special purpose, oil resistant synthetic rubbers. The processes standardized in the laboratory consisted of emulsion co-polymerization of acrylonitrile and butadiene at 5^{o}C using a free radical initiator.

Developed under the leadership of Kapur and S. Gundiah, with the active involvement of GRV and LKD from the Chemical Engineering Division, the technology was licensed to Synthetics & Chemicals Ltd., Bareilly (UP) in 1976. In fact it was partly sponsored by the firm, which later commissioned a commercial plant of 2000 TPA. Nitrile rubbers manufactured by Synthetics & Chemicals Ltd. by the NCL technology were marketed under the trade name Chemaprene.

The process was awarded an Invention Promotion Board Award of the National Research and Development Corporation (NRDC), New Delhi, on the Independence Day (August 15), 1979.

ISOBORNYL ACETATE

Isobornyl acetate is an intermediate in the manufacture of camphor. A new process involving the reaction of copaene with acetic acid in presence of a macro-reticular sulphonic acid resin (Amberlyst-15) was developed by Sukh Dev (assisted by LKD) and this was adopted in the production of camphor by the sponsorer (Camphor & Allied Products, Bareilly) of the project.

THERMAL REORGANIZATION OF OLEOSTEARATES

Intramolecular cyclization of oleostearic acids, chief constituents of tung oil (fatty oil from the kernels of *Aleurites fordii),* to cyclic products is of commercial interest. An efficient process for this conversion was developed by the tactical use of sulphur as a catalyst to permit cyclisation under milder conditions. This work was sponsored by the US Department of Agriculture, under PL 480.

A MAJOR UNDP/UNIDO PROJECT: ALCOHOL FROM BIOMASS, ETC.

The thing to me is that the changes in this field tend to be evolutionary, rather than revolutionary.[12]

Mark Hanna

Decades of research in almost all major centers of biochemical research in the world, which led to no substantial breakthroughs or revolutionary discoveries, unlike in many other fields, fully testify to this statement.

In 1981, the NCL was awarded by UNDP/UNIDO (United Nations Development Program/United Nations Industrial Development Organization) a project to undertake two important studies:

- Fermentative production of ethanol from renewable resources such as cellulose and sugarcane molasses both as energy and as chemical feedstock
- Development of controlled-release pesticide formulations both for farm use and for control of mosquitoes in stagnant waters

The two studies were undertaken as a combined program of the Biochemical Sciences, Organic Chemistry, and Chemical Engineering Divisions.

Fermentative Production of Ethanol from Renewable Resources

Ethanol as a source of power, not unlike coal, has been the victim of the changing perceptions of governments, with no steady policy long enough to make a difference in a comparative assessment with that perennial favorite, petroleum. The breakeven point was \$70 barrel of oil when the project was undertaken, almost three times the ruling price. Sustained research at multiple centers with adequate funding bolstered by a degree of urgency independent of political pressure, must have been the way to go. But that did not happen. Periodic bursts of interest, with no indications of sustained funding, led to many half-completed projects which were often difficult to retrieve from cold storage to be continued from there. This lent a negative perception that was only exacerbated with repeated assertions of being uneconomical that carried the inadequacy from "not now" to "never." It was against this background that the NCL study was undertaken, more with a view to collecting additional information than any real chance of a breakthrough. If success of a project can be measured on these lines, the NCL project was a success.

But not entirely. When it came to evoking sustained industrial support, the latent disharmony between the two participating divisions of the NCL (Biochemical Sciences and Chemical Engineering) burst into the open. This, more than anything else, buried forever any hope of industrial exploitation of the technology. The director felt that this part of the project was mainly an engineering exercise, and assigned it to the biochemical engineering group of the Chemical Engineering Division. As the Director (LKD) was himself a chemical engineer, the biochemists saw fingerprints of bias in this decision. More of this, preceded by the rest of it all, is told below.

The objective of the work on the fermentation of sugarcane molasses to ethanol was to develop and demonstrate on a pilot scale a continuous process with higher conversion efficiency and volumetric productivity than the conventional batch operation. Beads of several polymers such as Ca-alginate, cross-linked gelatin, agarose with entrapped yeast cells were tried initially in packed-bed as well as fluidized-bed reactors. All the systems tried had failed during extended operation due to contamination with the sediment formed during the fermentation. In contrast, a highly flocculent yeast (*Saccharomyces cerevisiae*) which was isolated by adaptation and clonal selection was retained inside the tower-type reactors as stable flocs during continuous operation. Unlike the parent strain, a brewery contaminant, the isolate retained flocculence even in the high-salt containing molasses medium. A demonstration pilot plant was operated successfully over a period of 100 days on 100L ethanol/d scale at ~95% conversion efficiency and 5g/L/h volumetric productivity at ~70g/L product concentration, the comparative conversion efficiency and productivity being ~85% and 1g/L/h, respectively, in batch fermentation. Although the objective of the project had been achieved in this regard, subsequent industrial scale operation had failed mainly due to microbial contamination. The reasons for this were many and there was enough blame to go round between biochemists and biochemical engineers several times over. The project was low-key for some years when it was revived and some improvements were made. It was no longer a UNDP project at the NCL but an NCL project operated with NCL funds. The director then decided to invite industrial participation.

Several parties responded and the technology was offered to a few parties. As already mentioned, in keeping with the practice of naming all NCL developments and discoveries starting with Enc, the yeast culture was named Encilium and the process was called the *Encilium process*. Details of this process and how it fared industrially were described in a section of this chapter which, along with all other projects of the previous sections, was devoted to NCL projects.

Mosquito Control

Now twenty years ago
This day we found the thing
With science and with skill
We found; then came the sting —
What we with endless labor won
The thick world scorned;
Not worth a word today —
Not worth remembering.

Ronald Ross, 1923 (Rowe 2000)
(discoverer of the malaria parasite, bitter that he had been forgotten)

Mosquito borne diseases such as malaria, filaria, dengue keep recurring as severe epidemics in India. The popular larvicide Abate had the least mammalian toxicology at the low doses at which it was effective on larvae of important mosquito vector species such as *Anopheles, Culex* and *Aedes*. Scientists from the polymer and entomology groups of the NCL incorporated this in a rubber strip and determined the optimum formulation and conditions of release. The entomologists carried out these trials in wells, ponds, septic tanks, drains and other miscellaneous water aggregations. Unfortunately, it was found that algal film deposition on the surface of the dispensers was blocking their microscopic channels and holes, and thus blocking the release. Algicides and fungicides were then added to prevent such deposition, but they were found to be of very limited use in the highly polluted natural water systems in India. At this time, UNDP involvement ceased, but not the NCL's pursuance of it.

A new dimension was added to this research as about this time the entomology group was also engaged in studies on control of the guinea worm disease or Dracunculasis caused by a nematode called *Dracunculus medinensis*, which was vectored by an arthropod called Cyclops (scientific name, *mesocyclops sps.*) through ingestion of drinking water in ponds, wells, lakes, etc. The nematode larvae ingested by *Mesocyclops* were released in the human host's body, where they developed into long worms which lodged in various tissues, but mostly in muscles. In its later stages, the victims became infirm and bed-ridden, adding to their and their families' woes in remote villages. The disease was rightly labeled a poor man's disease endemic to the poorer parts of some of the world's developing countries. In India it was endemic in six states, the most affected being Rajasthan where traditional step wells or *bawris* were commonly used by villagers for drinking water, and which were the prime and ideal infective sites. In view of the fact that mostly communities below the poverty line were affected by this crippling disease, the World Health Organization (WHO) at the global level, and the Indian Council of Medical Research (ICMR)/National Institute of Communicable Diseases (NICD), and the Water Mission in India had taken up research and eradication programs on Dracunculasis.

R. N. Sharma's group found that Abate could kill the vector Cyclops, *mesocyclops*, also. Based on this and the previous work of the NCL on larvicide dispensers, the Water Mission of India gave a grant to the laboratory to pursue these studies further. The project was assigned to Sharma, who was later also nominated to the WHO Expert Committees for surveying and assessing the status of the disease eradication programs in the affected states.

The NCL was thus able to pursue mosquito larvicide dispenser studies along with the guinea worm control ones. After many experiments, a system of incorporating Abate in polyacrylamide gel blocks poured into small or large tubes or discs cut out from plastic or vinyl tubing was devised. The larvicide was incorporated in the monomer, which was polymerized to gel *in situ* in several chosen casings. The most effective was the satellite, so called since the gel in these was encased in a round ball with 4–8 arms or tubes projecting from all sides of the ball, giving it the look of a space satellite. The advantage of these was that there were a number of small diameter outlets for the larvicide. This gave options for controlling the release by blocking some, or opening all, as the situation in the field may demand. This also reduced the surface area for algal/fungal adhesion, and in fact this actually ceased to be a problem with these dispensers.

The satellite dispensers performed very well on mosquito larvae in laboratory- controlled condition experiments. In field situations, these dispensers were tried out in rainwater potholes near rivers, tree holes and disposed junk tyres which all had stagnant water ideal for breeding of the dengue causing *Aedes aegypti* mosquito larvae. Unfortunately, in all trials, despite notices, requests, etc., the dispensers were pilfered or damaged by curious villagers in just 1–3 days of the trials. Even in a supposedly secure site next to the Lonavala Police Academy, thefts could not be stopped!

The use of these dispensers for mosquito control could not be actively pursued on account of occasional erratic behavior of larvicide release by some dispensers. This could not be investigated or corrected since all attention had to be diverted to the Water Mission Project on guinea worm which was gaining momentum.

The main objective of the Water Mission Project was guinea worm disease control through the use of Abate in the NCL polyacrylamide dispensers for Cyclops killing in village water aggregations. The formulation finally optimized for cyclopcidal control was given the name GWINCIL. Satellite dispensers with GWINCIL were tried out in actual field conditions with fair amount of success in various parts of Rajasthan and Maharashtra. It was even decided to patent GWINCIL and explore the possibility of developing and marketing this formulation in the NCL satellite dispensers by private parties.

However, by the time these plans could take shape, WHO declared India as a guinea worm free country. Thus all further work on NCL larvicide dispensers was stopped, an unfortunate end to a project with great promise.

CONSULTANCY FOR THAI ORGANIC CHEMICALS CO. (TOCC)

On a request from Thai Organic Chemicals Co. (TOCC), Thailand, an Aditya Birla Company, to improve the performance of their allyl chloride reactor, V.V. Ranade and R.V. Naik were assigned to carry out the job. This was a short duration project covering the period 2001–2002.

TOCC was manufacturing allyl chloride by the high temperature chlorination of propylene. This was done in a specially designed proprietary reactor from a Consortium of Europe. TOCC was not satisfied with the selectivity obtained from this reactor, which was below the design value. They tried to rectify the situation with the original technology suppliers, but were not successful.

The reaction between propylene and chlorine is a complex (series-parallel) scheme which, in turn, depends on the mixing, temperature profile, and other fluid flow parameters of the system, including mode of contacting, heat transfer mechanisms, and backmixing. Several decisions taken with respect to related equipment besides the reactor were also questionable, including heat recovery/heat integration, quenching, etc.

The NCL agreed to study the plant data, evaluate the design and put them in the right perspective. It also agreed to do, besides fundamental calculations on fluid flow, heat transfer and kinetics, a critical analysis of fluid dynamics and turbulent mixing of the chlorination reactor with the help of state-of-the-art CFD (computational fluid dynamics) tools. It agreed to suggest steps for total plant operation, rather than the reactor alone.

As a result of these studies, several recommendations were made for process improvement, and many of them were implemented without any loss of time by TOCC. The selectivity of propylene improved from 79–80 to 83–4%, which resulted in a propylene saving of over 500 TPA. There were several attendant benefits like long and steady plant operation, waste reduction, and better process control. TOCC expressed complete satisfaction with the inputs provided by the NCL and the benefits accruing to them.

CONSULTING WITH GENERAL ELECTRIC (GE)-INDIA TECHNOLOGY CENTER

The NCL consultant in this case was Ashish Lele. The area of consultancy was rheology and polymer processing.

Lele's interaction with GE started with a GE-NCL collaborative program on the rheology (shear-thinning) of copolymers of polycarbonates. In his next project with them, he was involved in a graduate-level training program on polymer science and engineering for several GE employees. Perhaps as a result of this association and also because of the fact that the India Technology Center did not have an in-house expert on rheology, Lele became a consultant to this firm.

SWISS AGENCY FOR DEVELOPMENT AND COOPERATION (SDC): A PROJECT ON ENVIRONMENT PROTECTION

The world is not divided into two types of being, one superior and the other merely surrounding it. Being, nature, the universe — they are all one infinitely complex and mysterious meta-organism of which we are but a part, though a unique one.

Vaclav Havel, *The Quiver of a Shrub in California* (Hakel, 1997)

Under the Montreal Protocol for the protection of the ozone layer, it was agreed that ozone depleting substances with high ozone depleting potentials, such as chlorofluorocarbons (CFCs), should be phased out in 2010 in developing countries. India signed the Montreal Protocol in 1992. Within this policy framework, an Indo-Swiss-German collaboration in ecological domestic and commercial refrigeration, the ECOFRIG project, was begun in 1992 with technology focus on hydrocarbon refrigerants and foam blowing agents.

ECOFRIG Project

This project was based on an agreement between the Swiss Government (SDC) and German Government (GTZ), and the Ozone Cell of the Indian Ministry of Environment and Forests (MoEF) as the lead agency within the Government of India. The project was managed by a Zurich-based consultancy firm INFRAS. The rationale of the ECOFRIG project was to contribute to the establishment of a level playing field for synthetic fluids (e.g. HFCs and HCFCs) and the fully environment-friendly natural fluids such as hydrocarbons in the Indian domestic and commercial refrigeration sectors.

When ECOFRIG started, no published data was available on the reliability of compressors. Therefore it was decided that the NCL should take up research in this field and perform systematic life testing of CFC-12 compressors with a range of refrigerants, simulating all possible options for retrofitting the existing appliance population. Therefore, association with FKW, Hanover, was initiated by the NCL.

The research at the NCL, done under the supervision of S. Devotta and S. Asthana, generated internationally acclaimed information which influenced decision making in the Montreal Protocol bodies with regard to Refrigerant Management Plan design as well as technology decisions in the Indian industries.

Human and Institutional Development in Ecological Refrigeration (HIDECOR) Project

The rationale for the Human and Institutional Development in Ecological Refrigeration (HIDECOR) project was phasing out CFCs from the refrigeration and air-conditioning servicing sector to comply with the phase out targets under the Montreal Protocol. HIDECOR falls under the Framework Agreement signed by the Government of India and the Government of Switzerland on Technical and Scientific Cooperation (Agreement dated September 27, 1966, amended from time to time).

The pilot phase of the HIDECOR project terminated at the end of 2000. The SDC had mandated the creation of a consortium comprising Swiss Contact and IT Power India Pvt. Ltd. to implement the main phase of HIDECOR. HIDECOR was essentially a training program involving training at all levels, including training for trainers (TOT). Its importance can be gauged from the fact that the Indian refrigeration service sector consists of about 40,000 enterprises and about 77,000 technicians. The NCL played the leadership role in conducting TOT trainings.

The NCL has developed prototype units for the recovery and recycling of refrigerants and evacuation and charging as per expert group's advice. It was actively involved in the task of revising the syllabus for the Industrial Training Institute and Advanced Training Institute, and drafted Industrial Guidelines for the trainers. Beside this, the NCL was actively involved in monitoring and hand holding facilitation in a number of training programs organized nationwide under HIDECOR.

India is a party to the United Nations Framework Convention on Climate Change (UNFCCC). The convention aims to stabilize greenhouse gas concentrations in the atmosphere at levels that would prevent dangerous anthropogenic interference with the climate system. Eradication of poverty, avoiding risks to food production, and sustainable development are three principles embedded in the convention.

National Communication Project (NATCOM)

The NCL was identified as a secondary institute for undertaking the GHG Inventory Estimation for the Industrial Process Sector under NATCOM by the Ministry of Environment and Forests, Government of India. The project was managed by Winrock India International, New Delhi. The NCL was assigned the task of estimating the emissions of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) from Indian industries.

For several reasons, including a change of leadership at the NCL, this entire program was discontinued. Mashelkar showed considerable interest in the project, which therefore flourished during his time. Ratnasamy's interest was low-key and Sivaram's interest was almost absent. Hence the project slowly faded away.

Going from Knowing to Doing

It took the NCL close to two decades to meaningfully do what it was created to do: develop commercially viable technologies. In terms of knowledge, the NCL scientists were not lacking. This was often confused with their ability to act. What better way of saying this than to reproduce the following powerful lines from Eric Dexler's *Engines of Creation*:

> *People who confuse science with technology tend to get confused about limits…they imagine that new knowledge means new know-how; some even imagine that knowing everything would let us do anything*
>
> Eric Drexler, 1986

In this chapter we saw the NCL (after an untutored learning process of 20 years abounding in blunders) demonstrate its mastery of known know-how. Progress beyond this stage — creation of new know-how — was its next objective, and is described in the next chapter.

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11

RAISING THE BAR

ON TO STATE-OF-THE-ART

It is science alone that can solve the problems of hunger and poverty, of insanitation and illiteracy, of superstition and deadening custom and tradition, of vast resources running to waste, or a rich country inhabited by starving people.…Who indeed could afford to ignore science today? At every turn we have to seek its aid…The future belongs to science and those who make friends with science.

Jawaharlal Nehru, 1962

The NCL had amply demonstrated its ability to develop and implement technology. As was discussed in Chapter 10, this success was not without consequences. There was a single-mindedness of purpose that sometimes blurred the vision of the NCL. Almost naturally and without Tilak ever realizing it, the laboratory went from doing something for the first time within the country to a state of promoting technology of any level, provided it was developed indigenously. The turn-key approach and unremarkable technology development, necessary as they were in the early years of technology transfer, were now redundant. They had to be replaced by an approach that restated the primacy of excellence in research and process development in no uncertain terms. This happened over a period of a decade covering the 1980s and has continued in different directions since. Doraiswamy is credited with bringing about this transformation (ref. *NCL — The Golden Years*, 2000, i.e. Golden Jubilee handout). Mashelkar, Ratnasamy, and Sivaram carried forward this emphasis on excellence into the globalization era by entering into collaborations and research alliances with well known multinational companies. Details of this are discussed in Chapter 12.

State-of-the-art Catalysts and Catalytic Processes

I am always doing things I can't do, that's how I get to do them.

Pablo Picasso, 1881–1973

The NCL's interest in catalysis was greatly revitalized in 1980 with the arrival on the scene of Paul Ratnasamy who would soon be Mr. Catalyst of India. The story of how he was attracted to the NCL is recounted elsewhere in the book. The program, which was essentially limited to catalytic reaction engineering and some scattered but successful forays into catalyst development, was now extended backward to include catalyst development as a main component. The total program may by summed up as follows: (1) carrying out state-of-the-art research in the areas of catalytic chemistry and reaction engineering, and (2) designing, developing and commercializing state-of-the-art catalysts and catalytic process technologies, in particular for the petroleum refining and petrochemical industries. To meet these major challenges, new specialists in catalyst development and chemical reaction engineering were hired (Ramaswami, Sivasankar, and a little later, Rajiv Kumar), in addition to Paul Ratnasamy, and major investments in relevant process equipment were made. Institutional agreements with catalyst manufacturers like Associated Cement Companies Ltd. (ACC) Mumbai, and United Catalysts India Ltd. (UCIL), Mumbai, were concluded to facilitate lab-to-manufacturing plant transfer of technologies for the production of catalysts. Efforts were made to involve the ultimate industrial users of catalysts right from the development stage so that catalysts and processes developed at the NCL and manufactured at the ACC or UCIL could be commercialized at the users' plants in a seamless manner. Thus the NCL entered a tripartite agreement in 1981 with the ACC and Indian Petrochemicals Corporation, Baroda (IPCL), for the development of a xylene isomerization catalyst. Similarly, the NCL, ACC and Hindustan Petroleum Corporation, Vizag, entered into an agreement to develop a superior catalyst and process for the manufacture of ethylbenzene from agro ethanol. Since it was proposed to use zeolite-based catalysts for both the processes and also in view of the emergence of zeolites as major industrial catalysts for many processes, a comprehensive research program on zeolite chemistry was launched including the influence of various operational parameters on the type and quality of the zeolites during their synthesis, their physicochemical characterization by various spectroscopic techniques, formulation of zeolite particles into extrudates, tablets, fluidizable particles with diameters in the range of 50–100 mm, etc.(see Chapter 8). Parallel to these investigations into the chemistry of zeolites, engineering issues like diffusion and heat transfer in zeolites, fluidization behavior of zeolite particles, and adsorption on zeolites were also investigated. Similar studies were also carried out on non-zeolitic catalysts used in many processes. An integrated pilot plant for producing adequate quantities of catalyst was set up (see Chapter 5). As a consequence of all these focused and sustained efforts, technologies for the synthesis and use of 10 novel catalysts were developed during the next 15 years as listed in Box 11.1. The xylofining catalyst is still operational and the Albene catalyst ran for over three years. Regarding the others, they were in commercial operation for brief periods of time after which, due mainly to commercial reasons, the production of those catalysts was discontinued. More than 200 patents in India and 50 patents abroad covering various innovations in the field of catalysts were granted to the NCL. Over 300 papers were published in international journals in this area.

In order to obtain a historical perspective of the catalysis program, three of the most successful efforts starting from catalyst development to process implementation are described in some detail below. These represent three firsts in the world and signaled the NCL's entry as a major player in the world of catalysis. Truly had the NCL moved from reverse engineering of known processes to the creation of sustained excellence in catalyst development and catalytic reaction engineering.[1]

Box 11.1: State-of-the-art zeolite based technologies developed by the NCL

S.No.	*Technology*	*Industrial partners*	*Year of commercialization*
1.	Zeolite catalyst, Encilite-1, for xylene isomerization (this catalyst operated,without deactivation,for 10 years in the plant, a world record !)	Indian Petrochemicals Corp. Ltd.	1985
2.	Zeolite catalyst, Encilite-2, for production of ethylbenzene directly from ethanol and benzene (the first and only plant in the world to use this technology)	Hindustan Polymers Ltd.	1989
3.	High silica zeolite, Encilite-3 catalyst for dewaxing of petroleum fractions.The catalyst is still being exported to Europe.	United Catalyst (I) Ltd.	1989
4.	Alumina support for naptha reforming catalysts for production of gasoline and aromatics	Indian Petrochemicals Corp. Ltd.	1990
5.	Mixed oxide dehydrogenation catalyst for production of styrene from ethylbenzene	Polychem Ltd.	1991
6.	High silica zeolite additives for enhancing yields of LPG in the FCC catalytic cracking process	United Catalysts (I) Ltd.	1991
7.	Alumina catalyst and process for ethylene from alcohol	Chemplast, International Catalysts (I) Ltd.	1992
8.	Iron-molybdate catalyst for formaldehyde from methanol	Cibatul, Atul Products Ltd.	1992
9.	Zeolite (Encilite-4) catalyst/process for p-diethylbenzene from ethylbenzene and dilute agro ethanol	Hindustan Petroleum Corp. Ltd.	1994
10.	Zeolite (Encilite-5) catalyst for production of linear alkyl benzene from benzene and C10-C13 olefins	Reliance Petrochemicals Ltd.	1996 (3 tons per day (tpd) pilot plant)

DIMETHYLANILINE: AN UNLIKELY DEBUT AS FORWARD TECHNOLOGY

Dimethylaniline (DMA) is a common intermediate used in the manufacture of dyes and the explosive tetryl since the early days of the chemical industry. An unremarkable time-worn process in which aniline and methanol are reacted in the presence of sulfuric acid at an elevated pressure suddenly came alive when it was transformed into a novel process, making its unlikely debut as the NCL's first forward technology. This new process was reported in the *Chementator* section of McGraw-Hill's *Chemical Engineering* accompanied by a feature article (L. K. Doraiswamy, G. R. V. Krishnan, and S. P. Mukherjee, 1981). And in this transformation lies a story.

The conventional process produces a side product, monomethylanile (MMA), in a quantity equal to the main product, leading to increased consumption of chemicals and therefore increased cost of production. Also, MMA and DMA have very close boiling points requiring costly chemical separation, further adding to the cost of production. Sahyadri

Dyestuffs Ltd. (SDL), who first reluctantly cooperated with the NCL, later agreed with the laboratory on the need for an altogether new process and commissioned the NCL for the task. The project was again assigned to the process development group of LKD, G. R. Venkatakrishnan (GRV) and S. P. Mukherjee (SPM). Based on the use of clay and bauxite (an alumina-containing mineral available in many parts of India) for similar processes in the then USSR, the NCL started laboratory scale screening of this and other catalysts for the reaction between aniline and methanol in the vapor phase. After almost a year of intensive research, a suitably treated bauxite was developed (as we soon learnt, bauxite, a mineral, should never be used directly as a reproducible catalyst).

In view of the urgency of commercializing this process, the NCL adopted a simple short-cut method of reactor scale-up. I mention this in some detail (as non-technically as possible) to make the important point that the NCL was slowly falling in the industrial groove of neither being too theoretical and academic nor outright empirical. (This approach is changing now, with greater attention to rigorous modeling.) The reactor chosen was what is normally referred to as the multi-tubular reactor in which a bundle of small diameter tubes of a fixed length is enclosed in a larger shell through which a heat-exchange fluid is circulated for supplying or abstracting heat as the case may be. In this case, heat had to be removed. The basic principle of most tubular systems of this type is roughly that the diameter of the tube determines capacity and the height determines efficiency. Since the capacity of a single tube can be chosen *a priori*, the diameter of each is also nearly fixed. The reactor height (i.e., the catalyst height in the tube) can be varied to obtain the desired efficiency (conversion in this case). With the main features and outputs fixed for a single tube, it only remains to compute the number of tubes to obtain the desired total capacity. This is a rough and ready way to scale up, which the purist in me as a reaction engineer should rebel against, but had to do for the purpose at hand! Anyway, it worked admirably.

Now came another question. The NCL realized that reproducing a catalyst prepared in the laboratory on a commercial scale was often a formidable task and could only be done by specialized groups. The concept of everything being done at a single place, long discarded in developed countries, was also yielding in the NCL to that of multi-party involvement. At the suggestion of the NCL, SDL approached Associated Cement Companies Ltd. (ACC), which was then among the few catalyst manufacturers in India to produce this catalyst. The NCL also warned the company that since bauxite was not a reproducibly defined catalyst, it would be desirable to start with pure alumina. It was found that neither bauxite nor pure alumina, when tested over a prolonged period of time, could sustain their activity. They deactivated slowly, leading to progressive lowering of conversion. This was caused by the tarry substances depositing on the catalyst that blocked its pores, a well known mode of deactivation. The NCL developed an additive that, if added continuously with the feed, helped remove these tarry materials, thus continuously regenerating the catalyst. Using this method along with the alumina catalyst continuously restored the activity, so that the reaction could be run for months without catalyst replacement. The entire process was successfully carried out in a semi-commercial plant of 300 tons per annum at the factory site in Pune. SDL then built a 2000 TPA plant at their Dewas site in Maharashtra, the engineering designs for which were prepared by Uhde India Ltd. The plant continues to be in production after 25 years.

This was a major success for the NCL and the beginning of its tryst with excellence in industrial research and process design. The subsequent announcement of this new technology, the first catalytic vapor-phase process for DMA, in *Chemical Engineering*, further buoyed the laboratory.

XYLOFINING USING THE NCL CATALYST ENCILITE 1: DEBUT INTO THE WORLD OF INDUSTRIAL CATALYSIS AND PETROCHEMICALS

Three things stand out in this process: the names Xylofining and Encilite, the NCL's entry in the competitive world of hydrocarbons and, more than anything else, its forceful announcement as a player in the field of industrial catalysis. Although the NCL had earlier developed the first and only catalytic process for DMA, it did not have an integrated program in catalysis. It was lacking both in specialized talent and sophisticated facilities. The DMA process was a stray example of success and, if the truth be told, the stuff of which some innovations are made, and not a planned result of sustained effort and inventiveness in a specific area. But this success prompted LKD to establish an entire section on catalysis at the NCL, by first attracting potentially the best available catalyst chemist in the country. How the NCL attracted Paul Ratnasamy is told elsewhere in this book. His assignment was to develop a world-class catalysis group at the laboratory, with initial emphasis on catalysts for selected processes of the IPCL. It was understood that the IPCL was at that time looking to revamp its xylene isomerization plant at Baroda, probably with a new catalyst from Englehart of USA. This prompted Paul Ratnasamy (PRS) to channel his efforts more selectively to the development of a zeolite catalyst for this process. His larger program on zeolite catalysis would continue.

The IPCL's initial program of production included xylene isomerization using Englehardt's catalyst and process. Xylene comes in three isomeric forms, i.e. with the same chemical composition but structurally different, that are difficult to isolate from one another. The three forms are the *para*, *ortho* and *meta* isomers, of which the IPCL was largely interested in the *para* isomer used in the manufacture of polyester fiber. The object of isomerization is to start with the naphtha fraction from the reforming of petroleum (another important fraction of which is gasoline used in automotive fuel), which contains all the three isomers, and treat it to get the *para* isomer selectively. The separation process is equally important as the other isomers are also used as starting materials for a variety of chemicals, such as the *ortho* form in the production of plasticizers for the PVC industry. In view of the increasing demand for polyester fiber, and therefore for the *para* isomer, the IPCL decided to double its capacity to 90,000 TPA and was negotiating with Englehardt for doing so with the firm's famous ZSM-5 catalyst. It was at this stage that the NCL's general interest in isomerization was upgraded, and indeed became its top priority.

The NCL had already developed a catalyst and filed patents in several countries including the USA. The Central Research Station of ACC in Mumbai was also engaged in a similar effort. It was fortunate that at this stage in the IPCL's history, a man of the vision of Dr. Subroto Ganguly was its Chairman and Managing Director (CMD). LKD approached him with the suggestion that he should give the NCL catalyst a chance by considering it along with other catalysts. He readily agreed and thus began an association that was to take both the institutions to a new level of catalyst development and recognition.

By an agreement between the IPCL, ACC and NCL, the NCL catalyst was tested simultaneously at all the three centers using the IPCL feedstock. The results were more than satisfactory and paved the way for further negotiation. By this time, it was decided by the NCL that the catalyst would be given an NCL-ish name that would clearly reflect its origin. Thus this NCL catalyst became the first in a series of catalysts christened as *Encilites*. The process by which isomerization of xylenes occurred was called *Xylofining*. At this stage, two crucial issues had to be addressed before the IPCL could take the matter to its board. This was particularly important since both Ganguly and I were interested parties, he as the CMD of the IPCL and I as a member of the IPCL's Board and Director of the NCL. The issues were as listed below:

- Although the catalyst was acceptable, the operating conditions worked out by the NCL were different from those in use at the plant. Thus it had to be established that the existing equipment could handle the changed conditions without affecting quality or capacity. A team of engineers from the IPCL and NCL was assigned to this task, and it was confirmed that existing equipment could be used with marginal modifications.
- The NCL catalyst had been tested on a laboratory scale for uniform activity over several days. Regarding performance over an extended period of time, such as 2–3 years, simulated data on deactivation, regeneration, and performance after regeneration were obtained. These were clearly not acceptable to the IPCL, and neither to the NCL for that matter. Further, loading the NCL catalyst in the reactor would mean undertaking a commercial trial over a scale-up ratio of 50,000, a highly risky proposition.

The implications of these two issues were discussed in considerable detail. Ganguly then took a bold decision to load the reactor with the NCL catalyst and run the plant for a trial period of one month. If the catalyst did not perform to specifications, it could be removed and the reactor reloaded with the old catalyst. An exhaustive program of experiments and analysis showed that there would be no impurities that would interfere with the separation process and equipment regardless of the catalyst used. If the catalyst failed, the loss to the IPCL would not exceed Rs. 1.5 crores. If it succeeded, the advantages would be many. The matter was put before the Board in the presence of a senior government representative. Ganguly and I both made brief presentations. The Board approved and the die was cast. The ball had irretrievably come back to the NCL's court and Ganguly had staked his reputation. The catalyst was manufactured by the ACC and the trial began in November 1985. The success was beyond expectations. Ratnasamy had scored! A photograph of the isomerization unit is shown in Figure 11.1.

Figure 11.1: The IPCL's xylene Isomerizer that produces the basic material for the manufacture of polyester fibers

Several months later, how Ganguly, Ratnasamy and I announced our success at a crowded function in New Delhi in the presence of the Commerce Minister to the Government of India and the Director-General of the CSIR (A. P. Mitra) is now a matter of history (Figure 11.2). An audio-visual presentation followed by a press conference concluded the event. The fact that the catalyst continues to perform beyond expectations even to the day of this writing, without a single reloading, is testimony to this great joint effort by the IPCL, ACC, and NCL.

In retrospect, the chief factors that contributed to the unique success of this project can be listed as follows:

- The NCL's decision to urgently establish a world-class group in catalysis and invite Ratnasamy to head it.

Figure 11.2: Photograph taken at the joint announcement in Delhi of the use of the NCL's encilite in the IPCL's isomerization plant at Vadodara, for producing the basic chemical for the manufacture of polyester fibers

- Novelty of catalyst and process for an important petrochemical
- The unwavering and bold decisions of the IPCL's CMD, Ganguly
- Involving an independent agency, the ACC, for catalyst evaluation and production in collaboration with the NCL and IPCL
- The historic decision of the IPCL Board to go ahead with commercial trials
- The excellent spirit of cooperation between the NCL, IPCL, and ACC, the developer, user, and manufacturer of the catalyst, respectively.

In recognition of the joint effort by the three organizations, ICMA presented its 1985 ICMA Award for Forward Development of Technology to them with the following citation:

> *The National Chemical Laboratory, Pune, has secured an astounding success in inventing a highly original catalyst for isomerization of xylene, containing ethylbenzene. This development calls for a very high level scientific inputs from diverse areas. They have successfully interacted with the Associated Cement Companies Limited and the Indian Petrochemicals Corporation Limited in transferring this complex technology in a record period.*
>
> *The Indian Chemical Manufacturers Association recognizes the successful penetration of the National Chemical Laboratory into this frontier high-tech area of world class and compliments the joint endeavour.*

As already stated, unreserved cooperation from the user industry was a major factor in the success of this project (not a common feature of those years). I would therefore like to end this section by quoting from a letter I received from Ganguly, who was the chairman and managing director of the IPCL when this technology was commercialized by it:

> *During my brief tenure at IPCL between March '83 and March'88, I had the good fortune of getting to know the considerable research and development strength of this laboratory* [NCL] *under your inspiring leadership. With support from my colleagues Mr. R. Sethuraman, Director Operations, Mr. Y. R. Trivedi, General Manager—Operations, and Dr. S. Sivaram, Head of the Polymer Division of our R & D, we had the courage and the confidence to try out a new generation of Zeolite based catalyst Encilite developed by the NCL for the Reforming section of the IPCL Aromatics plant. The aim was to reduce the import dependence of the monopoly of Mobil in the supply of reforming catalyst for maximizing p-xylene production to be used in our DMT plant.... We could take the risk based on the convincing evidence presented by you and your former colleague Dr. Ratnasamy. I could convince the IPCL Board of Directors to acquire the catalyst manufacturing facilities of ACC (CATAD) for a modest consideration. The bench scale work of Dr. Ratnasamy could be scaled up at CATAD and a complete charge of Encilite catalyst produced with the joint efforts of NCL and CATAD colleagues. Earlier fears expressed by some of my colleagues of IPCL to try an indigenous catalyst in place of the proven Englehardt catalyst were proved wrong. This new charge of Encilite not only exceeded the life cycle of the imported catalyst but also maximized the yield of p-xylene, an additional bonus.*

ALBENE PROCESS: FURTHER INROADS INTO CATALYSIS AND PETROCHEMICALS

The NCL had not just arrived in the field of industrial catalysis; it reinforced its position through several more high visibility catalytic processes. Following on the heels of the Xylofining process, it soon came out with a second new catalytic process, again for a petrochemical. This time it was not just catalyst replacement but a new process altogether: ethylbenzene from benzene and alcohol (instead of the conventional ethylene) using another Encilite catalyst. Christened the *Albene Process*, this was the first of its kind and also won wide acclaim.

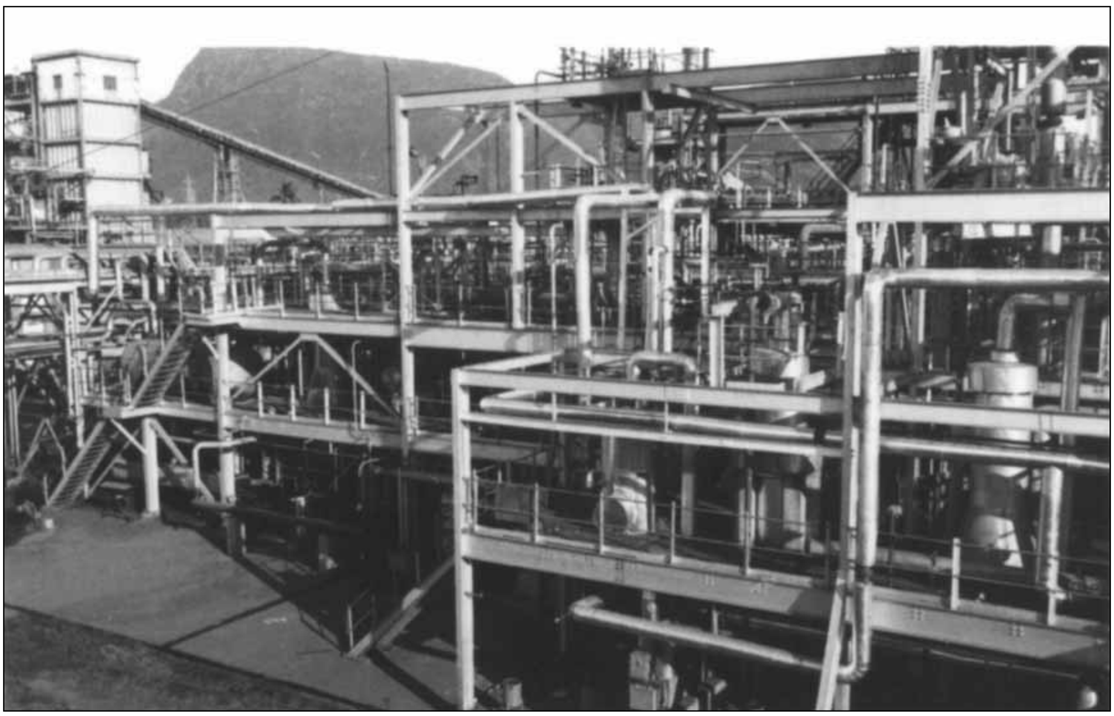
Ethylbenzene is a bulk aromatic petrochemical mainly used in the manufacture of styrene, which is the basic raw material for styrenic polymers like polystyrene, expandable polystyrene, co-polymers like ABS, AES, SAN, and synthetic rubbers like SBR. Internationally about 10% of the world production of ethylbenzene is used in the manufacture of other organic chemicals like *p*-diethybenzene. It is conventionally produced by reacting benzene with ethylene (by the well-known Friedel Crafts reaction). While in most parts of the world petrochemical ethylene is used, the three plants operating in India were based on ethylene made from alcohol. Since this process was usually limited to quantities much smaller than ethylene from the immense petrochemical industry, any ethylene for further conversion was produced at the site from alcohol. Thus there was always one more plant to contend with, leading to a two-step process where a one-step process might have been used. This was because of the traditional popularity in India of alcohol as starting material for a variety of organic chemicals.

If in today's world the alcohol-based technology for ethylbenzene was to compete with the more widely used petrochemical-based technology, its two-step process had to be replaced by a 1-step technology in which ethylene is completely bypassed and alcohol is directly converted to EB. This is precisely what the NCL did in developing its new technology for EB. There are several other striking features of this technology, one of which is that no harmful effluents are generated. The most important, however, is that dilute alcohol could be used instead of the absolute alcohol of almost 100% purity as in all processes using alcohol. This greatly reduced the cost of alcohol and hence of the EB produced from it.

I was at that time a member of the Vijay Mallya Science Foundation along with P. R. Krishnaswamy, Director of the Mallya Research Center at Bangalore. As Hindustan Polymers Ltd., a manufacturer of EB from alcohol and styrene from EB, was one of the companies of the Mallya group, I talked to Krishnaswamy about the NCL's EB process. He immediately agreed to have a team from the HPL examine the technology and take it from there.

Things moved swiftly thereafter, and soon the process was tried out in the company's ethylene plant (after some modifications) and was fully validated. The plant for converting ethylene to EB was not required as the NCL's process required only one step. Following this success, the HPL decided to go ahead with the technology, and the NCL arranged to supply the necessary catalyst for the manufacture of 15000 TPA of EB in the company's ethylene plant. The plant successfully produced EB at the stipulated capacity and purity levels of EB (Figure 11.3). Unfortunately, after running for nearly three years, there

Figure 11.3: Hindustan Polymers' Albene technology plant at Vishakapatnam for the production of ethylbenzene used in the manufacture of the popular polystyrene



was a repetition of the country's all too familiar pattern. The cost of the product had fallen dramatically in the world market, thanks to the relentless operation of the cost of production versus scale of operation rule. All the three alcohol-based plants in India were too small (15000 TPA) to stand up to this exponential rule, and they all closed down. Even a proposal for a much larger plant of Supreme Chemical Industries based on the much advertised Mobil-Badger process was abandoned. And so went a technically advanced process, after its successful debut and three years of profitable operation.

But the NCL's credibility had increased, not suffered, in the process. Indeed, once more, an NCL process had earned recognition from the ICMA. It won the 1989 award for Novel & Complex Technology for the first time in India, having a widespread impact on the chemical industry and economy. Once again it was a case of enthusiastic collaboration between the transferring and receiving cultures, a far cry from the earlier years of the NCL. A major fallout from this experience was the cumene technology which is discussed later in this section.

6-APA: INDIA'S FIRST IMMOBILIZED ENZYME TECHNOLOGY

> *The first immobilized enzyme process in industrial scale was the production of L-amino acids in 1969.*
>
> Sato and Tosa, 1993: 3–24

Immobilized enzyme technology, a state-of-the-art technology of the 1970s and 1980s, is an important area of enzyme catalysis in which the advantages of enzyme catalysts are combined with the advantages of a solid catalyst by anchoring the enzyme to a solid substrate that can be used either in particulate form, as a fixed bed, or a fluidized bed. In addition to experimental studies on these catalysts, theoretical studies on the diffusion-reaction problem involved in such systems were also carried out. But practically the most outstanding outcome of the NCL's efforts in this area was the development of an immobilized enzyme technology for 6-APA (6-aminopenicillanic acid). The technology was developed in two stages: one using a cellulose matrix under SivaRaman and the other using a macroporous, synthetic copolymer matrix under Ponnaratnam.

Semi-synthetic penicillins, which are used extensively in clinical medicine for the treatment of bacterial infections, exhibit a wide spectrum of activity, even towards many strains resistant to the natural, bio-synthetically produced Penicillin G and Penicillin V. The key intermediate in the manufacture of semi-synthetic penicillins is 6-APA obtained by the hydrolytic cleavage of Penicillin G or Penicillin V using immobilized penicillin acylase to release the side-chain moiety. Besides the obvious economic advantage of enzyme reuse, the immobilized system minimizes product contamination by allergenic macromolecules.

In a project sponsored by the Pune-based Hindustan Antibiotics Ltd. (HAL) at the NCL, a matrix system was initially developed by a team headed by SivaRaman for the immobilization of the soluble enzyme produced by the firm. The immobilized enzyme, covalently bound to activated cellulose powder, was used by HAL from 1985 to 1993 for the manufacture of 100 tons of 6-APA, valued at Rs. 20 crores at the time.

The immobilized enzyme system was the earliest example of the industrial application of enzyme engineering in the country and Sivaraman shared the VASVIK award of 1986 for the process.

HAL's 6-APA plant was shut down after 1993. The firm had leased out their penicillin production plant to a private company and was without their source of Penicillin G, the raw material for 6-APA production. But HAL R & D's interest in 6-APA continued, so did their sponsorship of the work at the NCL. A new system was developed, this time by S. Ponnaratnam of the Polymer Science and Engineering Group of the NCL, in which the enzyme was covalently bound to a macroporous, synthetic co-polymer matrix. The new system, unlike the cellulose supported enzyme, was more resistant to abrasion and remained active over more than 400 cycles of use in a pilot plant scale of operation, compared to 100 cycles in the case of the cellulose matrix in the production plant. The system was sold by HAL to other manufacturers for the production of 6-APA.

The NCL had scored another first in India, this time in the use of an immobilized catalyst. It was also a state-of-the art technology at the time.

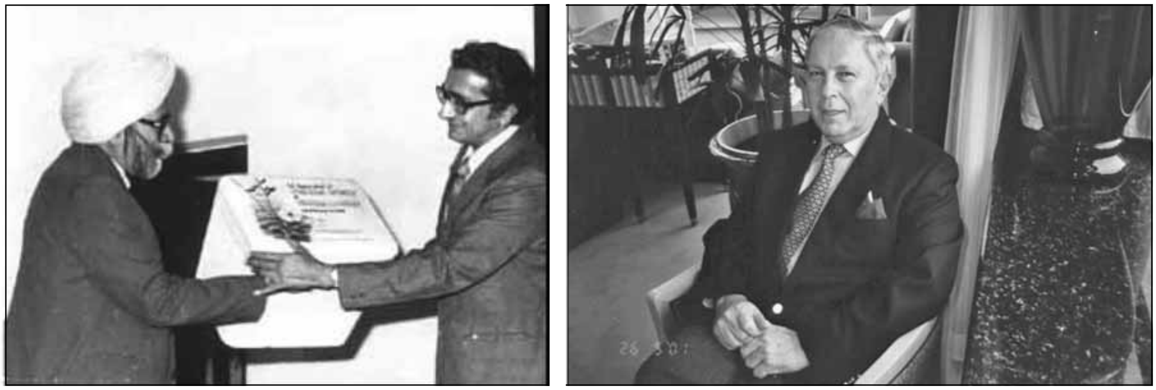
The NCL Enters the Pharmaceutrical Industry: Vincristine and Vinblastine

In the 1970s, India used to be the largest exporter of dried vinca rosea leaves to the US. It was the time when the pharma major Eli Lilly had a virtual monopoly in isolating vinblastine and vincristine, the two dimeric alkaloids widely used as anti-tumor agents, from vica rosea leaves imported from India. Even today, vincristine is a drug of choice for paediatric leukemia. But soon the US company stopped procuring the leaves from India. Thus stocks of these leaves piled up and the Government of Maharashtra, the state where the plants are grown, became interested in exploring opportunities for isolating vinblastine and vincristine from these leaves in India and exporting them to the USA and other countries. It seemed the ideal thing to do: instead of exporting the leaves and importing the finished products, we should be exporting the finished products themselves. It was at this time that the NCL stepped into the picture and, through partial funding from the Government of Maharashtra, commenced work on the isolation of these drugs from vinca leaves.

Under the leadership of Rama Rao, a novel cost-effective process was developed in less than a year and transferred to the Mumbai-based pharmaceutical company CIPLA. The commencement of production of these drugs by CIPLA in 1983, at half the cost of the imported drugs, was a landmark event in the history of the NCL, for it unequivocally proclaimed the laboratory's entry in the field of drugs manufacture. The occasion was celebrated by CIPLA and the NCL by a special event at the laboratory at which Dr. Yusuf Hamied, the CMD of CIPLA, LKD and Rama Rao (Figure 11.4) were present. The process has since been improved by CIPLA but continues to be in production. It is interesting to note here that Rama Rao, who later started his own company, Avra Chemicals, used the petals of the vinca rosea plant as the company's logo. This is a measure of the importance of the industrial exploitation of the NCL process for the vinca alkaloids.

Figure 11.4: Event organized by CIPLA at the NCL to announce the new process for the anti-cancer drugs, Vinblastine and Vincristine

(L) To the left is Dr. G. S. Sidhu, Director-General of the CSIR presenting the award.
(R) Dr. Yosuf Hamied, Chairman and Managing Director of CIPLA.



The NCL found CIPLA to be an excellent company to work with and made use of this relationship to commercialize a few other processes developed by it, for example, diazepam and ibuprofen.

Recall to Excellence Following Inadequacy of Routine Technology

There are instances where the NCL attempted a "routine" development of technology, in other words, did not attempt to give its best shot. This is the kind of apathy that sets in when R & D is taken up as a 9-to-5 activity and success or failure is viewed as a routine outcome. Fortunately, there was also the flip side, when failure ignited a determined response resulting in state-of-the-art replacements.

VITAMIN B6

Many NCL technologies can be declared as successfully completed, listed in the scientists' CVs, and consigned to files that would never be reopened. Going now from the anonymity of projects, names, and numbers to a specific case: the project was vitamin B6, the scientists were some senior scientists working under the overall direction of R. C. Shah, head of the single Organic Chemistry Division of that time and Deputy Director of the NCL, and the period was the mid-1960s. The project was indeed completed, but it could not be successfully transferred to industry. An attempt was made to resurrect it a few years later but with no better result. Then it went back to the files, seemingly for good, and would have remained there but for the scientific acumen and industrial instinct of a latter day divisional head, Rama Rao. (By that time, Organic Chemistry Division had been split into 2 and Rama Rao was head of one of them.)

Vitamins play a major role in correcting nutritional deficiencies which are fairly common in India. In the late 1960s and 1970s when work on vitamin B6 was in progress at the NCL, many of the basic vitamins were made in the country. All the technologies employed by both the private- and public-sector undertakings were already obsolete. Vitamin B6 however was not manufactured in the country and was wholly imported. This combined with its demand of 40 tons per annum valued at Rs. 26 million seemed to justify its manufacture in India. Thus it was felt that yet another attempt should be made to develop a new and viable process for its manufacture. This was accomplished by Rama Rao and his colleagues. The technology was passed on to the IDPL in Hyderabad for implementation.

Meanwhile, the NCL continued its work on the project and introduced several improvements which made it even more economical. The improved technology was passed on to Lupin Laboratories in Mumbai and Themis Chemicals, Gujarat through NRDC. The process involved a series of eight organic synthetic steps and offered unusual challenges in handling extremely corrosive and toxic chemicals, and design challenges due to the reactants undergoing phase changes. In addition, a high quality of the product was demanded to meet international standards. Lupin Laboratories took up the project seriously and carried out pilot plant trials with the full involvement of the NCL. Soon they went on to commercial production, and were still in the process of production while this book was being completed. The importance of this accomplishment by the NCL was recognized by the ICMA through its 1989 ICMA Acharya P. C. Ray Award for Development of Technology Indigenously.

The NCL's decision to retrieve a failed technology from its shelves and offer it to the same party at no additional cost was a clear signal that it would not brook failure easily. It was also a recognition of its determination to shelve the mundane and aim for the best. The days of textbook processes and of the FIAT (Field Information Agency Technical) and BIOS (British Intelligence Objectives Sub-committee) reports of pre-war Germanic vintage, which served as veritable storehouses for many CSIR technologies, were gone forever at NCL.[2] By and large, only the new and the exciting would prevail.

2-ACRYLAMIDO 2-t-BUTYL SULFONIC ACID (ATBS)

ATBS is a specialty chemical used in many applications, such as: co-polymer in acrylic fibers in enhanced oil recovery; in drilling; and as corrosion and scale inhibitor in boiler and water cooling systems. Following upon the interest shown by Adarsh Chemicals Private Ltd. (ACPL), the NCL developed a technology, commercially attractive but by no means technologically novel, for this important specialty chemical. The product was tested by the ACPL and found to be equivalent to that imported from Lubrizol Corporation of the USA. But for various reasons (including the physical and financial damage caused by a huge fire in their factory premises) they decided to shelve the project. What was more unfortunate was that the NCL had to wait till the expiry of the exclusivity period granted to the ACPL before the technology could be passed on to a third party.

When NCL was able to reopen negotiations with a third party, it was approached by Vinati Organics Ltd. in 1998 for a plant of 1000 TPA (adequate as co-monomer for a total capacity of 112,000 TPA of acrylic fiber in the country). In another quirk of fate, just as negotiations were finalized and a contract was about to be signed, there was a complete turnaround in the price structure and the venture appeared no longer profitable. This prompted the NCL to revisit the process and led to the development of a novel continuous one-step process with no effluent problem, for which two US patents were granted. This was distinctly superior to the earlier two-step batch process and was shown to be commercially competitive with the best anywhere in the world. As a result, Vinati agreed to commercialize it, with financial assistance from the Technology Development Board of the Department of Science and Technology, Ministry of Science and Technology, Government of India. Dalal Consultants and Engineers were assigned the task of building the plant which, after some on-site improvements by the NCL, operated satisfactorily. Thus, after a checkered history of uncertainty and doubt but resolute persistence by the NCL, success had been achieved. The interim rejection of the NCL process served as a loud recall to excellence that seemed to have lost its decibels somewhere along the line. It was all for the best, and the NCL had learned its lesson: never settle for the second best. "In the interest of expediency" should be a term rarely, if ever, invoked and acted on in technology development.

SORBIC ACID: AN EXAMPLE OF INDUSTRY'S REVERSAL OF OPINION

Initial failure as part of eventual success has been a feature of the NCL's history in many of its projects. Nowhere is this more evident than in the case of sorbic acid, a food preservative of great importance, particularly for milk and milk products like cheese, bakery products, soft drinks, ice creams, pickles, and sweets. In India, due to lack of awareness of the applications of sorbic acid, its consumption has been low, but seems to be rapidly picking up. It is manufactured by a small number of companies and the technology acquisition costs are high.

The major raw material required for the manufacture of sorbic acid is alcohol, which is easily available in India at sugar factories at a reasonable cost. Alcohol is converted to acetic acid and crotonaldehyde both of which are important intermediates. These are then converted to sorbic acid. Somaiya Organic Chemicals Ltd. (SOCL), manufacturers of these intermediates, was ideally placed to manufacture sorbic acid, and approached the NCL for the purpose. Based on its earlier experience with the cracking of acetic acid to a highly reactive chemical called ketene which, on further reaction with crotonaldehyde, yields sorbic acid in the form of its ester, the NCL agreed to take on this challenge — a challenge because ketene is difficult to produce in high selectivity and is a dangerously reactive chemical to handle. Following a collaborative agreement, the NCL set up a pilot plant at the site of SOCL. The ketene part of the pilot plant worked well but the product just refused to react with crotonaldehyde to yield the sorbic ester, unlike the ketene produced at the NCL on a laboratory scale (a scale-up problem in its severest form). This was a loss of face for the NCL, but instead of being a deterrent it became a challenge, particularly since scaling-up was the laboratory's forte. The company was unwilling to invest any more funds on the project, so the NCL studied the project *de novo* and was able to determine the reasons for the failure of the pilot plant-produced ketene to react. It then set up this unit at the site of the plant and showed a skeptical company that the ketene produced from the laboratory reactor was indeed able to react. This dramatically changed the attitude of the company, who then implemented every suggestion made by the NCL. Meanwhile, with the entry of China in the world sorbic acid market, prices fell, and SOCL abandoned their plan to put up a commercial plant. Instead they ran the pilot plant successfully with appropriate balancing equipment and were exporting the product to foreign markets as of this writing and paying royalty to the NCL.

Serendipity and the Birth of a Forward Area of Research at the NCL: **Jalshakti**

Many regard Jalshakti as a failure. From a marketing point of view it was, but that definition lends a certain wrong finality to the venture that is neither acceptable nor justifiable. In the larger context of scientific research that goes beyond the confines of markets, Jalshakti yielded results that were even more important: it created a new school of research at the NCL. All this started with a chance discovery by a scientific worker in the Biochemical Sciences Division. One does not know how many chance observations have remained unexploited. As Louis Pasteur has commented, *chance favors only the prepared mind*. That this chance discovery should have led to a product that almost made it commercially and then to a thriving school of research led by Mashelkar is as much a tribute to the role of serendipity in science as I can think of in India. We will now see if we can bring some order to this rather jumbled beginning to the Jalshakti story.

THE CHANCE DISCOVERY OF A SUPER-ABSORBING POLYMER

One of the scientists of the Biosciences Division was engaged in synthesizing a number of gels for testing them for electrophoretic separation of proteins. One of these gels exhibited a quite different kind of property: abnormal water absorption. One gram of this material was found to absorb as much as 100 to 500 grams of water. This observation led a team of polymer scientists to look for completely new areas where this product could be applied. The remarkable physical and chemical properties of the product also inspired some of our more imaginative scientists to refer to it as a 'solution in search of a problem!'

A number of super-absorbent products exhibiting similar properties were developed earlier in the USA and Japan, and their demand grew over the years. However, the impact of such materials in India due to the country's peculiar agro-climatic conditions can be far greater than in the Western world. They can have an enormous impact on agricultural production in India, since the rain-fed area accounts for about 70% of the total cultivable area. Due to the uncertainty in rainfall, these areas are often faced with an acute soil moisture stress. Use of these materials can make the difference between a strong start to the growing season and crop failure. In rabi and summer harvests, they can not only save water, but also enable a large area to be irrigated. They can also help in the development of wastelands and in afforestation programs.

The gel discovered in the NCL was processed as an off-white granular organic super-absorbent especially designed to improve plant-water relationships. Mixing it with soil, sand or any synthetic growing medium increases both its water retention capacity and aeration, thus improving the soil quality; it also helps in reducing the frequency of irrigation. By proper application, it can help protect plants against water stress, and by improving aeration of the growing media it can aid in producing healthier plants. Its water absorption capacity decreases in the presence of salts and is independent of temperature in the range 20ºC–70ºC. The product is quite hygroscopic but retains its free flowing character even at 50% water absorption.

The major use of this product was expected to be in agriculture — as soil amendment when mixed with soil, and as seed coating at the time of planting. It could also be used as a soil reclaiming agent in arid lands. Several non-agricultural uses are also possible, such as:

- Medical and personal hygiene products
- Textile printing thickener
- Nuclear waste disposal
- Oil field batteries

Exciting as the potential was, the barriers looked formidable. Overall, a much broader corporate commitment beyond the R & D stage was required. Any technical strategy had to enmesh with a business strategy to ensure commercial success. It was at this point that association was forged with Indian Organic Chemicals Limited (IOCL), a company with adequate experience of the agriculture market arising out of its involvement in bio-fertilizers.

PRODUCTION, NAMING, TESTING, AND TECHNO-ECONOMIC ASSESSMENT

The NCL set up a techno-commercial team consisting of scientists from the chemical engineering, technical services and biochemical sciences divisions, as well as technical and marketing personnel from the sponsoring company. This group also carried out in-depth surveys with potential customers in order to test the concept. Initial field trials were conducted in collaboration with the Department of Agriculture of the Government of Maharashtra and Bharatiya Agro Industries (BAIF) in Pune on a variety of crops. The results were extremely encouraging. In treated plots, trials on groundnut, fodder bajra and fodder jowar resulted in 17–42% increase in yield.

It was at this stage that a decision was taken to name the product appropriately — to convey fully yet simply the attributes of this material. LKD came up with the name Jalshakti, which meant a unique material with power (*Shakti*) to hold enormous quantities of water (*Jal*).

Encouraged by the results obtained, the team decided to conduct extensive trials on various crops under different agro-economic conditions prevailing in the country. It was soon realized that for this strategy to be successful, it was necessary to establish linkages with laboratories of the Indian Council of Agricultural Research (ICAR), agricultural universities, government agriculture and forest departments, seed processing companies, etc., because they not only had the requisite infrastructure for conducting the trials, but also the mechanism to take agro-technologies from laboratory to field. As a follow-up, contacts were established with directors of the ICAR laboratories, agriculture and forest departments, vice chancellors/research directors of agricultural universities, and many others.

While these linkages were being formed, the polymer group in the NCL developed a viable process for the manufacture of Jalshakti, and based on laboratory-scale production of 5 kg/batch, the NCL began to supply samples to various agencies. As demand grew, the scale was increased to 30kg/batch. Based on field trials with the product produced on this scale, it was found necessary to modify the product characteristics and formulations, and to introduce changes in the application technology to maximize the benefits to end-users.

As a result of this approach, within three years of starting the bench-scale work, the product reached the market place. A large number of trials were undertaken all over India with encouraging results. In fact, the benefit-cost ratio in the case of cash crops was so high that its regular usage in the country had already commenced. A semi-commercial plant was established and in operation in record time, and soon Jalshakti was produced and offered for general sale. The company established distribution channels to the district level. Figure 11.5 indicates the locations at which extensive field trials were carried out.

Based on the success in the field trials conducted, it was felt that the introduction of Jalshakti in India would be commercially viable. Unfortunately, the use of such materials, not just Jalshakti, did not assume the proportions anticipated and commercial production was discontinued. A sad end to all the excitement and multi-dimensional approaches created for the first time at the NCL, and perhaps within the CSIR, for the production, testing, and use of a serendipitous product. Several new collaborations were subsequently forged, many with huge multinational corporations, but none with such far-flung participation within the country as in the Jalshakti effort. It soon became admirable fodder for the present book on the history of the NCL!

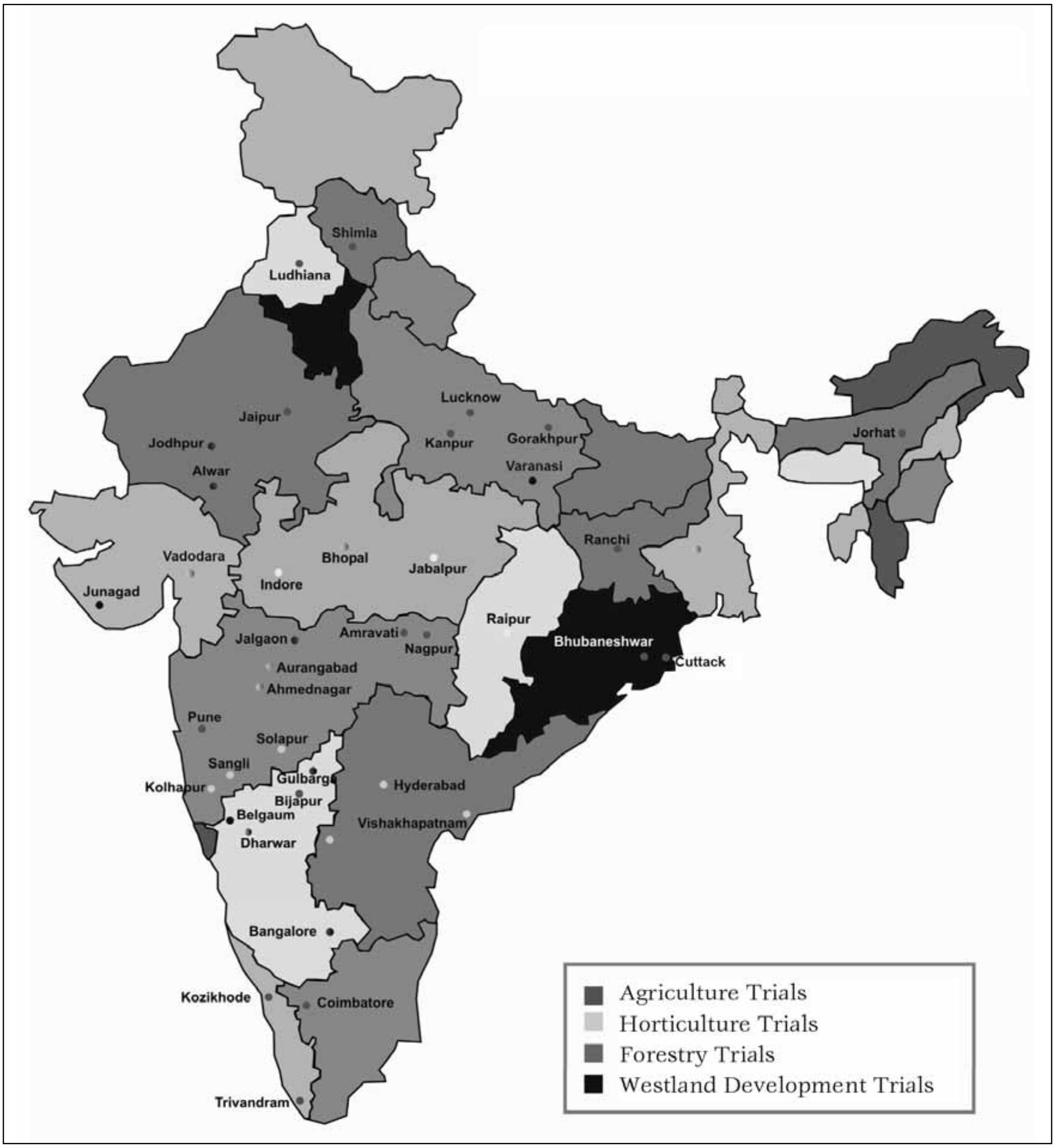
FUNDAMENTAL STUDIES

A number of fundamental studies were undertaken on Jalshakti, all under the leadership of Mashelkar, to understand the molecular basis of super-absorption at a microscopic level and also to examine a variety of attendant phenomena at a macroscopic level. Two findings will be mentioned.

It is commonly accepted that swelling of an ionic polymer like Jalshakti, which is suitably cross-linked, depends only on the permanent networks provided by chemical cross-links. This prevalent view was disproved by NCL scientists — who demonstrated that temporary networks (created by secondary forces) affect swelling in a dramatic way. This has given rise to a new concept: deformation dependent super-absorption.

A fundamental question was addressed by NCL scientists: in what state is water present in Jalshakti? They found that over 90% of the water is present as free water in the polymer matrix, the rest being bound to the polymer. These studies indicated

Figure 11.5: Map showing the large number of locations where Jalshakti's efficiency was evaluated



Source: NCL.

clearly the intimate relationship between the structure of the super-absorbent polymer and the state and extent of water absorbed by it.

The studies also demonstrated, for the first time at the NCL, how some of the laboratory's instrumental facilities could be used. The NMR group under Ganapathy was deeply involved in these studies.

State-of-the-art Technologies Let Down by Changing Government Policy/Commercial Climate

Two major projects of the NCL fall under this category, chloromethanes and chlorosilanes. These heavily engineering-intensive projects are of considerable historical relevance because they defined the NCL, more clearly than any other project before them, as a strong force in the development, engineering, and operation of traditionally difficult projects. They are also important because they were rendered commercially unviable due to short-sighted government policies and some unexpected changes in the commercial climate of the country.

CHLOROMETHANES

The NCL had worked on the chlorination of methane in a fluidized-bed reactor using methane generated in sewage treatment plants. This methane contains carbon dioxide to the extent of 40%. Based on these laboratory-scale experiments an Indian patent was filed on this process.

Standard Mills Company Ltd., Mumbai (SMCL), later called Standard Alkali Ltd. (SA) — a Mafatlal Group company — had established a plant to manufacture caustic soda, but the chlorine obtained as byproduct was not fully utilized. Therefore they decided to install a chloromethanes plant by getting methane from the National Organic Chemicals Industries Ltd. (NOCIL), another Mafatlal Group company, one of the first casualities of globalization, at the adjoining site. Methane was being flared in the stack by the NOCIL and was therefore made available to SA at fuel price. Navin Fluorine Industries, Surat, had been manufacturing chlorofluorocarbons (CFCs) which depended on various grades of chloromethanes as raw materials. In view of the availability of the raw materials as well as a ready consumer for the product, SA decided to undertake development work on chloromethanes based on the preliminary studies carried out at the NCL.

SA decided to establish a larger reactor to produce 1 ton / day of chloromethanes, and it was in this assembly that the developmental work was done at the site of SA. Five scientists of the NCL stationed at the site worked continuously along with an enthusiastic team of engineers put together by SA especially for this project. This period of developmental work was at once the most stimulating and frustrating. There were daily contacts between the site team and my colleagues GRV, SPM, and Sadasivan (who was shuttling between Pune and Mumbai) and myself in Pune. Usually, the call would come at my house in the night, often well past midnight, when there would be a prolonged huddle, after which instruction would be phoned back to Mumbai on the next series of runs or plant modifications to be made. Many were the days of gloom and vanishing hope, but SA never lost faith in the NCL. Vice President V. Ramadurai, who was in charge of the project, and Works Manager Anand Swaminathan never missed a chance to encourage their staff or reas-sure the NCL of their continued confidence in us. But for the helpful attitude on the part of Ramadurai and his senior colleagues, this project would never have seen the light of day. So committed was SA that, even though the Indo–Pakistan war was raging fiercely, blackouts were in full force, and anti-aircraft guns were drowning with their staccato fire the steady drone of the planes overhead, the work never stopped. The excitement and vigor of the time has remained with all of us who were part of this technical adventure, long after the troubleshooting was done and the daily contacts ceased.

Following the successful running of the pilot reactor the company decided to install a commercial plant to produce 4500 TPA of chloromethanes. As it turned out, obtaining a license for this plant loomed as a much heavier obstacle (although a deceptive one, as we were to learn later) than we had ever imagined. Ramadurai and I made several telephone calls to Delhi and even went there personally to convince the people in charge of the urgency for the license. One of Ramadurai's assistants in Delhi told us in the plainest terms that meetings between the heads on the two sides would not solve the problem but we brushed him aside, only to soon discover that he was all too correct! He then saw somebody way down in the hierarchy and got the matter settled (we did not bother to ask how)!

Once the license was obtained, the NCL was entrusted with the responsibility of preparing the detailed engineering designs for the commercial reactor. The reactor which was to be made of Inconel was fabricated in Sweden. A 6-tower distillation train was designed by SA to separate various fractions of chloromethanes. The plant was built in a record time of 14 months, after which the NCL was fully involved in start-up and commissioning. The entire experience was a rare exercise in learning for the laboratory by direct participation. It continued to be associated with the plant for 2–3 years, even after start-up for follow-up work and solving problems arising out of continuous operation and variations in raw materials specifications.

As the plant continued to steadily produce the required fractions of chloromethanes, and the NCL and SA were feeling relieved and satisfied, an entirely unexpected problem hit them both on the broad side. In 1984, the Government of India's restrictions on technology import were eased, as a result of which Gujarat Aromatics and Chemicals Ltd. (GACL) was granted a license to import technology as well as plant and machinery for a much larger scale chloromethanes plant. Also, as a consequence of the Gulf war, NOCIL drastically changed their pricing policy on methane, leading to a rise in the cost of methane by a factor of over a thousand! And the demand for chlorine rose to such an extent that SA found it uneconomical to divert chlorine to their chloromethanes plant. All these factors compelled the closing down of the plant at the end of 1984, a sad end to a great technical effort regarded as an outstanding achievement in the design, erection, and commissioning of a complex chemical plant. Although the plant does not exist any more, the memory of this effort lives in the ICMA Award for Process Design and Process Engineering of Chemical Plants for the year 1975, jointly with Standard Alkali.

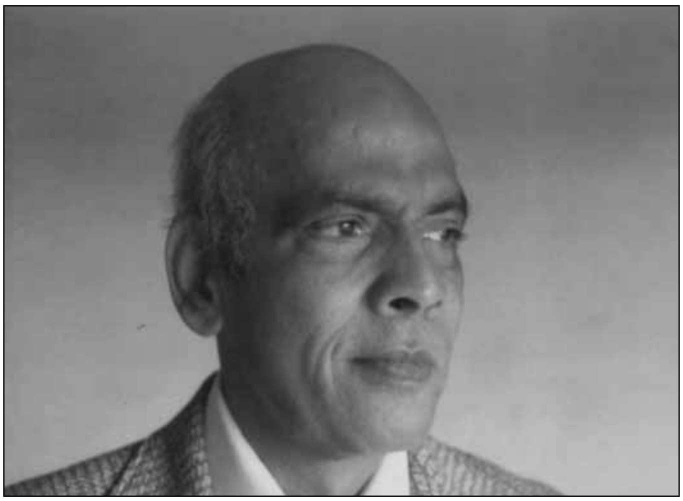
CHLOROSILANES

Chlorosilanes are important basic intermediates in the manufacture of silicone oils and emulsions that find applications in homes and a variety of industries. The most important intermediate among these is dimethyldichlorosilane (DMDCS). Chlorosilanes are prepared by the so-called Rochow reaction between methyl chloride and silicon metal in the presence of a copper catalyst. The NCL's interest in this reaction dates back to the early years of the laboratory when J. Gupta, Deputy Director and head of the Inorganic Chemistry Division, initiated exploratory studies on a laboratory scale. This was followed by more rigorous studies by the chemical engineering group. It was found that the use of a stirred fluidized-bed reactor — a design that is rarely used — greatly facilitated the reaction and was, indeed, the reactor of choice. During the reaction several chlorosilanes are formed, including DMDCS. As the components of the mixture have close boiling points, their separation is difficult and requires fractionating columns with a large number of stages. To circumvent this problem, the NCL adopted a process in which the chlorosilanes are first converted to the corresponding esters with ethanol. Since the esters have widely differing boiling points, they can be more easily separated with a simpler distillation train.

The process development group designed a pilot plant reactor assembly that could generate about 2 kg/hr of mixed chlorosilanes. It was operated successfully to reproduce the laboratory scale results. The NCL then demonstrated the process to Mettur Chemicals, a company manufacturing methyl chloride, and Industrial Development Corporation Ltd. As they delayed a final decision regarding the commercial exploitation of the process, the NCL initiated a dialogue with HICO Products Ltd., Mumbai, a company that used chlorosilanes for the manufacture and sale of a number of silicone products. The Managing Director of HICO, G. M. Abhyankar, a great believer in indigenous technology development, immediately agreed to work together with the NCL. His dream was to implement projects using Indian technology that were considered impossible by many other companies. Even though the NCL had no more than fragmentary pilot plant data, he was of the firm view that the development work could be completed on a time-targeted basis. He recruited engineers with experience in project development and also engaged an internationally renowned engineering company (Humphreys and Glasgow Ltd.) with the understanding that an outstanding engineer would be assigned full time to the project.

As per the norms of the agreement between the NCL and HICO, the process was to be demonstrated to representatives of the company on the scale on which it was developed. HICO procured methyl chloride from Mettur Chemicals and silicon metal from Indian Ferro Alloys Corporation for the demonstration. The demonstration was not a success as it was not possible to reproduce the results with respect to DMDCS. This led to a detailed analysis of the raw materials and discussions with both the suppliers. It was then learned that both of them had modified their processes leading to the presence of certain impurities deleterious to chlorosilanes manufacture. The presence of these impurities was not harmful for the other uses of the materials. While the development team was facing difficulties in resolving these issues, Abhyankar went ahead with his decisions on investments for the pilot plant as well as the commercial plant. Land was acquired, finance was arranged, and even the date of inauguration of the commercial plant was fixed! The proto-type pilot plant reactor and the distillation columns were installed and operated successfully to generate the design data for the commercial plant. It was clear that Abhayankar was working almost round the clock in managing the project, in addition to being emotionally involved in it. This was too much of a strain on his already frail health, as was clear to many of us who used to visit him at his home on the top floor of his laboratory. It was a common sight for me to watch him constantly monitor his own blood pressure. Seeing the concern on my face he would assure me that his doctors in the USA were very optimistic about his health. As it turned out, our fears were well founded, and soon he passed away quietly. He had a large number of friends and admirers not only in Mumbai but in many other parts of the country as well, and his funeral was hugely attended. Thus died a personal friend, a friend of the NCL, a nationalist, a man who encouraged talent and who strongly believed in India's destiny as a great industrial nation. In good faith and on firm grounds, he risked a huge investment, but in the end was sadly let down by an unflinching bureaucracy that chose to stymie first-rate indigenous effort under the pretext of looking forward (Figure 11.6). Fortunately, such instances of monumental short-sightedness are rare.

Figure 11.6: G. M. Abhayankar, CMD of HICO, whose untimely death was a great blow to the Indian chemical industry



Would that there were more industrial leaders with the vision and spirit of Abhayankar! It is to the credit of his successor, M. D. Dhamankar, that the commercial plant was commissioned on the date fixed by Abhayankar — the 13th plant in the world (Figure 11.7). But the story does not end here. The sordid details (not chronicled above) that plagued this technology during the period preceding its inauguration by LKD in November 1982, and more in later years, took their toll, and the plant was shut down in 1984. A detailed account of this failure of a successful technology has been lucidly given by Bhojwani and Lal (1991). I conclude the chlorosilanes story by summarizing relevant portions from that unfortunate chapter in the Indian technology development saga.

The NCL technology, ready in 1976, was different in several ways from other technologies available from Dow Corning of the USA, Imperial Chemical Industries (ICI) of the UK, Rhone-Poulenc of France, Wacker Chemie of West Germany, and Veb Chemiewerk of East Germany: it was based on indigenous ferro-silicon containing only 60–85% silicon as against metallurgical grade silicon of 97.5–98.5 purity; it used cuprous chloride reduced

Figure 11.7: L. K. Doraiswamy with M. D. Dhamankar, CMD of HICO, at the inauguration of the plant for chlorosilanes, used in the production of a variety of silicones

to copper with antimony and zinc as promoters, instead of copper; it employed a novel fluidized-bed reactor for the first time for this reaction. HICO, which seemed in many ways to be an ideal collaborator, signed an agreement with the NCL/CSIR in May 1997 for further development and collaboration. The chlorosilanes plant was part of an integrated complex at Kharsundi, a backward region of Maharashtra, consisting of a methyl chloride plant of 1200 TPA, a chlorosilanes plant of 1000 TPA, and a silicones plant of 300 TPA. HICO's investment in the chlorosilanes plant was Rs. 75 million, and the plant commenced production in 1982. There are three important measures of success of a plant of this type: composition of the product mix from the reactor, purity of the principal components of the product mix, and consumption of raw materials and utilities, the HICO plant was superior to any of its international competitors (see Bhojwani and Lal for actual figures). In addition, none of the arguments that were usually advanced for deriding technologies developed in the publicly funded R & D sector were applicable in this case. On the face of it, things looked so well that nothing should have stood in the way of unqualified success. Yet something went wrong, so wrong that the plant, inaugurated with such hope and fanfare as one of the best achievements of the CSIR, was shut down within two years of start-up. Where there might have been production, pride and profit, there was desperation, defeat and dejection. The same bureaucracy that had, through many of its investigative committees, trumpeted the NCL-HICO technology as superior to any, beat an unceremonious retreat that triggered HICO's decline and death, and caused the death of its CMD, in no uncertain terms.

As a matter of historical record, it is instructive to analyze the ostensible reasons for this turnaround. These reasons, summarized by Bhojwani and Lal (1991), portray more clearly than any other event of those times, the climate in which technology had to be developed and sold, not just to the industry but to the government as well, even under conditions palpably propitious for indigenous technology development in Indira Gandhi's India. Political will and bureaucracy's execution of it are two different things!

All these developments, particularly the unrelenting campaign to denigrate the NCL-HICO technology, drew a strong response from the director of the NCL (who happened to be LKD) in August 1986. It is also pertinent to mention here that even earlier, when the question of accepting the NCL technology was under discussion, LKD's personal encounters with ICI (who were arguing their case by denigrating the NCL's) both through correspondence and direct confrontation were far from pleasant. A senior engineer of ICI had described the NCL technology as "genetically weak." LKD took strong exception to this charge and responded forcefully. He and his colleagues were not going to allow ICI to get away with this attitude. Some of the government officials of the time were also not above giving ICI the edge for, after all, ICI was British and must therefore be scientifically more knowledgeable!

The arguments I presented to the government in defense of the NCL-HICO technology were many and may be summed up as follows. The cost of raw materials had gone up by 250% since 1982, while that of imported chlorosilanes had remained remarkably stable. Even so, the cost of production of chlorosilanes by the NCL-HICO process would be substantially less than the landed cost of chlorosilanes. I asked for import restrictions on chlorosilanes and silicone oils and emulsions, since the HICO production would be sufficient to meet all the country's needs. I also asked for exemption from excise duty for silicone oils and emulsions produced from indigenously manufactured chlorosilanes. But these pleas were not heeded by the government who put forward the simplistic global argument, not applicable at the time: if the technology was good, the product must sell.

More importantly, several formulator firms were persuaded to question HICO's product purity, in spite of certified test figures supplied by HICO. I suggested that these firms — Reliance Silicones, 3M, and Metroark — draw samples from HICO's running plant and analyze them in the presence of their representatives and compare the values with those of any other producer in the world. They had no option but to agree. However, when it was shown that the HICO product was superior to those from Rhone Poulenc and Wacker Chemie, the two firms from whom samples had been obtained, they still raised some irrelevant objections and refused to buy the HICO product. Inexplicably, the government went along with them without giving any valid reasons for their decision.

Around the same time came another big blow, with the Import-Export Policy (IEP) announcement for the period April 1985–March 1988, which placed methyl chlorosilanes as well as silicone compounds/fluids/oils/resins under Open General License (OGL). All these items were being produced in India at that time. Thus in one sweeping stroke, the government made all struggle to produce such an important item as methyl chlorosilanes in India redundant. The gates were now open to foreign suppliers to dump their products in the Indian market and wipe out the Indian challenge. Repeated pleas by HICO to reconsider the policy fell on deaf ears. Thus ended the hopes of HICO and years of development and struggle by the NCL to commercialize a technology that won ICMA's highest recognition, the 1982 award for Forward Technology Development. As Bhojwani and Lal wondered:

> *Were the votaries of this particularly brilliant technology seeking an unfair advantage when they desperately pleaded for a measure of protection against the onslaught of mighty international companies determined to see that Indian capabilities were nipped in the bud*?
>
> Bhojwani and Lal, 1991

But certain things are clear. It had cost crores of rupees, thousands of hours of scientists' time and, above all, the life of a visionary, a remarkable man. No other NCL technology had 'failed' so magnificently, so tragically. Bureaucracy had had the last laugh.

State-of-the-art Technologies that were Proved in Plant Trials but could not be Commercialized

The NCL records are full of technologies that did not materialize, for one reason or another. This is not surprising in a laboratory of the size and diversity of the NCL. Many of them were routine technologies with very little novelty about them, the so-called bread and butter projects undertaken by the laboratory with the object of building a small inventory of available projects in case a demand arose for them. The laboratory also tried to promote these projects in the hope of attracting clients. Some were very small projects that were fully developed; many others required a second level of study and would be pursued only under sponsorship. On the other hand, there were some which were state-of-the-art. I give examples of a few of these that were in a limbo as of this writing.

HYDROQUINONE AND CATECHOL

It is a usually a good sign for a laboratory to have a reasonable number of projects in its inventory of projects available for further development and sale-up in short order. Each laboratory must determine its own optimal number of such projects. The NCL had had too many projects in the past, partially developed and abandoned, perhaps never to be resurrected. These would not come under projects-in-a limbo. The projects that belong to this category are good projects, often state-of-the-art, that for various reasons have found no customers. Hydroquinone and catechol by vapor-phase hydroxylation of phenol on a titanium zeolite or TS-1 catalyst belong to this category. These catalysts are among the latest and are part of the revolution in organic technology.

The NCL successfully synthesized the required TS-1 catalyst for the manufacture of hydroquine and catechol by reacting phenol with hydrogen peroxide. These are important intermediates in making a number of specialty chemicals. Ratnasamy and his team who developed the catalyst were granted two US patents for the catalyst and process. The entire process was then standardized in a pilot plant assembly using a three-stage reactor system through which phenol was passed continuously and hydrogen peroxide introduced incrementally in the three stages. The entire pilot plant consisting of the reaction and distillation assemblies was continuously operated for six weeks and all the necessary data collected for process design.

At this stage, three parties showed keen interest in the technology: Asian Peroxides Ltd. (APL) of Chennai, Hindustan Development Corporation Ltd. (HDCL) of Mumbai, and Indo-Vanillon Chemicals Ltd. (IVCL) of New Delhi. The NCL demonstrated the process to all these parties simultaneously. It is matter of record that they were all going to pursue the project, but history is uncompromising in never looking back. Each of these parties became victims of financial turmoil or death of their senior most executives who were most interested in the project. So, as quickly as things looked good, they took a nose-dive and all activity towards project implementation ceased.

This is a case of a true state-of-the-art technology waiting to be ‘productionized,’ a common word in the Indian chemical industry (particularly the ordnance factories, but almost unheard of in the rest of the world), and waiting, slipped into history.

CUMENE

Phenol is a very important organic intermediate. There are two plants in India manufacturing phenol, both by the UOP (USA) process based on reacting benzene with propylene in the presence of solid phosphoric acid (SPA) as catalyst: Herdillia Chemicals Ltd. (HCL), and HOC (Cochin). This process generates a byproduct stream of heavy ends containing an important chemical, diisopropylbenzene (DIPB). Its importance lies in its conversion to cumene, an industrially important product. However, this stream was disposed of at fuel value at both the plants.

HOC desired to improve the plant’s profitability by recovering DIPB from its heavy ends and converting it to cumene. It approached the NCL to develop the conversion process known as trans-alkylation using its new series of zeolites. The NCL accepted the assignment and succeeded in developing a process in just six months. As the payback period for the plant was low, HOC decided to exploit the NCL’s technology. However, although the process was developed under HOC sponsorship, they desired financial guarantees from the NCL. Coincidentally, around the same time, a loan program entitled SPREAD (Sponsored Research and Development) from ICICI (The Industrial Credit and Investment Corporation of India Limited) was announced for implementing a new project whereby the loan would be written off in the event of failure of the project. HOC, with the help of the NCL, quickly applied for a loan under this program, and equally quickly was granted it.

When all seemed to go well, a new complication arose. UOP had developed a new zeolite-based technology for phenol and offered to revamp HOC’s old SPA-based plant using the new technology. They promised a 60% increase in production at minimal additional capital expenditure. They also seem to have convinced HOC that there would be no need for a trans-alkylation plant in their process. This was clearly incorrect since their process would also produce DIPB. But that is the way industrial salesmanship sometimes goes. In any case, HOC's reluctance to accept the NCL's rebuttal of UOP's claim apart, the company's financial position deteriorated and all talk of revamp or trans-alkylation was dropped. There is every reason to believe that the old process coupled with the NCL's trans-alkylation process would have prevented them from reaching this dire condition. The history of this project is important, along with that of a few others covered in this chapter, if only because it supplants the view that commercializing a process is much more than simple technology transfer. As mentioned previously, the NCL had to learn to play this game, particularly in the high stakes field of petrochemicals and polymers.

FORMALDEHYDE

Formaldehyde is a bulk organic chemical used for making a variety of resins. A number of plants were established in India based on the well known Chematur process, where methanol is oxidized with air over a silver catalyst in the form of a gauze. CIBATUL was one such company. They switched over to a new plant with state-of-the-art technology offered by PERSTOP. The new process yields formaldehyde at a higher concentration without the need for fractional distillation. As the catalyst had a life of only one year and was expensive, CIBATUL desired the NCL to examine the possibility of developing an equivalent catalyst with longer life. They agreed to take a commercial trial if the development work in the laboratory scale was found successful.

The NCL was able to develop the desired catalyst and even identified a catalyst manufacturing company that agreed to collaborate with the laboratory and offer a commercial lot. The manufactured catalyst was offered to CIBATUL when the catalyst change was due. The catalyst was offered at less than half the price quoted by PERSTOP and the performance was reported superior. They had produced 10% more formaldehyde with the catalyst offered by the NCL. Having commercially proved the performance of the catalyst, the laboratory also offered it to Kanoria Chemicals Ltd., another manufacturer of formaldehyde.

And then it happened all over again. The foreign company decided to offer the catalyst at a substantially lower price, knowing that capability to produce it in India was established. The Indian catalyst manufacturing company had by that time wound up their operations. Thus the opportunity to reprocess the spent catalyst and offer it at a still lower price to CIBATUL was nipped in the bud. CIBATUL was very cooperative during the development and proving stages of the technology by sharing their plant operating experience.

Modeling of PET and Other Polymerization Reactors

As mentioned previously, polymer science and engineering was firmly implanted in India over three decades ago, thanks to Mashelkar, soon after he joined the NCL in the early 1970s. Many problems, mostly of a fundamental nature, that were addressed by him and his colleagues almost immediately placed the laboratory in the world arena in this field.

The studies on drag reducing agents used in improving oil flow in pipelines, water absorbing polymers (typified by Jalshakti, see Chapter 10) and modeling of polymerization reactors are some typical examples of this surge in PSE at the NCL. The last item is particularly important in view of its application in the design and modeling of reactors for the production of polyethyleneterephthalate, PET.

Computer simulations of PET reactors (batch, semi-batch, and continuous) led to the development of software, which was successfully used by commercial PET manufacturers: JK Synthetics Ltd., Kota, and DCL Polyesters Ltd., Nagpur. A number of anomalies encountered in the industrial operation of these reactors were resolved through such simulations.

Modeling of reactors for co-polymerization (reaction involving more than one variety of building block, viz. monomer) was also undertaken, resulting in new methods of analysis and strategies of design for continuous reactors. Concentration and thermal multiplicities (i.e. sudden switching from one level of operation to another with the slightest perturbation in concentration or temperature), for which some new strategies were evolved earlier by Kulkarni, Ravi Kumar and LKD (see Chapter 8), were more specifically addressed for polymerization reactors.

Polyphenylene sulphide (PPS) is an engineering thermoplastic with excellent thermal and chemical resistance. A process for the synthesis of PPS was developed on a laboratory scale, and the polymer powder produced by the process could be used directly for corrosion resistant coating applications. Coating trials were successfully completed on metal and glass substrates. The crystallization behavior of the polymer was studied, based on which processing guidelines for injection molding were formulated. Structure development in solid-state processing of PPS and HDPE (high-density polyethylene) blends is an important property determinant, and was rigorously investigated.

More recently, a mathematical model was developed for continuous transesterification processes. The influence of various operating and processing variables (such as residence time distribution, temperature distribution, and the number of reactors) was studied. In particular, their influence on dimethylterephthalate (DMT) conversion and side products formation was critically examined. The model was developed with current industrial practice in mind, in which a single fractionating column is used for all the reactors and where ethylene glycol (EG) is refluxed completely to the first reactor. However, there also appear to be several instances where the old semi-batch plants are being converted into continuous plants. In such cases, each reactor has a separate fractionating column, and EG is refluxed back to the concerned reactor. It is obvious that these two different arrangements would produce different concentration profiles, thereby changing the levels of conversion as well as those of side products formation. The model developed earlier was therefore extended to describe this equally important situation.

From Known Know-how to New Know-how

Some if not all of the *new know-how* described in this chapter arose from the basic work reported in Chapter 8, particularly in the field of catalysis. Others were based on *known science* as reported in the literature. In none of the cases was it known know-how modified to suit specific client requirements, as the processes described in the preceding chapter, but new technology or technology involving new catalysts. This application of an underlying science was essentially new (at the time) irrespective of whether or not the science itself had its origin at the NCL.

This reminds me of the beaver's boast so admirably captured in the following lines (only, in this case, the idea itself was new, and not the outcome!):

> *A beaver and another forest animal are contemplating an immense man-made dam. The beaver is saying something like, "No, I didn't actually build it. But it's based on an idea of mine."*
>
> Edward Fredkin
> from Kurzwiel, *The Age of Spiritual Machines*, 1999

❄

12

THE NEW WAVE
ADAPTING TO GLOBALIZATION

In essence it [adaptation] *involves an environmentally produced effect becoming part of the development program.*

On the Baldwin-Waddington Effect:
Wolpert, *Evolution of Cellular Development*, 1998

In Chapters 10 and 11, projects transferred to industry during the planned development period of post-independence India were described. Many of those, particularly chloromethanes and chlorosilanes, were victims of shifting government policy on the ultimate outcome. The free market era is largely free of such effects. In a historical perspective of the NCL as a whole, the question arises: were the labs justified in expecting a measure of government support in the pre-globalization era? This question falls between two stools: planned development and globalization. I shall address that question first in this chapter before moving on to the NCL's response to free market demands. Wolpert's scientific statement, with which this chapter began, is amazingly true of all kinds of environmental influences, including that of globalization. One has only to read Fabian's compilation of lectures on evolution (1998) to see that environmental influences are as important in the evolution of societies as of science and the universe itself.

Was It Fair To Seek A Measure Of Government Support for Indigenous Technology?

It is clear from the way some of the technologies were transferred to industry that a measure of government support was necessary. In fact, it was sought (directly or indirectly) and given, with varying degrees of grace and readiness. In some cases it was withheld and indigenous technology outright discouraged. These different attitudes, both on the part of the NCL and the government, had little to do with the quality or ripeness of a technology (although purportedly so) but rather with their desire to promote or block an indigenous technology. Notwithstanding this general state of affairs with regard to the fate of an indigenous technology, it is a fact that government support was often an important determinant in horizontal technology transfer from a government laboratory to a public or private-sector undertaking. In its earlier years, the NCL, like many other CSIR laboratories, had to seek a measure of government support to get its technology accepted. On the other hand, as in the case of methylchlorosilanes described in the previous chapter, certain agencies of the government actively supported overseas technology in preference to its indigenous counterpart, irrespective of novelty, and gave the impression that they reveled in actions of the bureaucracy that promoted this view. It is worthwhile, in a historical sense, to examine the NCL's expectation of, and mild lobbying for, government support and of the denial of such support by certain wings of their active help to the private industry in obtaining alternative technology from abroad.

Initial support or jump start by the government was not a phenomenon peculiar to India. The days were different, national pride had a different meaning and expression, global communications and transfers were more stringent, the world had not yet begun to shrink; indeed, the economic and industrial structures of many countries were modeled significantly along different lines. Once this reality is accepted, the actions of the NCL become more comprehensible and less susceptible to accusations of jingoistic selectivity

In connection with this, it is instructive to recall the actions of the British government during and immediately following the Second World War. Taking the dyestuffs industry as a typical example, Venkataraman (1945) has described the fortunes of the British industry during this period. Although the first synthetic dye was prepared in England by Sir William Henry Perkin in 1856, it was in Germany that the industrial manufacture of dyes took root first. In fact, the dyestuffs industry was practically non-existent in England during the period up to the World War. England had a thriving textile industry and over 90% of the dyes required for that industry were imported from Germany. As the war progressed, dyes from Germany were no longer available to the British textile industry, which created a major crisis. The situation was actually even more serious since the production of dyes was so closely connected to the production of organic chemicals in general that the British dependence on Germany revealed a much more fundamental weakness in the its chemical industry than had been imagined. Having realized this fact, the British government took immediate and far-reaching steps to meet the challenge and correct the situation. As a first step, it provided a large subsidy for the formation of a new company, the Dyestuffs Corporation, which not only absorbed most of the existing companies but also was required to establish a strong research facility. The government went further when in 1919, it prohibited the import of dyes, except under license. A little later, it even prohibited the import of intermediates for the manufacture of dyes, except under license from the Board of Trade. This was indeed a bold and far-reaching step because most of the banned intermediates were also used in the production of a variety of other organic chemicals.

As a result of these actions and the injection of research in a major way, within a few years the situation was reversed: over 90% of the required dyes were produced within the country, along with a fair amount of export. This remarkable turnaround indicates how strong and decisive government action at the right time can be a major factor in a country's industrial revival. No country, even in the market-driven world of today, can sustain itself without appropriate, positive government measures to correct lopsided developments, from time to time (Borrus and Zysman, 1986).

Many other countries too have benefited from such positive government action to protect indigenous industries, such as the USA, Japan, and France. The USA's practice of protectionism in its steel industry is well known. Measures such as Super 301 and Special 301 were adopted to safeguard the country's industry, when its interests in trade or patents were perceived to be hurt. The protectionism was sometimes also symbolic, and almost ridiculous, and directed against a single country, such as when French fries were re-named (temporarily as it fortunately turned out!) as Freedom fries, in an outrageous move by some Americans, including the Congress, to hurt France in the USA in the wake of France's refusal to support the country's Iraq policy. France also indulged in protectionism which was heartily opposed by the European Community (EC), leading to, in 1984, its institution of legal proceedings against France under the Treaty of Rome for openly espousing its buy-national policy. The protectionist policies of Japan, which was the first country to initiate a policy of export-led growth without significant import liberalization, are well known. The closed markets gave Japanese firms a protected base of demand that facilitated the rapid expansion of production and innovation in manufacturing. The United States' experience with Cray computers, semiconductors and optical fiber light guides and Italy's experience with Fiat cars attest to the success of the Japanese model. The assumption that "if it is good it will sell" is too simplistic or too loaded with contrived naiveté when extrapolated back to the time when a market-driven economy was not the all pervading philosophy it is sought to be made today.

So, why should India as a country, and Tilak and LKD as directors of the NCL, be blamed for their attempts to have the NCL technologies for acetanilide, chlorobenzenes, endosulfan, and methylchlorosilanes accepted against foreign competition? They were only emulating the practice of several governments of the world in the interests of their countries. The commercial success of a technology often goes far beyond its technical excellence. *If linked to the quest for technological self-reliance, one will be up against forces of international competition with all their pressures and intrigues* (Bhojwani and Lal, 1991). The NCL did no more than recognize this reality and act to counter it.

Most importantly, the Technology Policy Statements (TPSs) of the government have, since 1977, repeatedly stressed the importance of self-reliance. For instance the TPS of 1983 clearly states:

> *Fullest support will be given to the development of indigenous technology to achieve technological self-reliance and reduce dependence on foreign inputs, particularly in critical and vulnerable areas and in high value added items in which the domestic base is strong.*
>
> *Our country has already invested significant amounts in setting up research and development facilities as well as design, consultancy and engineering capabilities. The technological capability inherent in this system of inter-linked capabilities must be fully utilized and in turn provide a fillip for further development from within the system. Incentives will therefore be provided for users of indigenously developed technology and for the products and processes resulting from such use.*
>
> TPS, 1983

These policies were reaffirmed in the later TPS of 1991. In spite of the clearly expressed will of the government, the bureaucracy took its own actions in the case of methychlorosilanes. All technical committees of the government appointed to evaluate the process gave positive reports. The foreign subsidies in India, for their own reasons, expressed a negative view. Some of them even reported that they could get foreign technology from their parent companies without any payment. The bureaucracy apparently accepted this view and used different reasons at different times to reject the NCL–HICO technology. As Bhojwani and Lal (1991) succinctly state:

> *It was non-availability of technology when India had no technology; technology could be offered at a price when Indian technology appeared to be coming up; the price was lowered when the Indian technology arrived; and when the Indian technology left nothing to be desired the technology could be imported even for free!*

The death knell to the Indian challenge came when methylchlorosilanes and the silicone products made from them were placed under Open General License (OGL), thanks to the persistent lobbying of interested foreign companies. Under the scheme, these items, produced in excess in the countries concerned, could be circulated in the Indian market at prices that could never be matched by Indian manufacturers. As a result, as mentioned previously, the HICO plant was shut down and the NCL–HICO technology blanked out forever.

In the globalization era of the 1990s and later, when the country had moved to a free market economy, there would be no such issues. Manufacturers would do what suited them most. But when the HICO–NCL technology was developed, the economic climate was very different. Manufacturers had succeeded in imposing their will on a shifty bureaucracy bereft of commitment or loyalty to the policy of the time (see section on Administration). These are perhaps strong words from a previous director deeply involved in the scheme of things in the pre-globalization era, but true nonetheless. In the economic climate of the 21st century, the NCL would perhaps have entered into a collaborative agreement, and rightly so, with the ICI or 3M or any other manufacturer of chlorosilanes to perfect and exploit its own novel technology.

Globalization Comes to the NCL

We have seen in Chapters 4 and 6 how the NCL moved into the free market era. Some salient features of globalization were also discussed. In particular, we saw how directors Mashelkar, Ratnasamy and Sivaram coped with this new reality. In a nutshell, the NCL, like most other government-financed institutions, had to fend for itself in terms of budget. Sheltered as it was by the luxury of finance without seriously working for it, this was a rather tall order. But the country as a whole rose to the occasion, thanks to the entrepreneurship of its people and the refreshingly surprising flexibility of its management cadres. An unusual number of agreements with overseas organizations were signed and the new free market culture flowed into its business dealings with unsuspected ease. The NCL was no exception to this new development.

The CSIR informed its constituent laboratories that they had to earn a sizeable portion of their funds, about 50%, and that ability to attract funds would be an important factor in assessing their performance. The NCL started this new era by displaying its competencies in very attractive formats (this was never done before, although there was no change in the expertise) and distributing it to all chemically-oriented global companies as well as major Indian companies. Mashelkar traveled extensively and sought agreements with a number of multinationals. He also invited them to the NCL to assess for themselves the kind of packages the laboratory could deliver. Any party intending to make use of the NCL no longer had to research its competence. It got the information unerringly and in many ways. Mashelkar, in addition to being an outstanding scientist, was dedicated to promotion — and very successful so. He adopted the new management language, and used sound bites and catchy phrases in a very imaginative way. Phrases like "concept to commerce," "multiple competencies under a single roof," etc. became common. Added to the core of proven accomplishment and credibility, this brought in a measure of global visibility unheard of in an Indian laboratory before him. Quietly and in his own way, completely different from Mashelkar's, Ratnasamy continued this paradigm shift equally effectively. The present Director, Sivaram, has been operating on a broader canvas, partly by reinvesting in Mashelkar's style but mostly by opening new doors to joint inventive endeavors, such as creation of an innovation park and a DST sponsored incubator program (see Chapter 9).

Thanks to an ongoing informal collaborative program in homogeneous catalysis between R.V. Chaudhari's group and Patrick Mill's group at DuPont, it was possible to forge a larger and more formal agreement with that organization. The signing ceremony was justifiably hailed as a major event (Figure 12.1).

The project was so successful that DuPont presented a certificate of appreciation to the NCL and DuPont scientists involved (see Chapter 8), and the agreement was renewed/amended in 1996 and then again in 2002. A photograph of the signing ceremony at the DuPont Experiment Station in Wilmington appears in Figure 12.2.

Figure 12.1: Signing of agreement with DuPont by Mashelkar

Figure 12.2: Signing of agreement with DuPont by Sivaram

The first contract with DuPont was quickly followed by an even broader agreement with General Electric (GE). Some features of the collaboration, outlined below took the NCL to a higher level of international recognition as an innovative R & D center:

- NCL-GE efforts have led to over 50 US patent application in the area of polycarbonate technology.
- More than 20 US patents have been granted till date.
- The NCL's contribution to GE's technology goals in polycarbonates has evoked wide interest and appreciation across GE's global sites.
- The NCL-GE relationship has been cited as the "best practice" case for all external technology programs across GE global sites.
- The success of the NCL-GE relationship was a key driver in GE's decision to set up a Global Technology Center at Bangalore in 2000.
- Several NCL scientists were provided opportunities to spend extended periods of time in GE's research laboratories in the United States.

- Continuing Education: Polymers for R & D scientists, engineers & managers; aiming to design and conduct intensive world-class training programs for R & D staff of GE's John F. Welch Technology Center, Bangalore

Of all the collaborative projects with major companies, this was perhaps the most satisfying. One thing I personally noticed about the GE projects during one of my visits to the NCL a few years ago was the constant conference calls between the NCL and GE scientists to review the projects. Although such reviews occurred in other projects as well, it seems to have been a particularly special feature of this agreement. Another special feature, one that has not happened in any other project with a global partner, was the involvement of an Indian company (Excel Industries) to manufacture the product developed jointly by the NCL and GE. As a rule, none of the products/processes developed jointly with a global company belongs to the NCL. The laboratory has no claim on them and cannot release them for exploitation anywhere in the world. An exception seems to have been made in the GE case with respect to manufacture in India, in that the NCL has been allowed a share in the profits.

Several more agreements were signed, including some consultancy agreements with a few countries in the area of plant tissue culture (see Chapter 8). For example, Figure 12.3 shows Ratnasamy signing an agreement with representatives of the Egyptian government.

Many other agreements were concluded in the areas of catalysis and polymers, partly because of the expertise of the last three directors in these areas. The NCL's expertise in a few other areas was the driving force for several more agreements (see Box 12.1 for a representative list of such projects).

Figure 12.3: Ratnasamy signing an agreement with representatives of the Egyptian Government to set up a laboratory for plant tissue culture in Cairo

Box 12.1: Multinational company projects

Representative List Of NCL's Global Era Clients And Nature Of Assignments Undertaken	
Client	*Subject*
BASF, Germany	Numerical methods for the description of electron transfer in molecular organic materials in the framework of Marcus theory
Proctor & Gamble Far East, Japan	Designing of new cationic surfactants using computer modeling
Solvay Solexis, Italy	Synthesis of perfluoropolyethers based compounds containing aromatic segments and ionic liquids
Invista Performance Technologies, UK	Super critical water research program, catalytic hydrogenation reactions
Lanxess, Germany	Synthesis/supply of active ingredients for protection of plant materials
Nikem, Italy	Synthesis of organic intermediates
NESTE OY, Finland	Developing intermediates required in paraffins/paraffin side chain of a hydrocarbon
Akzo Nobel Chemicals, Netherlands	Hydro processing catalysts
DuPont, USA	Hydrogenation, oxidation, polymerization reactions
Alcoa, USA	Closure shell and liner materials for pasteurizable and retortable applications
Scios, USA	Synthesis of organic intermediates
D & O Pharmachem Inc., USA	Medicinal chemistry, analogue design, developing alternative pathways
Invista Inc., USA	Wavelet analysis of yarn uniformity spectra
Honeywell International, USA	Synthesis & characterization of metal/metal oxide nanowires
UOP, USA	Synthesis of value added linear olefin polymers
Solvay Advanced Polymers, USA	Developing polyamide compositions for high performance films
Dow Chemical Company, USA	Catalysts for alkylation of aromatic compounds
Polaroid Corporation, USA	Preparation of reduced chalcone by catalytic reduction
General Electric, USA	Polycarbonates, THPE, silicones, carbonate monomers, etc.

Note: Even the bare details of the studies and the results obtained are covered by secrecy agreements, and hence were not disclosed by NCL.

The industrial scene had changed dramatically in India as the country heralded the free market era. Well known companies of the planned development era were fast disappearing. They were either closed down or, what was more common, the private sector was slowly but surely gobbling up all public sector undertakings one after another. Thus the IPCL and HOC, two giants of the former era, were bought over by the Reliance group of companies, which was rising like a giant star in the industrial firmament of India. The drug giant IDPL went the same way. The NCL, which had very close ties with the two erstwhile stars IPCL and HOC, lost no time in forging an alliance with Reliance. Here again, no technology transfers were involved, unlike with HOC and IPCL, but a consultative alliance was reached which opened the door for a wide range of knowledge transfers. The high points of the agreement, signed in 1999, were:

- Flexible, evergreen and designed for building relationships
- Ability to handle multiple programs
- Opportunity for RIL to tap multiple competencies and skills of the NCL
- Value addition through research, technical and analytical services, training, information, and consultancy

All these agreements differed significantly from pre-globalization era ones, which were more specific and did not fully tap the NCL's potential to define and reach more far-reaching goals (with the possible exception of agreements with HAL and HOC). The NCL also took on (for the first time in India) the difficult task of offering R & D management consultancy to a foreign country on the fast track to economic prosperity: China. Some details of this pioneering effort by an Indian laboratory, under the leadership of Mashelkar, were given in Chapter 6.

THPE: THE FIRST PROJECT IN THE FREE MARKET ERA THAT WAS COMMERCIALIZED IN INDIA

Tris-hydroxy-phenylethane (THPE) is a co-monomer used in the manufacture of specialty polycarbonates. GE Plastics USA (a subsidiary of General Electric, USA) was procuring this product from a single manufacturer in the USA. One of the first effects of free market economy and globalization in the NCL was a research alliance with GE in the early 1990s. One of the first projects GE wanted the NCL to undertake was a process for THPE.

THPE is obtained by the reaction of 4-hydroxyacetophenone with phenol in the presence of a catalyst. The work was initiated in the Polymer Chemistry Division in association with the Process Development Division. The NCL developed a novel catalyst and recovery system and was granted US Patents on these two aspects. The product obtained was subjected to detailed analysis and was found to be comparable to that being used by GE. The initial investigations on the laboratory scale were carried out with pure raw materials and subsequently work was initiated in the Process Development Division with commercial-grade raw materials. The process was scaled up in a batch reactor to produce 500g/batch of the product. Whereas the final product met all the purity specifications, it was not acceptable for the final application because it failed the color test. The unacceptable color was due to the presence of iron in the product in very low concentrations. The NCL had considerable difficulty in carrying out the analysis of the product to determine the iron content. It was finally able to locate a laboratory with the specialized instrument to undertake the analysis and was then able to produce the product of the desired specifications and impurity profile.

The co-monomer was used in making optical quality polycarbonate. The NCL was then assigned the task of process design for a commercial plant and preparing the estimates of capital costs and cost of production. As the economics of production by the new process was attractive for GE, they decided to have it custom manufactured exclusively for them.

GE was procuring THPE from US at a price of $10/lb, but the product made as per the NCL process cost less than $10/kg.

GE then desired the NCL to locate a party in India who would manufacture the product exclusively for GE. Meetings of GE with prospective medium scale manufacturers in India were arranged. GE was very particular that the company should manufacture at a facility that would comply with US regulations regarding environmental aspects. After a series of discussions and site visits, GE chose Excel Industries Ltd, Roha, for the custom manufacture of THPE. Excel had the required plant and machinery, analytical instruments and qualified and experienced staff. Clearly this was an Excel that was a far cry from the one of the 1970s, when my colleagues and I had to endure blasts of chlorine from open glass reactors and chlorine cylinders! Just as the NCL had evolved, so had Excel. GE trained Excel engineers in six sigma methods of production and quality control. After completing the signing of agreement, the NCL demonstrated the process to the staff of Excel in a 1 kg/batch reactor with all the process control and quality control tests. Excel subsequently prepared adequate quantities of the product on their own and supplied samples to GE. The samples were acceptable and they negotiated a commercial deal to buy THPE at a price below $10/kg. Excel has been supplying the product for the past few years and both the parties are happy with the arrangement. As per the agreement, GE was required to pay a royalty to the NCL. The total royalty received as of 2006 was US $225,000.

THPE was one of the projects in which the Polymer Chemistry Division and Process Development Divisions started working together and then took it to successful completion. The conceptual flow sheet had been prepared soon after completion of the laboratory scale work and areas of difficulty identified for further work. The scale-up work was planned to address these issues. The scientists associated with the projects were imparted training in six sigma methods and they were practiced in the development work. The success of the development work can be attributed to the team work of the scientists from the two divisions and the mutual appreciation of the chemistry and engineering aspects of the project and leadership provided by Sivaram. Excel did not need any services from the NCL after the process demonstration was successfully carried out. It is notable that both Sivaram and Devotta enforced the provisions of the NCL/GE contract so that GE pays royalty to NCL for the product they import from Excel.

A distinctive feature of this project was the continuous participation of GE in the development work by assistance in analysis and discussions through weekly tele-conferences. It exposed the NCL scientists to process development as practiced in an advanced company like GE. It also exposed them to the latest safety and various other protocols. Major credit should go to Sivaram for leading this effort on the NCL side and participating in the teleconferences. Like the projects in the Tilak and Doraiswamy eras that had set their own trends, this project, initiated as part of the research alliance crafted by Mashelkar and carried forward by Ratnasamy, saw its progress and successful culmination in the Sivaram era. It set the trend of the NCL's technology development efforts in the globalization era.

In recognition of this work, the CSIR conferred the Technology Award for the year 2003 to the NCL team.

LACTIC ACID: AN OUTSTANDING EXAMPLE OF THE CSIR LABS, AN IIT AND INDUSTRY COLLABORATING TO PRODUCE A WORLD-CLASS TECHNOLOGY IN THE GLOBAL ERA

Global era research in India was not all confined to programs with heavy involvement of multinationals. Many programs were undertaken at the NCL that were entirely Indian. The development of a forward technology for lactic acid is an outstanding example of such an effort.

Synthetic polymers in the form of synthetic fibers, plastics and synthetic rubbers are among the most easily available materials for application in areas including construction, transportation, packaging, electronic devices and medical appliances. Current plastics production is mainly from petrochemical sources. These plastics are more durable than the traditional natural materials they have replaced but are a major cause of environmental pollution. Additionally, they result in an increase in oil consumption.

In 2003, the technical sub-committee of The New Millenium Indian Technology Leadership Initiative (NMITLI) program, of which Sivaram was a member, organized a brain-storming session to look at possible joint initiatives between the Indian industry and academic institutions in the area of eco-friendly polymers. The objective was to develop polymers from renewable resources for mass consumption, which could eventually be recycled to the environment, without leaving a deleterious effect on it.

Lactic acid-based polymers were identified as an area that merited research and development effort. It was felt that these polymers, in their lifetime, had advantageous mechanical properties that would make them amenable to conventional use. After use, they were by design biodegradable and compostable. Polylactic acid (PLA) was identified as the most important member of the family of lactic acid polymers, because it was a thermoplastic high-strength, high-modulus polymer, which could be made from natural resources.

If lactic acid polymers produced from renewable resources were to replace conventional polyolefin produced from petroleum feedstock, then four very crucial issues needed to be addressed:

- The availability of an abundant and cheap renewable resource for production of actic acid by a fermentative route
- An economically viable fermentation and downstream recovery process for preparing an optically active lactic acid monomer
- Acceptable purity of the lactic acid produced, as required for making the lactic acid polymers
- A non-infringing process for making a polymer of high molecular weight and having suitable properties

The final research program, involving all the four components, was established involving four research institutions: The National Chemical Laboratory (NCL, Pune), Indian Institute of Technology (IIT, Mumbai), Indian Institute of Chemical Technology

(IICT, Hyderabad) and Central Salt and Marine Chemicals Research Institute (CSMCRI, Bhavnagar). The NCL was involved in developing lactic acid, producing strains using conventional mutagenic techniques, a fermentation process using suitable feedstock, downstream processing of fermentation broth and production of a high molecular weight polymer. IIT was involved in developing genetically engineered strains for lactic acid production, using reactive distillation for lactic acid recovery and processing of the lactic acid polymer by melt spinning. IICT was involved in the immobilization of lactic acid bacteria for developing a continuous lactic acid fermentation process. The industries associated with the program were the Reliance Group of Industries, Mumbai; Godavari Sugar Mills Limited (Somaiya Group of Industries), Mumbai; Prathista Biotech Pvt. Ltd, Hyderabad; and Anil Starch Ltd., Baroda. The role of the industries was to offer technical advice during the review meetings and to, eventually, implement the process developed under the program.

The first phase of the program resulted in the isolation of a mutant Lactobacillus strain producing L-lactic acid by NCIM using conventional mutagenic techniques. The biochemical engineering group of the NCL developed an economically viable nutrient growth medium with a cost of approximately Rs.20/kg of lactic acid produced. The specific productivity on 100 lit. fermentation scale was found to be close to 4 g/lit./hr. of L-lactic acid. Sugarcane juice was used as the carbon source, while a proprietary nutrient supplement was added for improved lactic acid productivity. Downstream processing of the lactic acid broth to yield a product having a purity of 99.9% was achieved.

Based on the successful outcome of this phase of the project, NMITLI decided to support the second phase of the program involving the NCL and IIT, Mumbai, with the objective of building a 300 TPA pilot plant for lactic acid production. Godavari Sugars Mills Ltd.(GSML) was identified as a partner in this program. Under this phase a pilot plant for downstream recovery of 5 kg/hr. of L-lactic acid was developed at the NCL at a cost of close to Rs.1.5 crores. The fermentation and downstream processing was tested on this scale as proof of concept. The fermentation pilot plant was commissioned at Godavari Sugar Mills in November 2007. The lactic acid fermentation productivity at the GSML pilot plant over several batches of 8,000 and 32,000 lit. scale was found to be approximately 5.5 g L- lactic acid /lit./hr. A photograph of the pilot plant at NCL appears in Figure 12.4.

The downstream processing plant at Godavari sugars is currently being designed using data generated in the NCL pilot plant and, of this writing, expected to go on stream in June 2010. The purity of lactic acid is expected to be 99.9% and suitable for poly (lactic acid).

THE FATE OF ALL OTHER PROJECTS

Of the nearly 30 other projects undertaken on behalf of overseas clients, not a single project was commercialized as NCL technology. As listed in Box 12.1, these projects varied from polymers to electron transfer to amino acids to catalysis, and more. The NCL was involved in carrying out certain well-defined assignments for which ample payments were made, after which it was out of the picture. Usually, these assignments were part

Figure 12.4: Fermentation pilot plant for lactic acid at Godavari Sugar Mills. Lactic acid polymers produced from renewable resources can replace conventional polyolefin produced from petroleum feedstock

of an overall project scheme of a company, and the laboratory was in the dark regarding the scope and ultimate fate of its endeavors. In a restricted sense this suited the NCL, for it was now able to switch its enormous talents from indigenous process development to being a part of the larger, more modern, scheme of multinationals. In this way, it was able to earn huge sums of money and rank as a top dollar earner among the CSIR laboratories. Simultaneously, thanks to Mashelkar who joined office at the right time as Director-General of the CSIR, this agency liberalized its policy of restricting its labs to outmoded protocols of expenditure and accounting, and gave them considerable leeway in spending the funds earned by them. The NCL made excellent use of this opportunity to procure a number of state-of-the-art instruments and equipment, and also to construct modern buildings including a first rate digital center (by Sivaram) and a modern hostel (by Ratnasamy) for its 400-odd research fellows. But the downside has been equally telling. There have been no Jalshaktis, Encilites, xylofinings, or albenes.

Has Free Market Research been Good for the NCL?

This is a limited question restricted to the NCL and the larger issue of globalization, loaded as it is, falls outside the scope of this book. As the views on this matter are quite divergent, I summarize them below as points.

- Association with a major MNC exposed the NCL scientists to modern methods of process development practiced by them. The importance of periodic discussions and time scheduling, though not new to the NCL, was brought home in a more compelling manner.
- The NCL learnt from its previous efforts that product purity was very important, but it was not until its association with an MNC that it learnt how critically important it was. In fact, NCL scientists found for the first time that their instruments were inadequate to detect impurities at the level required by industry. This must have come as somewhat of a shock for they were complacent in the belief that they had the best instruments and that there was no need for them to turn elsewhere for impurity measurements at such levels. Their experience with THPE, where they had to literally hunt for a party with the right kind of instruments to do the analysis, must have been a rude eye-opener!
- Safety has always been the NCL's weakest link in its technology development chain. Its experience with the THPE project showed that its scientists as well as the technical personnel of Excel had to undergo detailed training at GE before Excel got the green light for product manufacture.
- Once the MNC got what it wanted by association with the NCL, usually a distinct part of a technology or some data collection that could be done more cheaply in a laboratory of a developing country, the association was terminated or some other assignment given as part of a larger protocol of agreement.
- Any patents arising out of the joint work was assigned to the MNC and the final process that emerged would belong entirely to the MNC. The NCL's name would be conspicuous by its absence from any outcome of the joint effort.
- The only concession made to the NCL was that it would be entitled to a share of the profits if the process was commercialized in India.

This marked a major shift from the philosophy of the 1970s and 1980s when it was clearly stated that there should be something NCL-ish in all processes going out of the NCL, as typified by *Xylofining* and *Albene* technologies. True, the times had changed and the laboratory was falling in line. Even so, this meant that, in all likelihood, no Indian technology would be developed except as part of a collaborative effort (mostly with multinationals) with marginal or shared recognition. Whether the NCL will continue this philosophy or make suitable changes without perturbing the overall reigning philosophy of the day remains to be seen.

NCL Innovation Park

Cutting edge science has the potential to create new wealth in society, through startups and new venture creation. Scientists have been enabled participation in such ventures while retaining their positions in the laboratory. However, promoting such ventures, requires suitable support facilities and an eco-system which encourages innovation and risk taking.

With a view to encouraging scientists to start up companies, Sivaram initiated the creation of a new Resource Center called the "NCL Innovations" and a not-for-profit company called the "Venture Center". NCL Innovations and the Venture Center are located in a vendant 25 acre campus adjacent to NCL, called NCL Innovation Park. NCL Innovation Park will be a host to several new Public–Private Partnerships (PPP) in research as well as house a technology business incubator. Thus the NCL Innovations and the Venture Center is poised to propel the next wave of value creation out of frontier science and technology at NCL.

Resolving A Paradox: Excellence and Globalization

> *Tackling the paradox: Can attaining global research excellence be compatible with local technology development?*
>
> van Helleputte and Reid, 2004

Mentioned in the context of a multinational R & D center retaining its excellence without sacrificing the local excellence of its regional centers in technology development around the world, this statement is even more applicable to national laboratories like the NCL, retaining their excellence against the pull of multinationals to do their bidding through financial power. Will the driving force be

> *Fall in line or fall*?

Or will there be a concerted attempt to disprove the hackneyed saying (attributed to many):

> *Only dead fish swim with the tide.*

This is a very difficult situation to tackle and a built-in structure to retain excellence is needed. It is too easy for any current administration to inflate its budget by offering the excellence it has built over years to be a cog in the multinational wheel of development but sadly, and more so, money making. A fairly detailed discussion of this subject, which must someday be frontally faced, is attempted in Chapter 18. The NCL has so far been successful in avoiding this downside of globalization, particularly the present administration on which the onus has been the heaviest, but the future is uncertain.

With retirements of outstanding scientists looming large, or already a reality (for instance B. D. Kulkarni), and flights of seasoned talent by no means rare (for instance Murali Sastry, K. N. Ganesh, R. V. Chaudhari, M. K. Gurjar, Rajiv Kumar), the CSIR and the Advisory Council of the NCL would be failing in their duty if this problem were not addressed aggressively and with a full sense of urgency.

International Trading of Strengths and Weaknesses

In this and some of the previous chapters, we saw how globalization is neither a panacea nor a demon, although it is mostly viewed as the former. Values and local abilities tend to be sacrificed at the altar of economic prosperity. Nearer home, the NCL is no longer the place it was. No longer are its processes NCL-ish, but creations of multinational enterprises helped by activities outsourced to their Indian partners. One can debate the correctness of this statement, but its ominous potential is too real to be ignored. Its immediate effects are too exhilarating to implant a desire to probe more deeply. Everything has a price tag attached to it. So has globalization.

The NCL has changed dramatically since the advent of globalization around 1990. If this is an acceptable state of affairs, so be it. My own understanding of globalization lacks in depth what it attempts to make up in emphasizing the paramountacy of finding a balance. In the ultimate analysis:

> *From the suites of Davos to the streets of Seattle, there is a growing consensus that globalization must now be reshaped to reflect values broader than simply the freedom of capital.*
>
> John J. Sweeney, President, American Federation of Labor

❄

Part V
The *Compleat* Laboratory[1]

An excellent plumber is infinitely more admirable than an incompetent philosopher. The society which scorns excellence in plumbing because it is a humble activity and tolerates shoddiness in philosophy because it is an exalted activity will have neither good plumbing nor good philosophy. Neither its pipes nor its theories will hold water.

John W. Gardner, *Excellence: Can we be equal and excellent too*?, 1957

INTRODUCTION

The quotation at the beginning of this part says it all — almost. Excellence fulfills itself in many ways — and in many aspects of an institution. Take, for instance, the allegedly unimportant case of cleanliness. Many Indian institutions are notoriously unclean. The farther a site is from the big boss's everyday sight, the dirtier it normally tends to be. But then a certain uniformity in the lack of cleanliness is also possible when the chief himself is impervious to it, either through neglect or natural indifference. Cleanliness apart (my erstwhile colleagues used to complain of my unnatural obsession with it), there are several other non-research aspects of a laboratory in which also it must excel for the institution as a whole to cross a raised bar — into the realm of excellence.

These include streamlining and modernizing every aspect of the lab, technical and non-technical, such as the seminar program, working of committees, workshop, library, glass blowing, and safety, and also administration, finance, stores and purchase, medical services, guest house, horticulture, sports, residential colony, shopping facilities, recreation, etc. The present part touches upon the evolution of these and other such aspects of the NCL.

13

THE TECHNICAL COMPANION TO RESEARCH
THE NON-RESEARCH ESSENTIALS OF A LABORATORY

James Smithson was well aware that knowledge should not be viewed as existing in isolated parts, but as a whole, each portion of which throws light on all the other…Narrow minds think nothing of importance but their own favorite pursuit, but liberal views exclude no branch of science or literature, for they all contribute to sweeten, to adorn, and to embellish life.

Inscription on the National Museum of American History,
Washington, D.C., by Joseph Henry, first secretary of the Smithsonian Institution

In Chapters 3 to 12 we described the coming of the CSIR, the formation of the NCL and its evolution over the years. In the forthcoming chapters, 14 to 17, we will describe the essential infrastructure of the NCL, along with some technical and non-technical anecdotes and reminiscences. The present chapter that straddles the two sets is devoted to several essential features not covered in those chapters and rightly falls somewhere in between. It deals with such features as committees, seminars, restructuring, etc. I begin most of the sections in a lighter vein, with quotations seemingly derogatory of the subject, but not so — and only to reflect some popular (mis)conceptions. The actual descriptions are as serious as the technical contents of the previous chapters, as indeed they must be, and do not take an iota away from their extreme usefulness to the laboratory.

The NCL was increasingly involved in assisting the government in enquiries concerning major accidents and making recommendations for avoiding future such disasters. These were essentially non-research activities, although some experimental studies and mathematical modeling of accidents were undertaken. This chapter concludes with a brief review of this aspect of the NCL's activities.

The CSIR Review Committees

A committee is a group of men who take minutes to waste hours.

Milton Berle

Of all the major science agencies of the country, the CSIR is the most open. Some of the projects it undertakes through its various laboratories are covered by articles of confidentiality, but the mode of its operation comes under the public domain and is open to criticism, debate, improvement, and review by committees. This section deals with the committees appointed by the CSIR from time to time to review its functioning and make recommendations for improvement. A total of six committees have reviewed the functioning of the CSIR since its inception. In fact, the first review committee was constituted as far back as 1948, even before the NCL began functioning in 1950, and the second soon thereafter in 1954. Some of their recommendations go to the root of the functioning of the individual laboratories. The first five reports were of a qualitative nature, designed largely for the administrative and functional improvement of the constituent laboratories and for making the complex processes of the CSIR's numerous relationships more effective. I am particularly impressed with the Abid Hussain Committee report, not because Abid Hussain was my classmate at Nizam College, Hyderabad, but because of the way it has been crafted and the many far-reaching recommendations it has made. The Sarkar Committee report, to which I shall briefly refer later, was almost a judicial report, based as much on a review as on attention to complaints. But the most useful report was the latest chaired by Vijay Kelkar. It is superbly quantitative, and makes specific comments on the functioning of the six laboratories it has chosen as its base. The NCL is one of these laboratories and I shall fully document the Committee's conclusions on its functioning. These conclusions represent the cumulative essence of the laboratory's performance over the years.

The reports go by the names of their chairmen and are:

- Sir Ardeshir Dalal Report, 1948
- Sir Alfred Egerton Report, 1954
- Sir A. Ramaswami Mudaliar Report, 1964
- Sarkar Committee of Enquiry Report, 1971
- Abid Hussain Report, 1986
- Vijay Kelkar Report, 2004

There appears to be a great deal of commonality in the recommendations of these committees. They all suggest that basic research should be permitted to a certain extent but the laboratories should concentrate on applied research including investigations on a pilot plant scale. They all recommend that there should be greater collaboration between the scientists of a laboratory and between different laboratories. The last recommendation apparently resulted in mission-oriented tasks in which the center was directly involved to ensure continued cooperation between participating laboratories. Missions were defined in the 1980s but were not very successful. They were revived in the early years of this century but it is not clear whether their second appearance has led to better results.

The recruitment policy of the CSIR seems to have attracted attention from the Sarkar Enquiry Committee. This Committee viewed with disfavor the practice of the center holding on to the recruitment of many senior positions. The Committee categorically recommended that *the Central Office* should confine itself only to the recruitment of directors. For all other posts in the laboratories, the Governing Body should lay down broad guidelines, leaving actual recruitment to the laboratories themselves. This policy was practiced for several years but was changed in the last few years in view of the perceived disparity in standards of assessment of the different laboratories. A quantitative grading system was laid down by the center and scientists from different laboratories and from the outside met periodically as selection committees charged with the task of using this system for making recommendations.

And now I come to the quantitative conclusions of the Kelkar Committee with regard to the NCL. They are:

- The total budgetary grant for running the NCL over the eight year period was approximately Rs. 280 crore which works out to Rs. 198 crore discounted at 10% SDR to 4/1995 level. As against this, the corresponding lower bound of discounted tangible benefits are estimated at Rs. 187 crore. The social BCR is thus nearly one, indicating that investments in the NCL have been quite prudent.
- The NCL's activities have been mainly on delivering private goods and services to Indian and foreign clients; creating public goods by generating specialized human resources and to building, expanding, and keeping globally contemporary the instrumentation, intellectual and infrastructural assets.
- The NCL's knowledge generation activity is very strong, as evidenced by the record of publications (2375 papers) in foreign journals and scholarly honors.
- The NCL has an outstanding record of developing (specialized) human resources of around 50 Ph.Ds every year.
- The NCL has generated a strong portfolio of 160 foreign patents granted during the period of study, valuation of this intangible asset has not been done. Conservative guess-estimate places its value at over $10 million.
- The NCL has an impressive industrial clientele base.
- In FY 2002–03, the major cost heads were: research expenditure (30%), cost of assets (19%), pay and allowances of scientists (12.7%), pay and allowances of other staff (11%), and pensions (9.5%). Thus human resources related-costs are nearly one third of all costs. Its operation seems to be reasonably efficient.
- In FY 2002–03, the NCL raised only 25% of the operational expenses from non-CSIR sources of which 72% was from businesses. Considering the brand equity and strategic positioning of the NCL, it has the potential and capability to generate a higher percentage of its expenses from non-CSIR sources, not merely for the sake of financial self-sufficiency but to ensure its continued relevance to its customers.
- The NCL has generated impressive "reserves" from its externally funded activities.

The NCL Committees

A camel is an elephant designed by a committee.

An old saying, anon.

I would not dispose of this statement as complete nonsense, particularly in light of the following incident narrated by the one and only Richard Feynman, Nobel Laureate, in *Surely You're Joking, Mr. Feynman* (1985)! It seems that Feynman had agreed to be a member of a committee to approve science textbooks for use in California schools. He was overwhelmed when the book depository downloaded over 300 pounds of books for his reading. Having politely rejected the depository's offer to ease the job of reading all the books by getting someone to help him read them, he sat down to read them in his basement. From this point forward, the incident is best described in the famous physicist's own words:

> *The books were lousy. They were false. They were hurried…We came to a certain book, part of a set of three supplementary books published by the same company, and they asked me what I thought about it.*
>
> *I said, "The depository didn't send me that book, but the other two were nice." Someone tried repeating the question: "What do you think about that book?"*
>
> *I said they didn't send me that one, so I don't have a judgment on it.*
>
> *The man from the book depository was there, and he said, "Excuse me, I can explain that. I didn't send it to you because that book hadn't been completed yet. There is a rule that you have to have every entry in by a certain time, and the publisher was a few days late with it. So it was sent to us with just the covers, and it's blank in between. The company sent a note excusing themselves and hoping they could have their set of three books considered, even though the third one would be late."*
>
> *It turned out that the blank book had a rating by some of the other members! They couldn't believe it was blank, because it had a rating. In fact, the rating for the missing book was a little bit higher than for the others. The fact that there was nothing in the book had nothing to do with the rating.*

It would be wrong to generalize this ridiculous conduct and apply it to all committees, but it would be equally wrong to reject it outright. I have personally known a very senior scientist/bureaucrat who fell asleep during a meeting. When prodded into wakefulness by the kind member sitting next to him, he awoke quite unruffled (giving the impression that this was quite common with him) and with the utmost composure started making a small speech, for he was an important man who was expected to give a speech, and not make any comments. Obviously, he had a dress-for-all-sizes speech, and with a few changes here and there deftly thrown in, he spoke as if he was awake and attentive all the time! In any case, the NCL was fortunate to have had on its committees members of unimpeachable commitment and honesty who did their homework well, commented responsibly, and retracted gracefully when needed. Even so, certain incidents occurred which bear testimony to the composition of committees — the presence of a few regulars. An interview for a position at the NCL was in progress. For example, as one of the candidates walked into the room, the member sitting next to me said: *Oh, not him again*!

I have it on unimpeachable authority that the candidate remarked to his friend immediately on leaving the room: *Oh, it was him again — my fate is sealed*!

I desist from giving a name to the top committee of the NCL, because it has had several names, and it would be unfair to single out any one for the caption: Executive Committee, Executive Council, Research Advisory Council, Advisory Council. No doubt the functions of this top body have differed; even so, the plurality of names under which it has advised the NCL over the years cannot go unnoticed.

There is nowhere any mention of an Advisory Committee or Executive Committee for NCL prior to the year 1958. Apparently McBain and Finch ran the laboratory without any assistance from a committee. Then in 1958, an Executive Council was appointed with a distinguished industrialist as chairman. The members were drawn from government departments, public sector undertakings, academia, research institutes, sister laboratories of the CSIR, Bhabha Atomic Research Center, and the industry. The composition of the first Executive Council is shown in Box 13.1. Every process of the laboratory considered ready for release to industry had to be approved by a Process Release Committee, which also set the terms of release. This was more in the nature of a recommendation that had to the approved by the Executive Council.

Box 13.1: Composition of the NCL's first Executive Council

Name	*Affiliation*
Shri P. A. Narielwala	Director, Tata Industries (Pvt.) Ltd., Mumbai, Chairman
Shri Charat Ram	Chairman, Delhi Cloth and General Mills Co. Ltd, Delhi
Dr. K. A. Hamied	Chairman, CIPLA, Mumbai
Dr. B. C. Guha	Professor of Biochemistry, University College of Science and Technology, Calcutta
Dr. B. P. Godrej	Chairman, Godrej Soaps (Pvt.) Ltd., Mumbai
Dr. D. K. Banerjee	Professor of organic chemistry, Indian Institute of Science, Bangalore
Dr. M. R. Mandlekar	Director of Industries, Government of Maharashtra, Mumbai
Dr. G. P. Kane	Advisor, Development Wing, Ministry of Commerce and Industry, New Delhi
Major General Partap Narain (Retd.)	Utkal Machinery (Pvt.) Ltd., Rourkela
Dr. Jagdish Shankar	Atomic Energy Establishment, Mumbai
Dr. D. Banerjee	Vice President, Indian Rubber Manufacturer's Research Association, Calcutta
Shri Arvind N. Mafatlal	Head of the Mafatlal group of industries, Mumbai
Director-General	Scientific and Industrial Research
Financial Adviser to CSIR	CSIR
Director	NCL

Executive Council as on March 31, 1960.

In 1969, the Executive Council was reorganized as the Executive Committee with the Director of the NCL as chairman (and not an outside expert). The Process Release Committee was abolished. Instead, several advisory panels were formed, one for each broad area of research of the laboratory. Each panel had a very broad-based membership consisting of over 10 individuals drawn from different sectors of expertise. Panels were formed for each of the following areas: Biochemistry, Chemical Engineering and Process Development, Inorganic Chemistry, Organic Synthesis and Natural Products, Polymer Chemistry, and Solid State and Physical Chemistry.

In 1979, there was a policy shift and two separate committees were formed:

- Executive Committee: to approve proposals for management of the laboratory, with the director of the NCL as chairman.

- Research Advisory Council: for planning of R & D programs, with an eminent scientist (outside the NCL) as chairman and members drawn from the industry, ICMA, academia, other research Institutes, and a representative from the CSIR.
- This system operated from 1979 to 1987.

Then in 1988, there was yet another reorganization. The Executive Committee was replaced by a Management Council and the Research Advisory Council by a Research Council. The removal of the word "Advisory" made it possible for the CSIR to pay sitting fees to the Council members and thus attract top experts for longer durations. I was strongly opposed to this change but was comprehensively outvoted. The names of the chairmen of the top committee of the NCL, along with the name of that committee, for the period 1979–2006, are given in Box 13. 2.

Box 13.2: Names of the chairmen of the top committee of the NCL, along with the name of that committee for the period 1979–2009

Period	*Committee name*	*Chairman*
1979–82	Research Advisory Council	Dr. S. Vardarajan, CMD, IPCL, Vadodara
1982–84	Research Advisory Council	Prof. C. N. R. Rao, Chairman, Solid State and Structural Chemistry Division, IISC, Bangalore
1984–93	Research Advisory Council	Prof. C. N. R. Rao, Director, IISc., Bangalore
1994–97	Research Council	Dr. S. Ganguly, Executive Vice Chairman & MD, ACC, Mumbai
1998–06	Research Council	Prof. M. M. Sharma, Former Director, UDCT, Mumbai
2007–09	Research Council	Prof. D. Balasubramanian, Research Director, L. V. Prasad Eye Institute, Hyderabad

The chairman of a committee usually sets the tone of the deliberations. Sometimes, such as when T. R. Govindachari, that unusually taciturn gentleman-scientist (a reputed organic chemist), was chairman, the floor went to anybody who wished to speak, with no limits on time or content. Some were so commanding that the vocal attributes of the chairman made little difference. For good or for bad, they dominated and their opinions carried the day. The NCL has largely, willingly or unwillingly, respected their views.[1]

The Restructuring (and Renaming) of Divisions

What's in a name? that which we call a rose
By any other name would smell as sweet.

Shakespeare, *Romeo and Juliet* 1596

The original seven divisions were maintained in tact for a number of years. The first change occurred in 1963 when the Division of Survey and Information was renamed the

Division of Technical Services. It then underwent a few more changes. The other divisions too experienced changes in their names as well as functions. These changes are listed below. Official notifications of name changes are not available.

M. Damodharan was the deputy director and first head of the Division of Biochemistry, K. G. Mathur was the first assistant director in charge of the Division of Survey and Information, J. Gupta the first assistant director in charge of the Division of Inorganic Chemistry, S. S. Marsden the first assistant director in charge of the Division of Physical Chemistry, R. C. Shah the first assistant director in charge of the Division of Organic Chemistry, S. L. Kapur the first assistant director in charge of the Division of Plastics and High Polymers, and J. H. Truttwin, the first assistant director in charge of the Division of Chemical Engineering. The following changes then occurred.

- Division of Inorganic Chemistry (including Analytical Chemistry) changed to Division of Inorganic and Catalytic Chemistry
- Division of Physical Chemistry (including Electrochemistry) changed to Division of Physical and Materials Chemistry (including Nanoscience)
- Division of Organic Chemistry **divided into**
  - Division of Organic Chemistry and
  - Division of Essential Oils, **then as**
  - Organic Chemistry (Natural Products) and
  - Organic Chemistry (Synthesis), **again as**
  - Organic Chemistry-1 and
  - Organic Chemistry-2, **and again renamed as**
  - Organic Chemistry (Technology) and
  - Organic Chemistry (Synthesis)
- Division of Biochemistry **renamed**
  - Division of Biochemical Sciences, **divided into**
    - Division of Biochemical Sciences and
    - Division of Plant Tissue Culture,
    - (Including Plant Tissue Culture Pilot Plant as an independent unit)
- Division of Plastics and High Polymers **changed to**
  - Division of Plastics and Polymers, **changed to**
  - Division of Polymer Chemistry, **changed to**
  - Division of Polymer Science and Engineering
- Division of Chemical Engineering, **divided into**
  - Division of Chemical Engineering and
  - Division of Organic Intermediates and Dyes, **then consolidated again as**

  - Division of Chemical Engineering and Process Development

    Divided again into
  - Division of Chemical Engineering and
  - Division of Process Development.

- A new division of Homogeneous Catalysis was created out of the two

- More recently, the earlier Division of Chemical Engineering and Process Development was revived by recombining the Chemical Engineering and Process Development Divisions but the Homogeneous Catalysis Division remained

- Division of Survey and Information (The name Intelligence, as originally proposed,

  was quickly changed by McBain to Information. In fact, the division never functioned under that name), **renamed**

  - Division of Technical Services (DTS)

- A new entity Project Planning and Development Unit (PPD) was created
- DTS and PPD were **merged** to create a new Division of Research Planning and Business Development (RPBD).
  This new division was later **renamed as** Business Development Division (BDD).

Seminars

There was no question that the reaction worked
but transient colors were seen
in the slurry of sodium methoxide in dichloromethane
and we got a whole lot of products
for which we can't sort out the kinetics
next slide will show
the most important part
very rapidly
within in two minutes
and I forgot to say on further warming
we get in fact the ketone
you can't read it on the slides
you can't monitor this in the infrared
I am sorry in the NMR
my time is up I see
well this is a summary of our work

Roald Hoffmann, Nobel Laureate, *Next Slide Please*, 1987

This telling parody apart, the NCL has always had an outstanding seminar program. It was able to attract famous scientists to present seminars. The seminar program was at its height during Venkataraman's regime. It went down a little during Tilak's time and picked up again during Doraiswamy's regime. These represented minor fluctuations. All in all, the number and quality of speakers were uniformly high. In addition to these all-laboratory seminars, different divisions organized their own special seminars. These were usually a mix of the NCL and outside speakers and were meant to be educational. A. P. B. Sinha was a popular NCL speaker. So was Doraiswamy, although to a lesser extent. And to an even lesser extent was H. B. Mathur.

No complete list of speakers was available. Hundreds of speakers from all over the world lectured at the NCL. Some representative names that would be familiar to many scientists are: Linus Pauling, Robert B. Woodward, Lord Potter, Herbert C. Brown, Dorothy Hodgkins, Robert Grubbs, Derek Barton, Francis Crick, all Nobel Laureates; M. S. Swaminathan, FRS; Goverdhan Mehta, FRS; Philip Cohen, FRS; W. H. Hoelderich; Sukh Dev; Andreas Acrivos; Morton Denn; Obaid Siddiqi, FRS; T. V. Ramakrishnan, FRS; C. K. Prahalad; Peter Danckwerts, FRS; John Davidson, FRS; Richard Ernst; A. B. Metzner; Academician G. K. Boroskov; James Wei; Peter Goodfellow; Hermann Mark; Jean Claude Charpentier; Alex Bell; Donald Paul; Klavs Jensen; Arup Chakraborty; Joseph Kennedy. In addition, many renowned scientists (including E. N. Lightfoot, Rutherford Aris, M. A. Larson, Peter Reilly, Charles Glatz, James Hill, Paul Weis) made special presentations at the various international conferences held at the NCL.

Technology Absorption

No account of the NCL would be complete without a pointed reference to its strength in the scale-up of chemical processes. Its evolution in this respect comes through clearly in the earlier chapters of this part and in some sections of Chapter 8. This strength came in handy to the government in its negotiations with major world companies to insist on introducing a clause in the agreements that would allow the concerned Indian parties to share technical details with national laboratories. The inspiration for this move came probably from the Japanese model, which enabled that country to improve on imported technology. These improvements often were significant and novel enough for the technology to be called new. The question of importing improvements thus became moot.

One of the significant outcomes of this action as far as the NCL was concerned was the involvement of the lab in the design of the IPCL's acrylates plants using the information supplied by Asahi and Sohio as the basis (see Chapter 10). The success of this move prompted the IPCL to delve deeper into the entire question of scale-up or scale-down of imported plants, with or without improvements, using the data supplied by the foreign party as part of the technology package. Thus the IPCL would not be just using the imported technology, going back to the original supplier for additional details, or simply for trouble shooting, from time to time, but would fully assimilate or absorb the technology. The NCL was asked to prepare a report on Technology Absorption. This task was assigned by Tilak to LKD, who submitted a detailed report to IPCL. The subsequent fate of the report, even whether it was ever used, let alone taken seriously, is not known.

Another case of attempted technology absorption, again for the IPCL, was for the ammoxidation reactor, and was briefly described in Chapter 11. The NCL developed a mathematical model for the reactor under the leadership of B. D. Kulkarni, but differences between the development and production groups of the IPCL precluded experimental validation of the model, so necessary for technology absorption. The chief conclusion from these failed attempts appears to be that the brief span of time during which they were made was not the most propitious for success. More importantly, managerial commitment was not strong enough to override dissent or to make a second attempt at a later time, more suitable to the production group.

The NCL Research Foundation

The National Chemical Laboratory Research Foundation (NCL-RF) is a non-profit trust established in 1991. Its mission is to promote a culture of excellence amongst all employees of the laboratory, no matter what function he or she performs. The laboratory expresses its grateful appreciation by recognizing those teams and individuals who have shown exemplary performance.

The NCL-RF has the primary objective to motivate and recognize a high level of team and individual effort of scientists, engineers, technologists, research students and support staff at the laboratory for their contributions to the laboratory through scientific research and innovation.

A corpus raised from contributions from private organizations and individuals who are well-wishers of the NCL was created. Earnings from the fund are used to further the objectives of the Foundation. The NCL-RF recognizes the contributions of NCL scientists through institution of various awards such as the NCL Foundation Day awards, National Science Day awards and National Technology Day awards to promote excellence in basic science, applied research leading to commercialization of technology, new initiatives in R & D support systems, to recognize high standards of merit in individuals from the scientific and support staff and to promote a culture of safety in the laboratory.

The NCL-RF has been registered as a public trust and is managed by a Board of Trustees. The Trust has been granted an exemption under U/S80G of the Income Tax act 1961 to enable it to receive donations.

The NCL-RF is a unique, successful and a one-of-a-kind experiment in public-private partnership to encourage all-round excellence in all endeavors of the laboratory. It is managed through an independent and eminent Board of Trustees as a private fund within a public body. It brings to its activities a high level of transparency and encourages peer-group participation in all decision making.

One of the main functions of the Foundation was to honor former directors by creating Endowment Lectures in their names. The directors chosen for this honor were McBain, Venkataraman, Tilak, Mashelkar, and Ratnasamy. In the case of Doraiswamy, a different kind of lectureship was agreed to, with the entire initiative coming from outside. As he joined the Chemical Engineering faculty of Iowa State University after retiring from the NCL and taught there for 15 years, the Iowa State University initiated a Doraiswamy Honor Lecture Series in collaboration with the NCL-RF (but with very little financial involvement of the laboratory), according to which the selected scientists would lecture both at Iowa State University and the NCL. The names of a few Endowment speakers under the auspices of the NCL-RF were included in the list of seminar speakers given earlier.

Administration

> *Bureaucracy defends the status quo long past the time when the quo has lost its status.*
>
> Laurence J. Peter, 1919–88

> *Nobody ever went broke underestimating* the role of administration.[2]
>
> H. L. Mencken, 1880–1956

The word administration is incontrovertibly associated with what is generally regarded in scientific circles as a bad word: bureaucracy. For any improvement to happen, it is believed that one has to make friends with the reigning bureaucracy, as India's last and only Indian Governor General C. Rajagopalachari remarked, only half in jest, at the NCL's opening ceremony, when he was a Member of the Viceroy's cabinet (see Chapter 3):

> *— you may treat the government as one of* [the] *difficulties you have to overcome. You will have to make friends of all your difficulties including your Member-in-Charge* [equivalent to the minister of these days] *and the Finance Department also.*
>
> *NCL booklet* 1947, 1950, 1952.

It is a hopeless task to fight a system soaked in the art and practice of bureaucracy. While the process of making friends goes on, one should also not forget the old saying (anonymous, but there is an unconfirmed attribution to Mohammed Ali Jinnah, the founder of Pakistan):

An irresistable force acting on an immovable body.

Each institution must make its own adjustments, find its own shortcuts, and evolve its own escape routes, without in the least compromising the underlying ethical principles. Take, for instance, the allegedly lowly case of hygiene, a word that does not exist in the lexicons of bureaucracy. It was certainly not on the agenda of any director of earlier years. The Head Laboratory Supervisor did what he thought was adequate (which was woefully inadequate) and there the matter ended. Things changed rather dramatically in the early 1980s. The trend was continued in the 90s, albeit at a slower pace, but the issue regained prominence as the laboratory moved into the present century. The old saying *cleanliness is next to godliness* should never be regarded as hackneyed, and to relegate it to the outer regions of managerial attention is to invite a heavy toll on the NCL's overall reputation.

This lack of attention to the non-research aspects of the laboratory was, unfortunately, symptomatic of the CSIR as a whole. One had only to step into the CSIR canteen and rest rooms of those years to experience the truth of this statement — and feel the revulsion of unclean places of ingress and egress of the human system! But the issue goes far beyond this evidence of filth. There was no streamlining of administration and the old order continued unchanged through the first three decades of the NCL's existence. I recall once asking an AO to list the steps a purchase file had to undergo and the tortuous route it had to follow before it came to my desk. There were, I believe, 34 steps! The procedure was streamlined and the number of steps reduced to half, but it was hardly enough. There has been a dramatic change in the last few years since Ratnasamy, and particularly Sivaram, came on the scene.

But before that, the CSIR created a new position at a level between the director and the AO. All major laboratories were to have officers heading their administrative and financial wings, with enhanced powers. Typically, the additional powers were not given to the AO, but entirely new positions, Controller of Administration (COA) and Controller of Finance (COF), were created with their own offices and staffs. This is not to say that India is any more bureaucratic than, say, the USA, as is made out.[3] Indeed, Indian bureaucracy is less rigid, but has unfortunately earned a reputation for delay, not because of any undue emphasis on due process, but because of the lethargy and lack of commitment that have somehow crept into its structure (with refreshing exceptions that rise above the rules). I have always maintained that where there is a will, there is always a liberating alternative — complete with the right ethics.

Many administrative steps were eliminated, purchase procedures were simplified, modern accounting systems were introduced, provision was made for high-class constructions (thus eliminating the age old practice of accepting the lowest tender irrespective of quality) as so attractively exemplified by the state-of-the-art Digital Information Resource Center, divisional heads and senior scientists were authorized to plan their own spending and travel, routine functions such as maintenance, security, cafeterias, garden, etc. were contracted out to professional agencies, and the director's personal involvement in many managerial decisions was minimized, leaving him free to attend to more important issues. The offices acquired a modern professional look with pleasing furniture replacing ink-stained desks inserted wherever space was available in a room. One remarkable aspect of the NCL, noticeable throughout its existence, was the complete absence of shabby dust-covered steel cabinets lining the sides of corridors, an all too familiar sight in the secretariats of New Delhi. Trite as these may seem, they were all part of the NCL's evolution into a state-of-the-art laboratory in all aspects of its functioning. If an exception is needed to formulate a consistent set of experiences into a working rule of life individually (although, in the case of a natural law, according to Feynman, 1998, even a single exception is enough to disprove it), that certainly is provided by the rest rooms of the NCL. This appears to be a depressingly persistent cultural deficiency from which no quick relief is in sight.

I would like to conclude this section by emphasizing that the government (which dictates policy) and administration (a word often used interchangeably with bureaucracy) are two different things. According to Abraham Lincoln:

> *There is an important sense in which Government is distinctive from Administration. One is perpetual, the other is temporary and changeable. A man may be loyal to his Government and yet oppose the particular principles and methods of Administration.*
>
> Lincoln, 1942

> The NCL did not subscribe to Honore de Balzac's view that "*bureaucracy is the giant power wielded by pigmies*".
>
> Balzac, 1901

> nor did it agree with Vannevar Bush that "*virile creativeness* [is destroyed] *by the patronizing favor of swollen bureaucracy*".
>
> Bush, 1949

On the other hand, there is a "flexible rigidity" about administrative rules that defies comprehension. Depending on the level of office where an administrator works (such as a higher office in Delhi compared to one in Pune), his decision on a point may vary. There are ample instances to prove this point, but the one narrated in Chapter 16 — *the two faces of bureaucracy* — is particularly revealing.

Practically all the directors of the NCL have, without making a point of the difference between government and administration, enlisted the support of the higher administration, not by challenge or servitude, but by adroitly teasing out a favorable response. In the ultimate analysis, the government sets policy and administration implements it. As Adlai Stevensen said in a speech in 1952:

> *Bad administration, to be sure, can destroy good policy, but good administration can never save bad policy.*
>
> Stevenson, 1952

In the case of the NCL, the central government sets policy, which the CSIR (sometimes) modifies, and the NCL implements. So, NCL is largely concerned with administration, which, on the whole, has been good. As an instrument for implementing policy, good or bad, it has been very efficient, sometimes to the detriment of research. Ironically, it is this very efficiency — the unquestioning implementation of policy — that has prevented it from influencing policy. The evolutionary process has so far failed to build a working nexus between the two, and there are no signs of this happening anytime in the near future.

The Evolution of Communication

> *Big whorls have little whorls,*
> *That feed on their velocity,*
> *And little whorls have lesser whorls,*
> *And so on to viscosity.*
>
> Lewis Fry Richardson, 1881–1958

> In these beautiful words did Richardson explain the principle of atmospheric physics to the general reader. Would that some of our science writers explained in like fashion the principles of their own fields of specialization to their readers. The communicators of the NCL owe it to the general public to make this great attempt.[4]

The NCL did not start out with a full appreciation of the need for good, effective communication. Scientific communication was always good but general communication among scientists or between scientists and administrators left much to be desired. Communication with the outer world, particularly in terms of attracting industrialists and entrepreneurs to the lab, was no better than the writing skills of the individual scientists, which showed a wide variation. Although there was a Division of Survey and Information, which was renamed Division of Technical Services, it often acted as a clearing house, receiving and delivering information with marginal inputs of its own. The situation improved considerably over the next three decades till, around 1990, the explosive advent of the Information Age changed the old order dramatically.

The first major change occurred around 1980 when K. R. Srinivasan from the Division of Chemical Engineering and Process Development was transferred to DTS. His grammar was impeccable and he had written some very good books in a traditional style. This proved to be a very good move, for soon the tone and tenor of communications from DTS, correctly written, changed perceptibly. Historically, this represented a step change and over the years the improvement continued. In the art of writing general articles, using simple and correct English in the emerging style, H. B. Singh from the old DTS stood out. Another person, with an amazing command of the English language (also from the CEPD) who was persuaded in the early 1980s to move to DTS, was S. Krishna Das, but he contributed little to the growth of communication in the NCL. His pleasant but firmly rebellious attitude (with malice towards none) was stronger than the demands of any division.

The quality and clarity of scientific communication also improved over the years. The general apathy towards good communication and record keeping was brought to the fore most tellingly when one of the senior scientists asked me point blank: *Are you more interested in the work or in writing reports, keeping records, and communication*? Had they but known the remarkable instance of the prolific James Hutton, generally regarded as the founder of modern geology, who is far less remembered than John Playfair who rewrote his monumental 1795 masterpiece *A Theory of the Earth with Proofs and Illustrations* with singular clarity and acquired lasting fame. The readers can judge for themselves whether this was justified by reading the following classic passage from Hutton's original book:

> *The world which we inhabit is composed of materials, not of the earth which was the immediate predecessor of the present, but of the earth which, in ascending from the present, we consider as the third, and which had preceded the land that was above the surface of the sea, while our present land was yet beneath the water of the ocean.*
>
> Quoted, among others, in Bryson, 2003

The two versions of the same subject (Playfair's is not quoted here), written in diametrically opposite styles, show that precision is important and that the scope for interpretation must be minimized. Playfair perhaps did not specifically render the above passage in his own language. He was more interested in the substance of the book. But his general style of writing tells us that contrived simplicity, where a sentence is artificially restricted to no more than a few commonly understood words (a much admired American style), must also be avoided. It is no more desirable than pomposity and length where the substance is often lost in an overdose of sub-clauses.

The NCL Ph.D. theses were never subjected to rigorous review either for language or format (including uniformity), unlike in all universities in the the USA where a thesis has to be approved for language and format by a separate department, usually even before it reaches the major professor. Some suggestions are offered in Chapter 18. Many Indian scientists learnt their English the formal English way but later were more exposed to American English. This created its own problems in communication, as a careful examination of the present book (by an Indian who admires the English language, is equally comfortable with American, and finds it difficult to adhere completely to any one) will show. Fortunately, the distinction is not as blatant as George Bernard Shaw (1942) would have it: *England and USA are two countries separated by the same language*.[5]

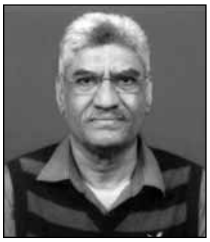
Figure 13.1: Some outstanding NCL scientists (excluding directors and scientists in position as of 2009)


Ayyangar, A. R.


Barnabas, John


Bhattacharya, S. C.


Chaudhari, R. V.


Choudhary, R. V.


Damodaran, M.

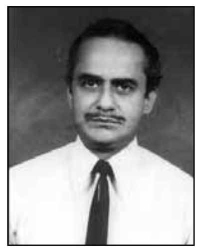

Gupta, J.


Iqbal, S. H.


Jagnathan, V.

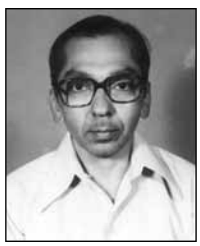

Kapur, S. L.


Mascarenhas, A. F.

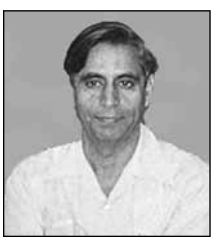

Mitra, A. B.

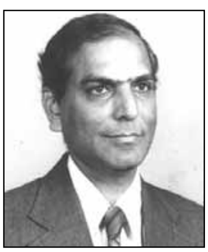

Mathur, H. B.


Nadgauda, R.


Rajappa, S.


Rama Rao, A. V.


Sadana, J. C.

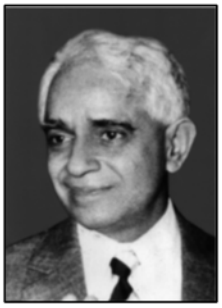

Sinha, A. P. B.


Shivaraman, C.


Srinivasan, M. C.


Sukh Dev

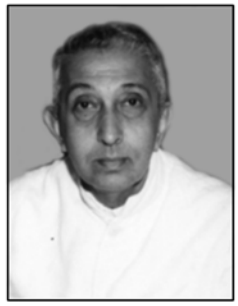
Figure 13.2: Photographs of people most associated with NCL



Kumar, Lovraj

Mafatlal, Arvind

Kumar, Rajendra



Narielwala, P. A.

Rao, C. N. R.

Seth, Darbari

Sharma, M. M.

Source: Photograph of P. A. Narielwala taken from the collection of the Tata Central Archives

A few words about the NCL scientists' skills as writers of research papers would not be out of place here. Possession and communication of knowledge are two different things. As a saying of unknown authorship goes, it is all too easy for young scientists *to mistake in their masters the certainty of knowledge for correct expression of it.*[6] The NCL has not found a way in the last 60 years to close the gap. This is unfortunately a national malaise that can only be corrected by central action. English is rapidly becoming a necessity in science education and research, and it would be unfortunate if Indians lost this inheritance through neglect, real or calculated, or a misplaced act of disapproval of a former occupier of India (see Chapter 16, LKD'*s naivete*).

An important aspect of communication is authorship. For general reports and publicity material, no specific names are necessary. The institution itself is the author. For scientific communications, viz. papers and patents, choice of authors in a multidisciplinary effort is difficult, and can lead to personnel problems, perceived or real. Time was when a few CSIR labs adopted a procedure, dictated by a director or devised by self-seeking scientists, in which the director's name was always included. Fortunately, no NCL director encouraged this policy. Venkataraman (KV) was positively sarcastic when he sent back a paper in which the senior author had included his name, evidently with the intention of pleasing the director. He only succeeded in provoking KV's anger which resulted in an official communication (more in the nature of a reprimand) from him that names of only those persons should be included who had a reasonable share in the contribution. I went one step further and decentralized the entire procedure, giving the divisional heads authority to approve communications, but requiring them to ensure that sensitive material was not published. Ratnasamy further decentralized the procedure, so that, today, the publication procedure is no different from that in the academia. With the laboratory becoming increasingly patent conscious, it may be desirable to revisit this entire question.

Involvement in Enquiries/studies on National Disasters

NCL scientists, not infrequently, were named to committees for the investigation of disasters. NCL soon became an important instrument of government through appointment of its scientists on committees for enquiries pertaining to chemical disasters. Among the incidents that were referred to the NCL for clarification/enquiry/recommendations, the following stood out:

- Bhopal Gas Tragedy (BGT)
- Maharashtra Gas Cracker Accident

and were perhaps the most significant from the point of view of its evolution over time as a key player in national issues. The Bhopal disaster, that became an important Indo–US issue involving judicial intervention both in India and USA, is briefly described below.

December 1984, when this accident occurred, was perhaps the most tragic month in the recorded history of the Indian chemical industry, indeed of India as a whole in recent memory. It was the day when an explosion in a chemical factory in Bhopal took thousands of lives, maimed many more, and held out fears of tragic genetic consequences in children yet to be born. The Government of India appointed a committee under the chairmanship of C. R. Krishnamurthy, a former Director of the CSIR's Institute of Toxicology, to examine all aspects of this explosion, and the report submitted by it speculated on dire consequences both to existing and emerging life in the Bhopal area. The CSIR was involved in all aspects of the investigation from day one, when Director-General Varadarajan paid a visit to Bhopal immediately after the tragedy. This was followed by visits by G. Thyagarajan, Director of the Central Leather Research Institute (who took an active interest in this matter), and many other senior scientists including N. R. Ayyangar and his group from the NCL, deputed by me to carry out an in-depth study of the accident.

From a practical point of view, the NCL's involvement started rather dramatically. I received a call from the police chief of Bhopal that samples of chemicals drawn from various locations in the plant were being sent to the NCL in a heavily guarded vehicle with instructions to deliver them to me personally. The samples were to arrive within a few days, and I was directly instructed by the Government of India to set aside a safe room with arrangements for a high-level of security. The room was to be under round-the-clock police surveillance. The lack of communication between the police chiefs of Bhopal and Pune did not make things easy. However, soon a room was prepared with all the required security measures, and I volunteered to take charge of the samples in front of the room. The police escort insisted on taking it inside the room, locking the room, and handing over the key to me! The mantle of its safekeeping had been passed on to the NCL!

Matters moved quickly thereafter. A strong analytical group was assigned to the Bhopal project, and interactions were initiated with outside organizations, such as the Bhabha Atomic Energy Research Center in Mumbai. A group of organic chemists headed by N. R. Ayyangar was deputed to Bhopal to fully understand the problems. R. B. Mitra, Head of Organic Chemistry-2, was named leader of the project. Mathematical modeling of the accident at an elementary level was also undertaken pending legal battles with Union Carbide, the supplier of technology. Soon thereafter, Mashelkar took over as the Director of NCL, and he was named chairman of a new committee to investigate the disaster. Thus there were two reports, the first by Varadarajan and the second by Mashelkar, with Ayyangar's report as the initial basis. The second report was a model of scientific insight, analytical thinking, and sophisticated mathematical modeling, and has been ranked in the same category as the now classical report of John Davidson (the renowned Cambridge professor) on one of England's major accidents, called the Flixborough Disaster.

Part of a Complete Story

All the features of the NCL described in this chapter are equally important. They are the non-technical companions of NCL that cater to the technical effectiveness of its scientists and the outreach of the laboratory. In concluding this chapter, I would like to emphasize one aspect that, in my view, is paramount. But not many seem to agree. That is grammar, on which the following anecdote attributed to Dwight Moody is rather revealing.

> *Gospels meetings were conducted in a hall where Dwight L. Moody received the practice and training in preaching that were of such incalculable value in later years. And it seems that he needed this training, for he attained his powers of extempore speaking only gradually. It is of interest in this connection to know that when he first rose to speak in a prayer-meeting one of the deacons assured him that he would, in his opinion, serve God best by keeping still!*
>
> *Another critic, who commended his zeal in filling the pews he had hired in Plymouth Church, suggested that he should realize the limitations of his vocation and not attempt to speak in public.*
>
> *"You make too many mistakes in grammar," he complained.*
>
> *"I know I make mistakes," was the reply," and I lack a great many things, but I'm doing the best I can with what I've got."*
>
> *He paused and looked at the man searchingly, adding with his own irresistible manner:*
>
> *"Look here, friend, you've got grammar enough — what are you doing with it for the Master?"*
>
> See Moody [Dwight L's son], 1977

Though seemingly negative, this episode brings out the centrality of grammar by intentionally side stepping it. While the ability to correctly and effectively communicate, a persistent weakness of the NCL except at certain higher levels and identified here only as an illustrative companion to research (granting a sliver of bias on my part to communication), is very important, the other concomitants to research are no less so. Their collective companionship to research (along with some more described in the next chapter) in the evolution of the NCL as a whole is indisputable.

❄

14

ESSENTIAL TECHNICAL MISCELLANY
WHAT KEEPS AN INSTITUTION GOING

> *I long to accomplish a great and noble task, but it is my chief duty to accomplish humble tasks as though they were great and noble. The world is moved along, not only by the mighty shoves of its heroes, but also by the aggregate of the tiny pushes of each honest worker.*
>
> Helen Keller, quoted in *The Treasure Chest* by C. Wallis, 1883

No institution, scientific or otherwise, large or small, can sustain itself without the infrastructure to cater to its various needs and the active participation of every one of its workers. Take, for instance, the macro-scale development of India itself. As already mentioned in the early chapters, independent India inherited a working bureaucracy from the departing British. No doubt, this had to be modified, and in many cases drastically remodeled, to suit the aspirations of a resurgent country. Institutions like the NCL started with everything new, so the infrastructure grew along with their research activities. It was a micro-infrastructure within the meso-infrastructure of the CSIR, which itself was born only a few years earlier and grew within the longstanding macro-infrastructure of British India. But within the mandated framework of the macro-meso rules, the directors had sufficient leeway in running their laboratories.

The infrastructure of the NCL had parts such as Administration, Finance, and Stores (Materials Management) that had to be as planned by the CSIR for its constituent laboratories, which had little say in their bureaucratic organization. Here, too, the NCL did manage to introduce many new management concepts to improve their functioning and to aid in the better handling of projects. Facilities like library, safety, workshop, and glass blowing, which may be called scientific infrastructure, were left almost entirely to the individual laboratories to develop within the financial discipline of the CSIR. The NCL created and developed these facilities, rather slowly at first, then with increasing speed and modernity as it entered the computer age in the late 1970s, and with much greater urgency and change in management style as it entered the electronic age in the mid-1980s. The present chapter is concerned with this kind of infrastructure. The more general kind of infrastructure like those concerned with horticulture, colony facilities, entertainment, sports, etc., are considered in the next chapter.

Library

If a man empties his purse into his head no one can take it away from him. An investment in knowledge always pays the best interest.

Benjamin Franklin (attributed)
(unverified, but see Burton Stevenson, 1967)

Books are good enough in their own way, but they are a mighty bloodless substitute for life.

Robert Louis Stevenson, c. 1875

Books, journals, patents, and a variety of more specific documents — knowledge in short — are the lifeblood of a research laboratory. Besides, the ability to quickly access any desired document, in particular any specific item of information needed without struggling through volumes of material, has emerged as perhaps the most important single item (generally called information technology, IT) of technical pursuit in the last decade.[1] Notwithstanding the nostalgia mentioned in the footnote, it is a fact that the world of books has come a long way since the goldsmith Gutenberg invented the printing press in the 15th century. Almost every activity has gone digital in the last decade and, in the word of the Amazon chief, Jeffery Bezos, 'Books are the last bastion of analog' (Levy, 2007). He is also credited with the statement that *the future of reading is only a click away*. The device that can do this is called the Kindle, to evoke *the crackling ignition of knowledge*. Using this, any book written anytime since printing was invented can be accessed by a click! It is said that the Kindle will *change the way readers read, writers write, and publishers publish*. The NCL should brace itself to this impending destruction of the library before we are half way into this century. In less than 6,000 years man has gone from the papyrus of Egypt to the Kindle of Amazon, most of the advance coming in the last 30 years!

Starting with a bare minimum of about 350 documents, including books, journals, etc. in 1950, simultaneously with the founding of the NCL, the library waded through 35–40 years of continuously expanding collection of these till it hit the IT explosion. And then it was not found wanting in moving into the new reality with a naturalness that has been the laboratory's hallmark in all spheres of its activity.

THE EARLY YEARS

The library's early years were marked by an air of informality and the absence of rigid rules. This atmosphere made for a situation where the library sometimes became a place for casual meetings and discussions among friends, without much regard for the basic tenet of any library: silence. But then all noise ceased the moment there was a request (never a complaint) and silence was restored. There used to be about 350 visitors every day, including many outsiders. There were no restrictions and no permits were required. Anyone who wanted to make use of the library was welcome. The majority of the visitors came from industries and government institutions in and around Pune, including Mumbai. The following account by V. P. Menon, an early employee of the library, makes interesting reading.

> *They* [the visitors] *came with the hope that the library could cater to their requirements on any topic. The enquiries ranged from the structure of the earth to the formation of the universe. But the enquiries were such that the staff had to possess a sixth sense to read the minds of the enquirers. The enquiries posed many difficulties. Only a few of the visitors came to the library with full details of their needs. Among the inadequate details that the others had brought were wrongly spelt authors' names, incomplete titles, a vaguely remembered article published somewhere in a serial volume as a chapter, and so on. Many of them thought that 'ibid' and 'J' were names of periodicals not available in the library. Some of the visitors came with the sole idea of making use of the reports such as BIOS, FIAT, CIOS, etc.*
>
> *In spite of all sorts of hurdles, which were only to be expected in a developing institution, on no occasion people had to go back disappointed. Instead, compliments came pouring in.*
>
> *There was a splendid reason behind it. The situation existing then had amply offered full freedom and opportunity for the staff to develop their skills by tapping the hidden talents, intelligence and energy within themselves. Services were neither designation nor profession oriented but need-based. There used to be a practice of screening all publications received and store in* mind *the important information for use when the need arose. If there is such a thing as 'mental documentation,' this was it. Current awareness services were in existence although this technical phrase was unknown.*
>
> *Books like Colloid Science, Solubilization, Lime Stone, Diffraction, Microscopy, and Synthetic Dyes written by eminent NCL scientists enriched the library collection during this formative period. Frankly speaking, the number of publications in periodicals, patents, a good number of theses, reports on projects released for commercialization and awards won by our scientists and the growth of chemical industries around Pune, etc., could be attributed, to a certain extent, to the above-par services of the library in the past. These achievements speak for themselves although no documentary proof of such excellence in the past exists. To think of the past and its achievements is like attending a refresher course and gives one an enviable satisfaction although not any monetary benefit.*
>
> *An example of the type of enquiries the library staff received those days and how they were handled would be quite interesting. A gentleman called Ram Dayal, a native doctor from Pimpri* [close to Pune], *once called at the library. His interest was books on medicine. He was given the necessary help, but when he began to read the lofty tomes, he found them hard nuts to crack. He then changed his interest to books on diseases. None of these books gave him satisfaction either. He gave vent to his unhappiness and he was also getting angry. He was told that the library might be in a position to help him if he could spell out clearly what exactly he was looking for. He was very reticent. The matter, it appeared, was a trade secret. After some more hesitation he at last took the library staff into his confidence.*
>
> *He was a person, it seemed, who suffered from pain in one half of his head and he had some patients who were plagued by the same ailment. He had tried many medicines but in vain. At last he had come to the NCL library in response to a friend's advice. The library staff told him that the library could provide him information on a very simple and inexpensive ayurvedic treatment not only for the headache but for scorpion sting as well. The practice of mental documentation now came in handy and he was told to refer to two articles that gave a description of the treatment.*

> *While departing happily he repeatedly made requests not to disclose the information to anyone. He also promised to return again on the third day with some suitable gifts but his promise is yet to be kept.*
>
> *The library staff may be forgiven for not sharing the pledged secret information with their colleagues. But the following references may let the cat out of the bag:*
>
> Indian Forester, 80, 64 (1954), Indian Forester, 82, 49 (1956) (Menon, 1979).

Allowing for a certain degree of nostalgia and a sense of frustration at being overwhelmed by the tide of modernization, Menon makes an interesting point. The library staff of the earlier years were technically involved and by a process of *mental documentation* (an interesting phrase) were able to help many visitors. Although it would require trillions of Menons to keep up with the information explosion of today, there is something sad about the surrender of this period to the inexorable advance of time.

The NCL library was no exception to this friendly onslaught of computerization. It started gradually around 1980, picked up speed around 1990, and became a part of the computer/electronic revolution around 2002 (although still slightly lagging behind the West). Its history can broadly be divided into three periods.

- 1950–1975 Collection Development
- 1975–1995 Computerization and Information Center development
- 1995–2005 Electronic Resources Development

COLLECTION DEVELOPMENT

The collection began with the donation of many books by INSDOC (Indian National Scientific Documentation Centre), Delhi, and other institutes. Simultaneously, a number of reference books, journals, abstracting and indexing periodicals, patents, standards, theses, etc. were also procured. The library was, in every respect, functioning as a traditional house of books. It did not have then, and does not have today, a separate building as most large research centers do. It occupied a big hall immediately behind the imposing entrance enhanced by a mezzanine hanging over tall pillars with the auditorium on one side and a pool of water in an artistically designed marble tank in front. In the 1980s, in Doraiswamy's regime, an opening was made in the floor near the front desk with stairs leading to the basement, from where the store was removed to a new building and the released area fully made available to the library. The library offices and rooms were fully modernized during Sivaram's regime, in the early 2000s.

The use of the open access system helped readers to select the books as per their needs. Some special services were started in late 1974. NCL scientists needed the latest information on their projects. In response to this, the library started issuing information bulletins on a number of projects, for example, pesticides, insecticides and herbicides; and solar energy. The bulletins covered bibliographical details of the articles along with short abstracts where available. This selective dissemination of information and subject bibliographies proved to be of considerable value to the scientists.

COMPUTERIZATION AND INFORMATION CENTER DEVELOPMENT 1975–1995

In 1980, the computerization of the library was initiated using the CDS/ISIS software developed by UNESCO for libraries in general. Data on books was entered on an experimental basis but it was observed that the software was unable to satisfy the functional needs of the library. Wipro (a computer company) was then requested to develop software specifically for the NCL. Using this software WILISYS, the library catalogue was computerized and also some other functions like book and serials procurement.

In 1983, with the help of its telex machine, NCL was connected to the host computer of the Dialog Corporation at Palo Alto, California. Online search on particular topics was possible through this facility. The National Information System for Science & Technology (NISSAT), under its sixth 5-year plan, established several National Information Centers. One of them, the National Information Centre for Chemistry and Chemical Technology (NICHEM), was located at the NCL and became fully functional in 1986–87. The major services assigned to this center were:

- Library services
- Consultation, reference service, and lending of documents to academia and the corporate sector
- Information and documentation services
- Compilation of bibliographies on given topics, and online search of international databases on given topics
- Reprographic services
- Translation services
- Publications

The center brought out a number of bulletins.

Most of these services are still continuing and are known as Document Delivery Services (another instance of a new name for an old service!). They are, however, infinitely faster and much more efficient since they are rendered through the computer and communication technology facilities set up at the NCL.

This period also saw the NCL emerge as a major center of information and documentation services in the country in the area of chemistry and chemical technology. NISSAT established two major activities at the NCL library. One was the National Access Centre for International Databases (NACID) in 1998, one of five such online centers set up to provide information support services to scientists and technologists in the country. The NCL was required to cater to the needs of the western region comprising Gujarat, Madhya Pradesh, Maharashtra, Dadra and Nagar Haveli, and Goa, Daman and Diu.

Another was the Value Added Patent Information System (VAPIS) launched by NISSAT at the NCL in 1995. The library also subscribed to the WIPO patents for a short period of 2–3 years. More importantly, it was an inspection center for Indian patents and related publications. In addition to serving the greater national need, these patent services were of considerable use to NCL scientists in their project work

ELECTRONIC RESOURCES DEVELOPMENT 1995–2005

The software WILISYS, used till 1994, was not found to be entirely satisfactory. Hence a study was conducted of a variety of available commercial software including those used by major Indian libraries like that of TIFR. Based on this study, it was decided to use the software LIBSYS, developed by the Libsys Corporation, New Delhi. Several features were introduced which are considered normal in most advanced libraries but which provide a historical perspective to the entry of the NCL's library into the electronic age. Some of these are:

- The library was placed on the internet in 1995.
- Barcoding of library documents was started in 1998 and completed in 1998. The entire circulation was then carried out using barcode scanners.
- An access control door was installed in 1999.
- User code photocopying was introduced in 2000.
- Using the digital facilities introduced at the NCL, several electronic features specific to the library were introduced. From the year 2000 onwards, various electronic resources were procured, such as a number of databases on CD and a CD-ROM tower. With the help of LAN (Local Area Network), databases were made available to scientists on their desktops. Some of them are *Chemical Abstract on CD* from 1977, *Current Contents* (4 sections), *JCR* (*Journal Citation Report*), *CBNB* (*Chemical Business News Base*), etc. The library started subscribing to a few electronic journals in 1999. In 2000 it provided access to *Science Direct*, Elsevier Science Publisher's site, and about 1,400 online journals. The same facility was later made available to NCL scientists under the CSIR e-Journals Consortium Program. In 2005, the NISCAIR (National Institute of Science Communication And Information Resources) and the CSIR entered agreements with 11 renowned STM publishers, and as a result, all the CSIR labs could get access to over 3300 e-journals.

The library staff is proud of the fact that in acquiring the new, it has not fully discarded the old. As a result, the NCL's library has proved to be a very fine combination of print and electronic media, a hybrid library. All core journals of chemistry and chemical technology are available in print since around 1960, some from their inception. This collection was recently supplemented by subscription to the electronic parts of the journals. Almost 150 journals amongst the 200 foreign journals subscribed to by the library are available online to scientists on their desktops. The library also takes advantage of the CSIR's NISCAIR e-journals consortium program to provide online access to over 3300 e-journals to the scientists. Some old journals were digitized and CDs stored for reference. The old volumes have been preserved as archives.

As of 2005, the library had come a long way since its modest beginnings in 1950. Today, the library has more than 1,330,000 documents which include books and bound volumes of journals. A separate collection of various reports e.g. BIOS (British Intelligence Objectives Sub-committee), FIAT (Field Information Agency Technical), CIOS (Combined Intelligence Objectives Sub-committee), SRI (Stanford Research Institute's Report) adds value to the document collection. In 2005 the library subscribed to about 250 journals, 200 foreign and 50 Indian. The budget was Rs. 2.35 crores, over twice the entire budget of the NCL around 1980!

Behind this progress, continuous and dedicated efforts of the library staff and strong support of all the directors were involved. The library should be particularly thankful to M. K. Kelkar, M. G. Gokhale, R. S. Singh and presently Ms. M. P. Chirmule and S. Krishnan for its enormous progress, particularly Krishnan, who steered the library into the digital age.

Safety

Early and provident fear is the mother of safety.

Edmund Burke (1792)

The NCL, like all other chemical laboratories in the country, did not regard safety as a major consideration — even a minor one — when it was launched. In fact, safety consciousness was a much later addition to Indian laboratories.

Surprisingly, it made a rather quick entry in the chemical industry after years of almost total neglect. True, seminars were held at periodic intervals to emphasize the importance of safety, but very little concrete action resulted. Then, around 1980, a change in attitude was discernable. Gone would be the days when chemical factories could dump their toxic wastes with impunity into nearby rivers, a situation nowhere more exemplified than in the Thana creek near Mumbai, where factory wastes were freely released into the waters. An outstanding example is Excel Industries, whose disregard for safety in the 1970s, as personally experienced by me, was briefly narrated in Chapter 10. In a most remarkable turnaround, they became by the 1990s, one of the most safety conscious companies in the country winning national awards for safety. The NCL, too, had reason to experience this turnaround when the American firm GE selected Excel to handle the production of the monomer jointly developed by them and the NCL. A similar change occurred at the laboratory, although in comparison with Western laboratories it was necessary to do much more.

EARLY YEARS OF LITTLE SAFETY AWARENESS

To trace the historical evolution of safety at the NCL, one should go back to the 1950s when, beyond a few safety showers and elementary fire fighting equipment, nothing existed. Safety gear such as eye goggles was made available but their use was not made compulsory. In fact, many scientists regarded any such compulsion as an invasion of their personal liberty (Independence had brought in its wake an opposition to anything imposed irrespective of context!). Safety was something that had to be dealt with when an accident occurred, after which it was quickly relegated to the obscurity from where it had briefly emerged. There was a casualness about the attitude to safety that would today be regarded as staggering, and in some cases may even invite criminal proceedings. But things changed dramatically over the last decade, particularly after 2000. In the 1950s and 60s, there were hardly any committees on safety. There was not even a formal procedure for reporting and recording accidents. From my own experience, safety never came up for discussion in meetings. I do not believe that it was brought up at any of McBain's Monday morning meetings, Finch's famously infrequent staff meetings, and Venkataraman's Senior Common Room meetings. There was a change for the better during the Tilak and LKD regimes but it was never an important agenda item. Most actions were retroactive and very few were proactive. Which was rather unfortunate since any safety action, like insurance, is a proactive investment to forestall death and waste. It is unfortunate, too, that this simple truth was not realized, but fortunate that the tragedies that resulted were no more than two deaths and a few explosions and fires with no significant damages.

It was in the 1970s, during Tilak's time, that some minimal attention was given to safety. There was a safety committee headed by Doraiswamy and a formalized method of reporting accidents, but still no method of tracking safety violations. Ms. S. A. Patwardhan, an organic chemist, seems to have taken a lot of personal interest in safety. She propagated the practice of safety entirely of her own volition, without any official position, and often wrote articles on safety in the NCL in-house bulletins. No other senior scientist, the director not excluded, evinced any personal interest. Since almost any activity needs a champion for any sustained results, nothing much really happened. This starvation by neglect continued in LKD's regime. Some improvement notwithstanding, no significant nutrition was supplied in Mashelkar's regime. Ratnasamy was the first Director to lift safety from this situation. Sivaram nourished it to a position when by the first years of the new millennium it had become a major feature of the NCL.

Right from the beginning, the NCL library maintained several books on chemical safety in its reference section for the use of the staff to gather information on the hazards and risks in the use of chemicals. But all these actions were entirely voluntary and there was hardly any imposition of safe practices (except for wearing aprons).

The facts stated above represent the general attitude to safety as the NCL evolved over the decades. This can be exemplified by several accidents that occurred during these years. As there are no complete records of these accidents, I shall recount two accidents in which I was personally involved (although even these are not on record!) to illustrate the laxity of the NCL at all levels in this regard during those years.

The first concerns a junior laboratory assistant, S. L. Phatak. I had asked him to bring from the chemical stores a 10-liter jar of aniline to my pilot plant area. As I sat waiting for him, I heard a thud and the noise of breaking glass followed by a stifled cry. I rushed outside to the pilot plant area and was confronted by a frightening sight. Phatak was lying face down, bleeding (not very heavily), with splintered pieces of glass all around and on him, and most of his frail body covered with the carcinogenic liquid. He was immediately lifted and washed, and when told that he would be rushed to a hospital he refused to go. Much persuasion followed by threats of his imminent demise was required before he agreed to go. He was already getting blue in his lips and I was beginning to be afraid for him. And then when for some inexplicable reason the doctors decided that there was no need to keep him under observation, it served only to strengthen his own insistence on going back home, and I could do little about it. It was by the sheerest chance that he did not develop any complications and the crisis passed. I informed the director about this accident and there the matter ended!

The second incident was even more serious. two of my colleagues, Satyesh Banerjee and Dinesh Bigg, were conducting some experiments, which required their presence the whole day in the laboratory without a lunch break. They therefore brought their lunch drinks and stored them, unlabeled, in a laboratory refrigerator, against all my instructions not to do so. At lunch time they removed what they thought were their bottles (a thought encouraged by the fact that many other items stored in the refrigerator were also unlabeled) and drank without a care. Soon they spluttered, made strange noises, spat out the liquid along with some blood, and almost collapsed on the floor. They had consumed a few mouthfuls of concentrated caustic soda! They were in agony as they were rushed to the hospital, where I was told that the esophagus had been badly damaged and that special plastic tubes had to be inserted to keep them from crumbling. The prognosis was not good. But they pulled through and surprisingly the laboratory was none the worse for this frightening experience. All that happened was that a couple of police officers interviewed the two scientists in the hospital and took statements. They also took a statement from me. And that was it. Matter closed!

Till the early 1970s, there were no enquiries into any accidents. All that would happen, if at all, was that the director or the head of the division concerned would warn the scientists to be more careful.

INTRODUCTION OF BETTER SAFETY PRACTICES

As a first step in improving the safety practices, the National Safety Day, on March 4, was celebrated every year, with a chief guest invited to deliver a lecture and films related to chemical and fire hazard being screened. In addition, competitions were organized for best slogans and posters and cash awards were distributed at the hands of the chief guest.

Then came the Bhopal gas tragedy in 1984, when the deadly MIC released in to the atmosphere killed thousands of people. And with it came to the fore, as never before, an appreciation of the hazards of chemicals and the high risks associated with their use. Many NCL scientists were asked to assist in the investigation of the tragedy and recommend measures to augment safety in the chemical industry. This major accident also had its effects on safety at the NCL.

A new safety committee with wider scope and greater authority than in the past was constituted with V. Ranade as the first chairman. Other members were selected from the different divisions and were also placed in charge of the safety of their respective divisions. The committee took a keen interest in the activities of the safety unit and the individual members took personal initiatives in bringing about safety awareness. A laboratory safety manual was brought out and distributed to the scientists. A new format, much more elaborate and meaningful than the earlier one, was created to record all the major and minor accidents in the lab.

Several more improvements were introduced from around 1997, when G. S. Grover was appointed in charge of the safety unit. It was the constant endeavor of this unit to increase safety consciousness and improve safety-related working conditions in the laboratory. The response from the staff appears to have been quite encouraging and supportive, with many of them coming forward with suggestions. The laboratory management responded to this situation very positively and suitable renovations were carried out. This was indeed necessary since the older laboratories were conspicuous by the almost total absence of safety considerations both in basic design and additional features. The annual budget for the safety unit was raised from a paltry Rs. 5000 to Rs. 25 lakhs, a phenomenal 500-fold increase.

The upgraded facilities included items that would be considered normal in any modern laboratory, like installation of gas leak detectors and good quality fume hoods, better flooring, modern work benches, etc. Handling of compressed gases in cylinders, which was being done casually, was also taken up on a priority basis for improvement. Gas cylinder trolleys were procured and it was made mandatory to use these with the cylinders securely chained to them.

How far the laboratory had come in the management of safety would be clear from the following incident. Carbon monoxide gas was required for the carbonylation reactions being conducted in the lab. As it could not be readily procured from outside, not an unusual situation in India for many chemicals, including gases, it had to be produced in the laboratory and compressed in cylinders (see Chapter 10), section on the Fine Chemicals Project established for preparing needed chemicals that could not be procured from outside. This was of course done in an open laboratory, after taking all the necessary precautions, including wearing positive air flow masks. Complete safety drills were carried out, in the event of any mishap. For the detection of trace amounts of CO, a kit was developed at the NCL and used. These may seem routine and even trite, but in the NCL, this was a significant development. Even with these improvements, the NCL's safety was not impressive, as commented on by an American professor who was on a brief visit to the laboratory: 'LK, your NCL is a great place with some outstanding research going on there, but when it comes to safety, it's decades behind.'

Over time, new strategies were continually introduced to increase safety awareness. For instance, every year, on the occasion of safety day, a few NCL scientists would be invited to deliver lectures narrating their experiences and advocating safe practices. This particular practice proved to be highly beneficial as the incidents narrated could be related to ones own work.

Scientists were encouraged to recycle solvents and recover as much of them as possible. This not only reduced expenditure but also the burden on waste solvent management. Moreover, the staff was systematically advised to collect waste solvents in appropriately labeled cans for suitable disposal, rather than pouring them down the drain. There is perhaps an element of naiveté in relating this simple procedure, as well as others, as significant safety measures. The following practice of earlier years should dispel any such conclusion. A large portion of land at the back of the laboratory was set aside as a dumping ground for tins, cans, empty bottles, etc. But many scientists found other uses for it. For instance, they would carry, or ask their peons to carry bottles filled with unwanted chemicals and throw them in the dump yard. They dumped cap, container and content alike without a care. When admonished, their constant refrain was: 'Why don't you improve the labs first before coming to the dump yard?' While there was no merit in this defense, they made a significant point. I recall pleading with the Chief of Planning at the CSIR to grant funds for modernizing the labs. Their constant response was that they would consider my request if it was directed towards a more important scientific item.

Fortunately, things changed in the free market era when directors had to earn most of their keep and with it they earned the right to use it according to their priorities. Ratnasamy and Sivaram made excellent use of this newfound financial freedom, resulting in the 500-fold rise in expenditure on safety mentioned before.

MAJOR EXPLOSIONS, FIRES

In addition to the two accidents mentioned previously, several recorded and unrecorded accidents (explosions and fires) occurred over the years. Considering the laxity in safety till recently, the number of accidents was surprisingly small. Three major accidents occurred:

- Sometime in 1976, a scientist succumbed to injuries after a minor explosion and inhalation of toxic fumes. The press, which was not friendly to Tilak (neither to me for that matter), played it up to expose the inadequacies of NCL's management in so many ways and chipped in with juicy descriptions.
- In August 1990, while a high pressure reaction was being carried out, a gas cylinder exploded and a scientist died as a result of burn injuries. The press did report this fatal accident but this time, the imagination did not run amok.
- A major fire occurred in January 2002 when an organic laboratory caught fire on a weekend evening. But, thanks to the much better preparedness of the laboratory and the efficiency of the Pune fire department, the fire was brought under control within two hours. There was no injury to anyone.

NEW SAFETY MEASURES

Historically speaking, there never were any formal guidelines, alert bulletins, documented procedures, or mandatory requirements following international practices on safety at the NCL. It was not until 2002, after over half a century of the laboratory's inauguration, that the first stumbling steps in this direction were taken. One reason for such late introduction of normal safety practices can be traced to the fact that no earlier director was ever exposed to the stringent safety requirements of a modern chemical factory. It is unfortunate that, although all of them had worked in Western laboratories, they did not attempt to import the safety practices of those laboratories to the NCL. Sivaram broke through this strange safety inertia, as I would call it, introduced a new outlook, and made many safety procedures mandatory. This was probably because of his experience at the IPCL, which was one of the most safety conscious companies in the country. As mentioned before, another, perhaps the most important, reason was that any attempt to do so by the previous directors met with a blank financial wall which the CSIR never helped to scale.

The safety committee became proactive and even started issuing alert bulletins on various aspects of the use of hazardous chemicals. Some highlights of the activities and achievements of the safety unit are given below, if only to record the extent to which the NCL had become safety conscious and to provide a historical perspective to safety in the laboratory.

- The safety committee was declared a statutory body. The commitment to safety was further emphasized when the director himself was made the statutory chairman.
- A safety home page was uploaded on the NCL intranet, which provided information and links for MSDS fire safety manual, NCL manual, toxicological data on chemicals, safety related films, alert messages, and much more.
- All accidents were duly recorded and investigated.
- Fire detection and alarm systems were installed in certain sensitive areas of the laboratory.
- Gas leak detection systems were installed in many laboratories.
- Safety practices and SOPs for many unit operations including autoclave operations were enforced.
- Regular training was imparted to staff on the use of portable fire extinguishing systems installed in various parts of the lab.
- Bulletins were regularly issued alerting the staff to news and incidents occurring elsewhere.
- Restrictions were imposed on the use, storage, procurement and disposal of 30 chemicals that have been classified as known carcinogens to humans by agencies like OSHA (Occupational Safety and Health Administration), NTP (National Toxicology Program) and IARC (International Agency for Research on Cancer).
- The use of benzene and mercury was prohibited.
- Safety inspections were carried out on a regular basis.
- Guidelines were issued for late working in the labs for scientists, research students, and temporary staff.
- An ambulance was placed on call in case of an emergency.

It will be noted from the actions taken that many of them were in keeping with practices in modern laboratories in the USA or Europe. Certain features were, however, peculiar to the NCL and perhaps to Indian laboratories in general, for example: provision of an institutional ambulance, practical training to scientists to deal with an emergency (only the professionals of the safety unit are authorized to handle any emergency situation in the Western laboratories), guidelines for working late in the laboratories (no such guidelines exist in Western labs, probably because the safety unit is equally accessible at all times of the day, which is not true of the NCL or perhaps of any other laboratory in India), periodic issues of safety bulletins, etc.

A very important and effective feature of safety in Western labs, for instance in the USA, is that there are consequences for violations of safety norms. What more punitive consequence than the curtailment of funds! Major funding agencies such as the Department of Energy and the Environmental Protection Agency send out strong teams for safety inspection and, based on their reports, the extent of fund curtailment is determined. Repeated violations may have even more serious consequences, such as blacklisting the concerned department for a specified period. Funding agencies in India do not have any such mechanism. The CSIR, which has five chemistry-based laboratories under its jurisdiction including the NCL, has no central mechanism for inspecting or overseeing safety in its laboratories.

Workshop

There would be no pilot plants and no special metal fabrications in the NCL without the workshop. Outside fabrications alone could never have fully sustained a lab like the NCL.

A workshop for creating a variety of equipment including pilot plants, for the installation and maintenance of equipment, and for assisting the civil engineering section in residential colony maintenance was an integral part of the NCL right from its inception. The first head of the workshop was R. V. Kulkarni, who was assisted by a foreman K. B. Kaushal. According to K. Venkataraman (KV), Kulkarni was one of Finch's great discoveries. The workshop was located in the basement of the main building and occupied a floor area of approximately 7500 sq. ft. Finch initiated action to expand the workshop and a separate satellite building came up in KV's regime, with a total floor area of over 15,000 sq. ft. While the head of the workshop was in charge of running it, ever since the days of KV the overall management of the workshop was in the hands of an engineering services committee headed by a senior scientist.

The workshop started out with the usual machines and tools, with no significant additions for a number of years. Its management too was quite prosaic with no innovative concepts. There was an element of hostility between a few dissatisfied mechanics and the management, primarily Kulkarni. The main reason was the rather unjustified claims of those mechanics for promotion. They organized protest meetings and go-slow strikes but Kulkarni stood firm and the directors (both Tilak and LKD) supported him fully. Realizing the futility of their attempts, the strikes and protest meetings ceased. As this agitation prone batch of mechanics retired and younger ones replaced them, the atmosphere improved and there were hardly any protests or strikes since the mid-1980s.

The chairmanship of the engineering services committee was usually changed every two years. Among the longest serving chairmen were G. R. Venkitakrishnan, V. P. Fernandez, P. G. Sharma, S. Devotta, and P. V. Rao. Fernandez was a mild-mannered gentleman whom I had named for this position. He did not interfere with the running of the workshop and the task of running it was left entirely to the workshop superintendent. Things changed dramatically when he was replaced by P. G. Sharma. Sharma was more than a chairman. He was quite the opposite: he actually ran the workshop. This had its merits as he was strong on discipline and enforced it firmly. On the other hand, as he had no prior exposure to engineering, he got into trouble with the scientists of the laboratory and the foremen of the workshop. On the whole, he was a successful chairman since he brought in what the workshop needed badly at that time: discipline.

The history of the workshop can be divided into three periods: the period prior to 1990, 1990–2000, and that beyond 2000. The first period was staid, the second was marked by the beginnings of modernization, and the third saw a leap into the computer age.

PERIOD 1950 TO 1990

The first 30 years of the workshop up to 1980 were eventless but there were some changes in the decade of the 1980s. There were four sections in the workshop and these have essentially remained the same over the decades:

- Machine shop, which included various machines such as lathes, milling machines, shaping machines, drilling machines, grinding machines, welding transformers, gas welding sets, fitting and fabrication machines, etc.
- The Plumbing section, which was responsible for new jobs as well as maintenance related to piping of gas, water, air and vacuum.
- The Carpentry and refrigeration/air conditioning section.
- The Electrical section, which was responsible for new jobs and maintenance of laboratory and colony, as well as the telephone exchange.

Jobs were requisitioned through job cards. Each job card went through several steps before the job was finally assigned to a mechanic. The costing was done in four parts: material cost, material overheads, labor cost, and labor overheads. It is interesting to recall the figures used at that time: the labor rate was Rs.18.11/hr, the material overheads were calculated as 10% of the cost of raw material, and the labor overheads were calculated as 118% of the labor cost.

THE PERIOD 1990 TO 2000

This was the period when computers were introduced in a significant way in the NCL. The workshop too was a beneficiary of this new trend, and the old job card system was changed from physical registers to databases. The system was designed in dBASE III/Foxbase and was inspired by the National Aeronautical Laboratory, Bangalore. The system's back end contained three major database files: job card register, time booking, and materials. The format of the job card was changed and the new format was called the work slip. The supervisor had only to feed the data in the above three databases through a user friendly program developed in-house.

THE PERIOD 2000 AND BEYOND

With the surge in IT in the country, new facilities like internet and intranet were introduced in the NCL (see Chapter 5) and every scientist had his/her own PC connected to the central intranet from where almost every item of information could be accessed, and PC to PC communication all over the NCL became a routine practice. Engineering requisitions could be made online and the status of a job found at any time. The computer system for all this was developed in ASP, Java and Oracle using Win 98/2000/NT.

MODERNIZATION OF FACILITIES AND MAJOR JOBS DONE

Till around 1990, there were no substantial additions to the machines and tools with which the workshop started in the early 1950s. Then following the onset of globalization in the NCL, about a dozen new machines and new infrastructural facilities were purchased.

The addition of these modern facilities, along with the computerization of the workshop did much to lift the laboratory's general infrastructure to a level commensurate with the laboratory's standing as one of India's top centers of research.

Over the years the workshop has completed, or helped in completing, several major jobs in the laboratory. Among these may be mentioned: tissue culture laboratory, a new building with all facilities like bio-clean rooms, AC, telephones, etc.; ethylene oxide pilot plant; silicon pilot plant, fermentor; membrane cast machine; repairing of NMR probe; renovation of laboratory furniture, steel and concrete fume hoods; and assistance in construction of the DIRC building.

Glass Blowing

Glass blowing is at once an art and a science. It can fashion things of singular beauty and delicacy, or blow and assemble the most intricate apparatus for the chemist.

Glassware is central to laboratory research in chemistry. It is therefore surprising that the NCL did not start out with a full-fledged glass blowing section like the workshop. All glass apparatus required for research was imported, leading to long periods of waiting for the simplest of items and enormous expenditure. Further, some of the imported items needed to be modified or repaired. To take care of some of these requirements, one of the scientists of the Physical Chemistry Division, Lakhbir Singh, who was known for the dexterity of his hands and who practiced glass blowing as a side-interest, agreed to help out. In fact, it was around that time in 1950–1 that glass blowing made its informal beginning as a one-man activity in the Physical Chemistry Division, with Lakhbir Singh helping out with some of these jobs based on his personal equation with the scientists and the technical novelty of the job. Soon he was joined by an enthusiastic, unpaid apprentice, Niranjan Singh, who exhibited great potential as a glass blower. Under the able tutelage of Lakhbir Singh, he developed his skills remarkably well and would soon become one of the finest glass blowers the NCL had had.

It was at this stage, in 1953, that the NCL finally thought of having a separate Glass Blowing Section. As was to be expected, this was started with Lakhbir Singh, a scientist, in charge of the section, in an area of approximately 150 sq. ft. feet in the Physical Chemistry Division (in a large room adjacent to the director's office), with Niranjan Singh as the sole official glass blower, and one burner as its sole asset! The strength soon increased to three glass blowers. The new entrants were recruited from a training center for glass blowing started in 1958 by the Maharashtra Small Scale Industries in the Agricultural College Campus in Pune. This training center was closed in 1984 and there has not been another in Maharashtra since. In fact, glass blowing as a trade has not been taught in any other institution or college.

Through internal training and recruitment from other laboratories, the staff was increased to 21 by 1990. During this expansion, the section was moved to a location opposite the stores in the basement (before the stores was moved to a separate building) and continued there till in 1968, it was again moved, this time to a separate building with a floor area of 5,000 sq. ft. and with reasonably modern facilities.

The competence of the Glass Blowing Section grew steadily till it reached a stage when it could make high vacuum connections, including the setting up of a full BET unit. The section has been a source of tremendous help to NCL scientists. From manual job-card oriented, almost personalized methods of processing jobs, it moved to full computerization of its facilities in the 1990s. This enabled the scientists to track the progress of work and of expenditure.

The NCL earns considerable revenue through sponsored projects, and the Glass Blowing Section is self-sufficient in generating external cash flow. Over the years the section developed expertise in fabricating highly specialized apparatus. Some of the major fabrications of 1960s and 70s have been preserved for display.

Among the items fabricated were: condensers, reactors of complex design, heating coils, flasks of various sizes (including 4-neck flasks), flanges, heating mantels, different types of joints (male and female), and all sizes of stopcocks. One will not fail to notice that some of these items are almost ridiculously common and could be readily purchased. This observation captures in a nutshell the story of the NCL's evolution. Even the simplest of items had to be locally fabricated for they were largely unavailable in India and had to be purchased from abroad at a heavy cost, both in money and time. This is no longer true, leaving the Glass Blowing Section free to fabricate specially designed items.

Students who have passed the SSC (Secondary School Certificate) examination are engaged as trade apprentices for a period of two years and receive excellent training from the NCL's skilled staff in almost all aspects of scientific glass blowing. As and when vacancies arise within the laboratory they get absorbed, or they become strong contenders for outside jobs as a result of their training at the NCL.

The NCL's Glass Blowing Section was renowned for its skill and, along with NPL and a couple of other laboratories, was quite unique in the country. With time, several other institutions also acquired similar skills and the NCL unit is perhaps no longer unique, although still among the best. H. P. Chakraborty and. R. K. Choudhary, former heads of the Glass Blowing Section, received the Best Glass Blower award of the All-India Glass Blowers' Association.

Instrumentation

> *Delicacy was the key word. Not a whisper of disturbance could be allowed into the room containing the apparatus, so Cavendish took up a position in an adjoining room and made his observations with a telescope aimed through a peephole. The work was incredibly exacting and involved seventeen delicate, interconnected measurements, which together took nearly a year to complete. When at last he had finished his calculations, Cavendish announced that the earth weighed a little over 13,000,000,000,000,000,000,000 pounds, or six billion trillion metric tons.*
>
> Bill Bryson, 2003

This was back in 1797. The value has hardly been improved upon in the two centuries that followed. Though self-evident in today's instrument intensive research, I cite in the footnote below a few early instances of great originality in accurate measurement in scientific research — and politics.[2]

A small Instrumentation Group was set up in the mid-1950s by Finch as an extension of the Physical Chemistry Division. It was essentially a one-man show operated by A. U. Momin (see Chapter 5). It was then established in the early 1960s as a full-fledged facility by KV, with the principal objective of providing in-house expertise in the maintenance, repair and upgrading of a wide range of sophisticated analytical instruments and also to develop new experimental setups and prototypes as and when needed.

It has successfully developed a variety of analytical instruments and transferred technologies to the industry for regular production. The first instrument developed was a gas chromatograph and the technology was transferred to the AIMIL Group. The advent of microprocessors in the mid-80s gave a new dimension to the design of analytical instruments and their automation. Using microprocessor-based instrumentation, a double beam infra red spectrophotometer was developed with financial support from the DST. The instrument was inaugurated in May 1987 by V. R. Gowarikar, Secretary, DST. This technology was transferred to the Electronic Corporation of India Ltd., Hyderabad. PC-based instrumentation, embedded instrumentation and now virtual instrumentation using LabVIEW platform have opened up new avenues for instrument development and automation and have strengthened computing power. The Instrumentation Group remained up-to-date in the implementation of these new technologies at the NCL.

Temperature rising elution fractionation units, V probes, on-line PC-based gas-liquid flow characterization systems, state vector machines (SVMs) using MATLAB, LabVIEW-based non-linear process monitoring systems, microcontroller-based leaf area computers, and microprocessor-based fraction collector were among the more notable developments completed for chemical engineers, polymer engineers and other scientists. A Brewster Angle Microscope (BAM) along with Langmuir trough was developed and automated using LabVIEW. This instrument has opened up new dimensions in image based applications in nanotechnology.

The research and development activities mentioned above explore only one side of the coin. On the other side, the Instrumentation Group always had the responsibility of maintaining the lab's sophisticated analytical instruments. To provide an indication of how far this group has come since its modest beginnings in the early 1950s, when it started its activities by constructing the NCL's first indigenous unit, a gas chromatograph (largely by reverse engineering), some major activities are listed below.

The NCL has a wide range of sophisticated state-of-the-art machines like IR and UV visible spectrometers, FTIR, LC-MS, single crystal X-ray diffractometer-SMART APEX-latest generation CCD diffractometer, powder X-ray diffractometer, transmission electron microscope with powerful CCD attachment, ESCA, hi-shear capillary rheometer, parallel plate constant stress rheometer, tensile stress/strain tester which extends assistance to many research institutions, universities and industries for characterization of materials and studies in rheology and processing. Some machines were upgraded or modified with current technology tools to cope with the requirements of the end user.

During the year 1999–2000, the NCL established a new resource center, the Central NMR Facility consisting of three superconducting magnet NMR spectrometers with 11.7 Tesla-500 MHz field frequency, 7 Tesla-300 MHz filed frequency and 4.7 Tesla — 200 MHz filed frequency. The facility is also equipped with other dedicated accessories such as CP-MAS, HR-MAS high temperature and triple resonance high speed MAS probe heads, AMT high power amplifiers, micro-imaging, probe-tuning and testing setup, silicon graphics work stations and dedicated data processing software. The mission of the facility (described in Chapter 5) is to innovate and employ modern NMR spectroscopic methods, to explore new avenues in methodology for liquids and solids, to apply NMR in a multi-nuclear, multi-dimensional context, to innovate and develop new structure characterization tools for material applications, to act as an in-house resource center, and to pursue activities towards advancement of fundamental knowledge in magnetic resonance. The full instrumental capabilities offered by the modern front-ends on these spectrometers help the facility to implement a variety of experimental methods in diverse areas.

During the year 2002–3, the NCL established another resource center, the Combinatorial Chemistry Bio Research Center, equipped with state-of-the-art technology, which facilitates the rapid synthesis of organic molecules with a wide range of structural diversity. This is indeed a powerful facility, particularly when coupled with the natural product libraries and high throughput screening system, an HT evaporation system, an accelerated solvent extractor, a SEPBOX for HPLC and SPE, a parallel synthesizer, and isothermal titration calorimeter, a highly automated array spotter, and a high resolution array scanner.

Starting from August 1, 2005, the Instrumentation Group was allotted the responsibility for voice communication at the NCL. The new communication system, Alcatel Omni PCX Enterprise, is a modular, latest Server Gateway technology globally available in the telecom market. The backbone of this communication system will be used for video-conferencing at the NCL in the near future.

The Instrumentation Group is also deeply involved in academic activities and played a major role in the latest International Conference on Instrumentation and Control (INCON-04) held at Pune during December 19–21, 2004.

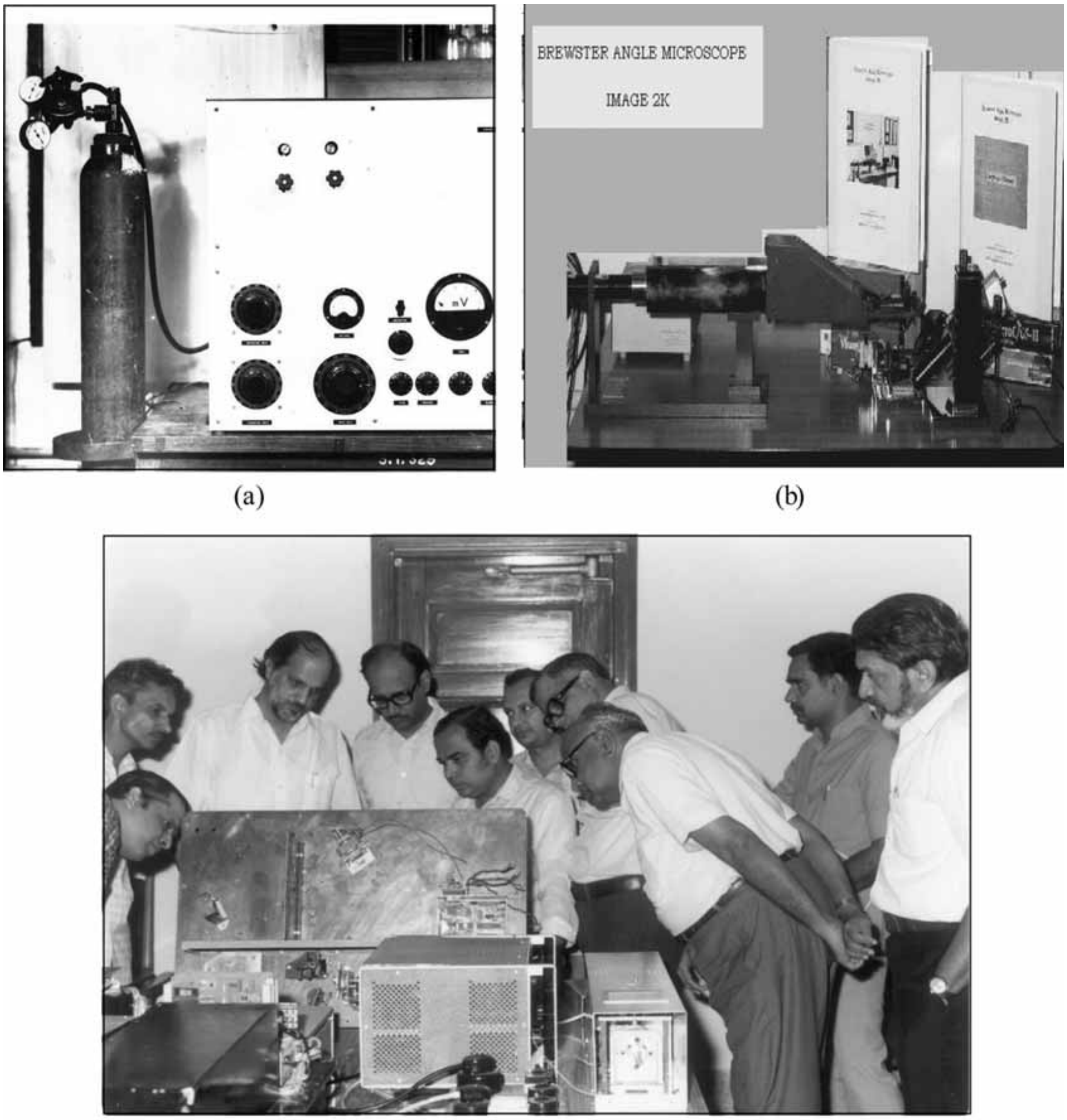
A large number of instrument scientists and technologists have helped in the evolution of this group. In particular I would like to mention A. U. Momin, who gave a sound start, and S. D. Bakare. My special thanks are due to Neelima Iyer for giving me a first hand account of the instrumentation group as it evolved over the years.

The instrumentation section has come a long way indeed, from its one-man beginning in the early 1950s to the sophisticated group it has now become. When the first GC unit, a rather simple unsophisticated instrument, was fabricated, it was considered to be a great accomplishment worthy of announcement in the presence of a distinguished gathering presided over by Vasant Gowarikar, Secretary to the Department of Science and Technology. But today, much more sophisticated units are fabricated, and state-of-the-art units are repaired, as a matter of routine. This glaring evolutionary contrast is brought out in Figure 14.1.

Miscellany Or Orientation?

Miscellany is perhaps not the best word to describe this chapter, for it implies a status less than the primary. In a way it is also true, for it exists because of the needs of the primary. On the other hand, it is indispensable, and no primary can exist without it. Any person joining the NCL must first be oriented so that he/she knows where to go to get

Figure 14.1: Instrumentation at the NCL, "then" and "now": (a) the first unit, a gas chromatograph (GC), constructed at the NCL around 1964 and commercialized by AIMIL, (b) a modern unit Brewster Angle Microscope fabricated more recently, and (c) the success of the GC unit being publicized as a major achievement at a gathering presided over by Vasant Gowarikar, Secretary to the Department of Science and Technology, Government of India



(a) (b)

(c)

things done. The universities and some major companies call it orientation. Somehow, this word has never entered the CSIR lexicon. One major reason is perhaps the restriction of its application to the initial stages of an entrant's career in an institution. There is something more lasting about miscellany. I would like to emphasize its central role in getting things done within the framework of rules at the NCL (as in any other institution with similar broad objectives). On the other hand, there is something Eastern and revealing about orientation as against miscellany, which implies an assortment of disconnected but essential events/entities:

> *As you know, orientation is a compass word — orient means the East, from "oriri," to rise; and the word suggests that you'll be lost in space, disoriented, until you learn the coordinates for charting your way.*
>
> Richard Brodhead
> President, Duke University, 2007[3]

Notwithstanding this powerful prod in favor of orientation, I adhere to the less student friendly term miscellaneous, if only to conform to practice and in deference to the fact that the NCL is not a university (see Chapter 18 which throws more light on this).

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15

NON-TECHNICAL MISCELLANY

A CITY WITHIN A CITY — A DISAPPEARING FACILITY

Independence had come to India. Its first Prime Minister, Jawaharlal Nehru, was faced with a difficult decision. Should it be left to the private sector to move the country forward, or should the government have a hand — a large hand, if needed — in adding haste and urgency to the process. He decided on the latter course, not by introducing socialism but by working towards a *socialistic pattern of society*. Thus was born the concept of government sponsored (or public-sector) undertakings in remote areas with practically no amenities for meeting even the basic needs of everyday life, and held sway till around 1990. The very nature of these areas would militate against professionals from various walks of life and tradesmen coming to join these enterprises. This drove the government to create "complete" units including housing, medical, recreational, and other facilities. This was true even for fairly well developed areas like Pune, where the NCL was to be located, since location would usually be in the outskirts of the city. In such cases "a city within a city" had to be developed — which explains the rationale of this chapter. The NCL colony experienced all the phases of evolution: the beginning, growth, stagnation, decline, and the fresh air of interest blowing again. This is because the eye for detail, for aesthetics, and for the shopping and recreational needs of the residents was not the same for all the eight men who have directed the affairs of the NCL so far.

As the NCL grew, and with it the residential colony (as it was called), so did the social and shopping needs of the residents living as they were in the outskirts of Pune. Starting from McBain who actively encouraged the formation of an NCL Cooperative Society (coop), all subsequent directors have, to different degrees, helped in making the NCL residential colony a thriving society with all major amenities available within the extended campus area. Many senior scientists, like P. G. Sharma, V. Jagannathan, P. N. Rangachari, B. V. Ramachandaran, J. P. Pandey (who was killed in a motorcycle accident within the NCL gates), A. P. B. Sinha, I. D. P. Srivastava, and several others, played active roles in making this possible. With the emergence of the free market era around 1990, the shopping and all other facilities for normal life were extended to once outskirt areas like the villages of Pashan and Aundh. This did not actually ring the death knell for the campus facilities but certainly reduced their importance. The need for self-sufficiency had peaked and a downward trend was ominously visible. It is likely that in the not too distant future most of the campus facilities will become things of the past, a memory in the minds of the old, a curiosity in those of the new. As did the coop, which, almost like a pre-ordained symbol of free market's influence, had faded away quietly. Of course some amenities will always remain, like the NCL school, the medical center, the horticultural section, the children's park, probably the shopping center, and a few more. I will speedily describe many of these as they evolved over the years, with greater emphasis on the more important ones. From the point of view of projecting an image of the laboratory as a whole to guests and other invitees, the image that persists is the first one — at entry. This is best provided by an elegant and efficiently run guest house as a foretaste of what is to follow. The NCL is also an educational institution in that research leading to Ph.D. from various universities is an intrinsic part of its programs. The consequent need for elegant student housing was thus always an urgent issue that became even more urgent in later years, but was addressed only in the 1990s by Ratnasamy. I begin this chapter with the guest house followed by student housing and other amenities, in no particular order.

Guest House

We dare not trust our wit for making our house pleasant to our friend, so we buy ice cream.
Ralph Waldo Emerson, 1803–82

Guest houses are a common feature of many countries in Europe and the British Commonwealth, less so in the USA. The guest house at the NCL began as an extension of the staff hostel, which came up simultaneously with the main lab. It served its basic purpose of providing a place to stay for the NCL's guests, nothing more. If at all it projected an image of the laboratory, it was certainly not a flattering one. Then, in 1984, there was a dramatic change. The first major international conference was organized by Doraiswamy. It was called the International Chemical Reaction Engineering Conference (ICREC) and almost every noted reaction engineer from all over the world was slated to attend. LKD wanted a new guest house to house the special invitees.[1] Thanks to the efforts of the then AO, M. M. Sharma, and the civil engineer, D. H. Kannal, a brand new construction came up within a year with lawns, a rose garden, two special VIP suites and a tastefully designed dining hall. The road leading from the main Pashan Road to the building was similar to the road from the NCL's main gate to the laboratory, with trees and landscaping on both sides. As intended, it did serve as a window to the laboratory and attracted very laudatory comments from the ICREC participants. A photograph of the guest house in 2001 is shown in Figure 15.1.

For almost two decades after its construction, no special attention was paid to the guest house, but around 2004, Sivaram had many rooms revamped, Internet facilities installed, and the old (original) dining room was remodeled into a conference hall.

THE MUMBAI GUEST HOUSE THAT WAS NOT TO BE!

Almost there, but not quite — as we shall see! In view of the large number of overseas visitors to the NCL, there arose a need to have a second NCL guest house at Mumbai. Negotiations were complete for buying an excellent apartment in a nice neighborhood, and Director-General G. H. Sidhu's approval was also obtained to buy and run the guest house. The day arrived when papers had to be signed and the Administrative Officer

Figure 15.1: The NCL guest house

M. M. Sharma was deputed to close the deal. Just then, there was a call from the CSIR informing me that the new Director-General, S. Varadarajan, who had just taken over as DG (after I had declined the offer), had decided that this guest house should be run by the CSIR and not the NCL. The entire matter would be taken over by the CSIR and the NCL would have no further role to play. Within days, the CSIR went ahead with the purchase and handed over its running to another CSIR laboratory, thus ensuring total termination of any NCL connection.

Golden Jubilee Hostel

There was a hostel of sorts (for staff and students) constructed soon after the laboratory's inception, and then another, but a relatively modern hostel exclusively for students came much later, as India ushered in the globalization era.

The student population had grown from less than 20 at start to over 400 in 2006. Many students were accommodated in the first hostel that came up along with the main lab. It was meant only for the regular staff but students were also accommodated there. Realizing the need for more extensive accommodation for students, LKD had a second hostel constructed. Unfortunately, he did not take any personal interest in this construction and left it entirely to the CSIR engineers. They went in for the lowest quotation and ended up with a well-designed but shabbily constructed building. This was in keeping with the CSIR rules of those days which provided only for the cheapest kind of construction materials and fittings. If LKD had taken the same amount of interest as for the guest house, it might have been a different story. I mention this to emphasize the point that the personal involvement of an institutional head has always been a key factor in India. This was more forcefully emphasized in the quality of construction of the new DIRC (Digital Information Resource Center) building in which the Director-General, Mashelkar, took personal interest by authorizing the use of the most modern and highest quality materials, and Director Sivaram followed it up enthusiastically.

In the latter half of the 1990s, Ratnasamy addressed afresh the question of student housing and allocated well over Rs. 1 crore for the construction of a new hostel to mark the occasion of the NCL's Golden Jubilee. The result was a first-rate NCL Golden Jubilee Student Hostel. This was a splendid addition to the NCL that also enhanced it's potential to attract high quality students. A photograph of the hostel appears in Figure 15.2.

Appropriately, Ratnasamy (with characteristic originality) invited not a local leader or a Delhi politician but A.V. Rama Rao to inaugurate the hostel. Rama Rao had begun his career at the NCL as a junior research fellow by living in the first hostel, rose to be head of the Organic Chemistry (Natural Products) Division, and then moved on to the IICT as director.

Figure 15.2: The NCL Golden Jubilee student hostel

Medical Services

Good health is not just the most valuable treasure of life. It also makes for healthy mind, balanced behavior, and overall wellness — all assets to good work and the pursuit of science.

Thomas Jefferson, 1743–1826

The NCL medical center has undergone periodic changes in name, consistent with its evolving scope and importance: from first-aid room to NCL dispensary to NCL medical center. Thus today, the center, housed in a separate building and excellently managed, is fully equipped and staffed to maintain complete medical records of all the NCL employees, attends to annual immunizations and other medical needs consistent with the availability of excellent hospitals and nursing homes in Pune where patients can be referred as needed. It has the ability to treat a large number of medical conditions, and outside referrals were less than 10% in 2007. The government's medical rules allow the staff to seek medical help directly from outside hospitals and experts, if they wish to.

The need for a small medical unit was felt as far back as in the early 1950s soon after the NCL was inaugurated in the January of that year. To start with, two part-time doctors were appointed and they were soon replaced by M. K. Joshi, a full-time doctor, in mid-1953. When I first joined the NCL in 1954, I heard some interesting tales about one of the part-time doctors.[2] When Joshi joined, he needed help, so a pharmacist was recruited in late 1953. Soon thereafter a nurse was also appointed. No account of the NCL's medical services will be complete without reference to a local Pune physician, K. S. Rao, who enjoyed the full confidence of the NCL staff, many of whom continued to seek his services almost till 1990, albeit in decreasing measure. A good doctor by all accounts, his talents as a card player and a social figure vied with demands on him as a physician. More than anything else, he was a very likeable and friendly soul, who visited the NCL more to see friends than to treat patients.

Medical help in real form started when M. L. Ram succeeded Joshi in 1962. As he had worked in a pathology department, he initiated a pathology laboratory for routine investigations. The staff strength soon went up to six, Ram still being the only medical doctor. As the size of the NCL increased, especially the number of women, a lady physician, A. V. Agashe, was appointed in 1973, with one more pharmacist added in 1971.

The dispensary, as it was still called, was earlier located in the main building in the west wing, near the entrance. As the space was limited, extending the dispensary within the laboratory was not possible. Also, the to-and-fro movement of staff families disturbed the working of the laboratory and created security problems. So a new building was constructed in the campus about 200 meters from the main gate in 1975, to which a small extension of two rooms was added in 1991. It was then renamed as the NCL medical center. As of this writing, the center had a staff of 12 permanent employees.

UPGRADING THE FACILITIES

New facilities were added from time to time, particularly after 1990 when, thanks to the free market economy, the laboratory earnings increased several fold and considerable discretion was given to the director in spending these. After over 40 years of its existence, the center was provided with facilities in 1994 to maintain files and card indexes for all permanent NCL employees (1800 in all). The pathology section was considerably modernized, and soon all the data including pathology reports were computerized. The number of pathological investigations carried out in 2004 was about 4000, a remarkable rise compared to earlier years. Over a 100 medicines were readily available at the center, which were dispensed to over 35,000 patients per year. The annual expenditure on medicines dispensed from the medical center went up from Rs. 1,242 in 1983–4 to Rs. 10.3 lakhs in 2004–5 (no figures were available for earlier years). This does not include medical reimbursements and medicines supplied from outside or the hospital bills for regular employees and pensioners. In 2004–5 medicines worth Rs. 60.3 lakhs were supplied to NCL pensioners. The figure today stands at Rs. 1 crore and twenty-five lakhs.

SOME SALIENT FEATURES OF THE MEDICAL CENTER

A number of features were introduced over time, such as: home visits and emergency treatments after working hours; availability of doctors during hazardous experiments; first-aid treatment to visitors and guests; periodic reviews of the incidence of DM and HT and correlation between the two (there was a 4-fold increase from 1994 to 2004 in both these disorders, and an increase in one was accompanied by an increase in the other); entry level medical check-up for certain categories of staff and setting up of a Medical Board for higher categories; setting up of annual voluntary blood donation camps; arranging pulse polio programs as and when announced by the government; arranging special camps for eye check-ups, dental check-ups, and diabetic neuropathy; organizing lectures by experts; arranging for NCL doctors to attend Continuing Medical Education Programs; and extension of full facilities to NCL pensioners and their dependents.

The NCL medical center distinguished itself by winning trophies for best support group out of a total of 15 in the NCL (as voted by the scientists) for three consecutive years from 1996 to 1999. It was very thoughtful of the center to withdraw from the competition for the fourth year to give the others a chance, as Agashe, the head of the center, told me with justifiable pride and probably a smile that was continents beyond my sight, as the sentiment was conveyed electronically and not in a face-to-face discussion.

Over the years, excellent medical facilities were developed in Pune. Even so, the medical center has continued to remain fully relevant as the first responder to any call for medical attention.

Horticultural Section

Bread feeds the body, but flowers [and plants and general greenery] *feed the soul.*

Anon.

The main laboratory of the NCL complex always had aesthetically designed and beautifully landscaped lawns and gardens around it. That was largely because they were made part of the construction from the beginning and were appropriately budgeted for.

On the other hand, the ancillary buildings such as the pilot plant buildings, cafeteria, guest house, hostels, etc., which came up at various times after the main building, did not enjoy the same privilege. CSIR had quickly realized the need for constraint (the error of its ways!) and the directors, in turn, were more eager to have additional functional space than beautifying the environment and excluded from their budgets all expenditure besides that for the functional entity. Thus buildings came up on barren land, often with impediments like ditches all over the approach roads (if any) to clear passage. The NCL was no exception. (One might as well have put up a sign at some distance giving the name of the building followed by the challenge: *Enter if you can!* Or, by the less confrontational *Enter if you must!*) However, thanks to the efforts of some directors, gardens and landscaped lawns soon came up around all constructions. Good approach roads were built. Trees were planted all over the laboratory campus and in the colony to add to the green cover and to act as green lungs to the surrounding areas. A Horticultural Section, headed by a Horticultural Superintendent, was created with full responsibility for the proper maintenance and up-keep of these gardens, lawns, rose garden, and tree plantations. The Civil Engineering Section, created by the CSIR at the outset as part of the larger Engineering Section at the headquarters in Delhi, was increasingly brought under the purview of the NCL administration.

HOW IT EVOLVED

In 1950, when the NCL was inaugurated, it was located on a barren patch of land (Figure 15.3). The transformation of this barren land into pleasing, lush green surroundings, as shown in the same figure (along with two other constructions), was a gradual process.

Many have contributed to this development. One of the most important factors in this change was the interest, support and guidance of all the directors. There have been four Superintendents, M. Krishna Rao (1950–60), M. Puttuswami (1960–70), A. D. Tarakunde who died in harness (1970 –75), A. D. Mane (1975–80), and M. M. Jana (1981–till date). Krishna Rao gave a flying start and although those who followed him maintained the lawn and gardens, it was not till Jana arrived on the scene that a new shape was given to the NCL gardens and several new activities were started.

Figure 15.3: The greening of the NCL

In the early years of the NCL, the laboratory was regarded as being on the outskirts of the city and there were no markets nearby. Most of the staff stayed in the city and commuted to the laboratory. Those who stayed on the campus had to commute to the city, by bicycles or by tongas (horse-driven carts), as public transport buses and autorickshaw's (bicycle-driven carts) did not ply to the NCL for less than 2–3 times the normal fare, to purchase even essential items. Thus the Horticultural Section took upon itself the responsibility of growing vegetables and fruits on a piece of land near the well behind the main building. They were sold at no profit to the staff residing in the colony.

In the 1960s and 70s, the Horticultural Section, apart from maintaining the garden, produced aromatic plants and flowers yielding essential oils for research in the Essential Oils and Natural Products Divisions under S. C. Bhattacharya and Sukh Dev, respectively (see Chapter 8). The section had also started to maintain excellent ornamental plants, which marked the beginning of the NCL as a major presence in Pune (indeed in the state of Maharashtra) for such flowers.

PLANNED DEVELOPMENT

Till the early 1980s, the only organized garden was the one in front of the main building. According to a note from M. M. Jana, the present Horticultural Superintendent,

> *The then director L. K. Doraiswamy took a keen interest in improving the aesthetics of the laboratory surroundings. A committee was constituted under the chairmanship of C. SivaRaman (a garden enthusiast) to plan and develop the estate. The other members of the committee were: B. D. Kochar (who took part in all major extra-curricular activities), M. M. Joglekar (another garden enthusiast), S. C. Srinivasan (civil engineer,) and. M. M. Jana (convener). The horticultural activity was divided into two categories: (1) laboratory campus, and (2) colony.*

Laboratory Campus

The original lawn in front of the main building, garden and the trees was replaced in the 1980s. Serious horticultural development work started under the guidance of the committee just mentioned. Somewhat at the same time, lawns and gardens in front of Pilot Plant Buildings I, II, III (1983) and Polymer Science and Engineering Building (1984) came up. When a new cafeteria was built adjacent to the old one within the NCL complex, and a new guest house was constructed next to the old hostel about a mile away from the main building, plush lawns and gardens sprung up in those areas. The lawn in front of the guest house was particularly attractive and has been the scene of many parties thrown by the NCL under floodlights. A lawn and a rose garden also arose in front of the newly constructed Biochemical Sciences Building in 1985. About a decade later, this was considerably improved and expanded and, in addition, several trees were planted in this nearly tree-less expanse.

It may be noted that, historically, several activities of the Horticultural Section almost naturally acquired a formal character: (1) landscape design and development, (2) collection, propagation and maintenance of foliage plants for indoor arrangements, (3) participation in flower shows, and (4) establishing new varieties of roses and other ornamental plants. The section seemed to show particular interest in growing good varieties of roses, seasonals, orchids, crotons, and other foliage plants through breeding. It also acted as a supporting group to assist plant scientists in their work.

As part of the NCL's continuing interest in growing roses, Jana developed three new varieties of the flower. Two of these were named after Shakuntala Venkataraman and Rajalaxmi Doraiswamy. The *Shakuntala* was developed from the Scarlet Night (H.T.) variety and the *Rajalaxmi* from the Carol variety. Photographs of these roses are shown in Figure 15.4. The black rose *Rajalaxmi* performed well in the field and has been growing nicely since; *Shakuntala* did not fare so well. Jana also standardized rose cultivation practices and popularized them in Pune.

Figure 15.4: New NCL-developed roses Shakuntala and Rajalaxmi

Shakuntala Rajalaxmi

Participation in Rose Shows and NCL Events

From 1981, the NCL garden was a regular participant in the flower shows organized by the Rose Society of Pune and the Pune Women's Council in Pune, and the Indian Rose Federation in many parts of the country. The Indian Rose Federation instituted over two dozen prizes for various varieties of roses, the most important of these being: the King Rose, the Queen Rose, and the Most Fragrant Rose named after Rajalaxmi Doraiswamy (by Jana and Pune's Rose Society). The NCL won first or second prizes for the first two categories, but till 2005 had failed to win the Most Fragrant prize.

Around 1982, the director of the NCL started the practice of giving token cash awards and letters of appreciation to the garden staff and *malis* for winning awards, but it seems to have been discontinued since 1990.

During the period 1950–2008, covering almost the entire period of the NCL's existence till the present time, many events took place at the laboratory, including the Silver and Golden Jubilees and several international conferences. The garden was kept particularly neat on these occasions, with excellent flower arrangements at many locations within the laboratory. During the Golden jubilee celebrations, the Horticultural Section and the Rose Society of Pune jointly organized a Rose Show at the NCL on January 4 and 5, 2000.

This show provided a great attraction for the visitors, the NCL staff, and the dignitaries who participated in the celebrations.

Residential Colony

As mentioned previously in an earlier chapter, 5,000 trees were planted in the early years of the NCL under a national program initiated by Pandit Jawaharlal Nehru. Unfortunately, due to almost complete failure of rains that season, very few plants survived. Then, for over 30 years, no additional trees were planted, till in 1986,a planned forest (or planned jungle, as LKD called it) was developed as part of an overall arboriculture plan for the NCL. A man-made forest and a genetic garden (by the Plant Tissue Culture Group) were also set up during this period. Then, on June 5, 1989, World Environment Day, further trees were planted by Mashelkar who had just taken over from LKD. A. F. Mascarenhas, the Head of the Tissue Culture Group, provided funds for planting tissue culture raised trees. Tissue culture raised Eucalyptus, Teak and Bamboo plants were planted in 1995 near the NCL post office across the street from the lab at the initiative of Mascarenhas.

When Paul Ratnasamy became the Director in 1995, he took keen interest in garden development and tree plantation in the colony. Though the children's park was established in 1986 by LKD, it had deteriorated considerably in the following 10 years. In 2001, much improvement was made to the park by Ratnasamy and was named Nandanvan. This had a 1 km jogging track and many diverse play units for children.

In 2002, extensive tree plantation was organized in *Nandanvan* as part of its formal inauguration at the hands of Ratnasamy.

Besides attending to the garden needs of the NCL, the Horticultural Section also helped several local government and other organizations in planning their gardens (as honorary consultants). Some examples: beautification of the campuses of the University Department (renamed Institute) of Chemical Technology (UICT) in Mumbai, the National Physical Laboratory (NPL) and the Central Forensic Bureau (CFB) in Delhi, the Indian Institute of Tropical Meteorology (IITM), and the Bombay Engineering Group (BEG) in Pune.

THE GREENING TO CONTINUE

As of 2007, the NCL had an extensive green cover comprising lawns over a total area of about 10 acres, gardens over a total area of about 40 acres, a plant nursery of an area about 3 acres, and plantations of forest trees grown over a total area about 35 acres. The Horticultural Section was active in the conservation of rare and endangered species of plants and in the propagation of commercially important and medicinal plants required for research carried out in the laboratory. Specimens of aromatic and other important plants, which were being investigated by the Plant Tissue Culture Group, Plant Molecular Biology Group and the Natural Products Group, were also being grown and maintained in the nursery.

In 2002, at the initiative of Director Sivaram, a major program was initiated: the labeling of all the plants and trees on the campus. This was designed to emphasize the biodiversity of the NCL's flora and to benefit scientists and students who visit the laboratory. Through this and other activities, Sivaram initiated a program of renovation and improvement of the NCL's deteriorating colony infrastructure. Many of these have already been mentioned at the appropriate places.

Although this is not historically relevant, I would like to conclude this section with a brief indication of the ambitious plans for the Horticultural Section as set out by Jana. They are: (1) to establish a collection of medicinal and aromatic plants, plants of commercial/industrial importance that are required for research by NCL scientists and scientists from nearby institutions, (2) to collect and conserve rare and endangered plants from western India using mist chambers, shade houses, and polyhouses, (3) to establish an *orchidarium*, (4) to establish a live plant library, and (5) to improve the irrigation facilities (rain water harvesting and the NCL Golden Jubilee Lake). These plans bring out the importance attached by the NCL to a healthy, green, and flowery environment, and indicate how the laboratory has been building, and will continue to build, on the firm foundations laid in this regard almost at its inception.

NCL Staff Recreation

Facilities for staff recreation were accorded high priority by McBain and most succeeding directors. The initial need for these was quite urgent considering the distance and relative inaccessibility of the laboratory neighborhood. As mentioned in an earlier chapter, McBain was instrumental in establishing the coop. The story of its tremendous success and eventual demise is a story of the NCL's growth and its progressive integration with the rapidly expanding city of Pune.

The two most popular sources of entertainment were the cinema and sports.

CINEMA

A film show at the NCL was an occasion not just to watch a movie but for gossip and bonhomie as well. Films were screened at least once a week in the laboratory's auditorium, and this practice continued for over two decades. As the staff strength grew, the rush to the auditorium acquired an unhealthy aspect — the place would be a literal mess after each show, with some chair seats torn and some soaked in drinks. This prompted Tilak to have a screen fixed in an open area in 1975, but films continued to be shown in the auditorium as well. LKD then had a huge open-air theater constructed in 1985 and banned the showing of films within the laboratory. Grudgingly at first, and enthusiastically later, the staff accepted this change, and the practice is continuing to this day. A recreation center was also constructed by LKD with many amenities, including an open area with trees where parties could be held.

As the strength of the laboratory grew, so did its social and cultural activities. Sports, Reading Room and Library, Drama and Arts came into the fold of the Club which was later renamed the NCL Club and then as the NCL Staff Recreation Club.

NCL SPORTS

It all started in 1949 — along with the NCL itself. The main building was not yet complete. A patch of ground was cleared by the staff members themselves and a football team was organized. The main force behind all this was Har Narain Sharma, who was an outstanding footballer and had represented prestigious teams at the Nationals in his youth. From this humble beginning, the coming years saw a full-fledged Sports Club taking shape under the able guidance of Hari Har Mathur, another able sportsman with a flair for planning and organizing sports activities to the minutest detail. Solid support was provided by stalwarts like S. P. Kaushika, Kartar Singh, B.V. Ramachandran, Lakhbir Singh, P. G. Sharma, P. N. Rangachari, K. K. Chakravarti, C. SivaRaman, M. Goswami and A. S. Gupta.

At the CSIR level, the SSBM (Sir Shanti Swarup Bhatnagar Memorial) tournament is held once in every two years to perpetuate the memory of the first director of Scientific and Industrial Research, Sir Shanti Swarup Bhatnagar. This tournament started some time in 1955 on a triangular basis. A sports meet was arranged between the CSIR Headquarters and the two Delhi-based laboratories — the National Physical Laboratory and Central Road Research Institute. As the popularity of the tournament grew, it was decided to invite the other CSIR laboratories to join in; the NCL and two other laboratories did so in 1957. What had started as a small local event soon assumed all-India proportions.

As B. D. Kochar, the prime initiator of sports and many other extra-curricular activities at the NCL, pointed out to me:

> *The Club Management Committee worked relentlessly to provide its various activities with modern and up-to-date facilities and equipment by setting up a permanent infrastructure with the active support and financial assistance of the NCL authorities. As a result, a cricket ground with a small pavilion, a flood-lit tennis court, an indoor badminton hall, a club house with indoor games facility, an open-air theatre for movie goers, and a large hall for reading room and library were built.*
>
> *With these facilities and infrastructure in place, the club had established itself on a sound footing and contributed significantly to the promotion of sports. Its representatives also ably served on the CSIR Sports Promotion Board and rendered assistance in the conduct of SSBM Tournaments as well as conducting various coaching camps for CSIR players selected on an All-India basis.*
>
> *It gives one nostalgic feelings to remember the grand old days, and I* [B. D. Kochar Ex- PS (personal Secretary) of the Admin. Officer of NCL, who joined NCL in 1950 and retired in 1988] *thought I should share these feelings with you by recapturing glimpses of 2 of our past sports activities.*

He then went on to give an account of two major events, one in cricket that the NCL won, and the other in basketball which it lost. As a President of the CSIR Sports Promotion Board, I had the privilege of presiding over one of its events at Goa.

Shopping Center

The NCL residents did not have access to easy shopping. They were the days when private transport was severely restricted by the heavy cost and scarcity of motor cars. Some residents had their own motorcycles but this was hardly the answer for family transport. As already mentioned, autorickshas and taxis charged more than double the normal fare as the NCL was considered by them to be outside the city limits. All this created huge problems for NCL residents. LKD addressed this deficiency in1982 by authorizing the clearance of an area next to the medical center and inviting tenders for the setting up of shops catering to normal needs. The shops were in place and functional within a year. The shopping center (Figure 15.5) was an instant success, indeed one of the most successful projects undertaken by the NCL. Several institutions and localities in that section of Pune also benefited greatly by this new facility, and the director was deluged by expressions of appreciation.

Unfortunately, there was no further addition or improvement and the status quo continued, till around 2004, Sivaram took personal interest and had the center revamped.

Figure 15.5: A view of the NCL shopping center

Children's Schools

One of the main impediments to attracting talented scientists, particularly returnees from the USA, was the lack of good schooling facilities for children. Aware of this obvious shortcoming, the NCL took two lines of approach to redress the situation: starting a school for small children within the NCL campus, and attracting Pune's two best schools, one for boys and the other for girls, to establish branches at the NCL.

The NCL school started at the kindergarten level, adding 1 or 2 higher classes every year, as though to keep pace with the growth of the children already in the school. Soon, a new building was constructed which was also periodically expanded to accommodate the increase in student strength and classes. Then in 1970, the management of the school was handed over to the Deccan Education Society. Today it is a full-fledged school (Figure 15.6) with a high reputation in the city. The start and growth of this school are a testimony to continuity at the NCL, progressively building on an existing strength till the final goal is achieved.

The second approach was the brainchild of Venkataraman. Not satisfied with providing schooling facilities only for young children, he approached Pune's leading boys' school, the St. Vincent's High School, to start a new school in the NCL campus — and made the offer particularly attractive by offering a large track of land (10 acres) at the rate of Rs.1/year. He insisted that the school must admit the children of the NCL employees and that a representative of the NCL must always be on their Board of Management. Father Rudolf Schoeck, a German missionary, who was the principal at that time, agreed to these stipulations and the foundation stone for what is now the Loyola High School for Boys was laid by M. S. Thacker, Director-General of the CSIR, on 29 January, 1961. Unfortunately, the relationship between the school and the NCL deteriorated steadily, particularly during Tilak's time. The school reneged on the stipulation to admit the children of NCL employs except through the usual process of selection. This defeated the very purpose for which the school was sponsored by the NCL. In any case, soon the school became a major presence in Pune, with a much improved relationship with the laboratory.

A girls' school, St. Joseph's High School, had been established much earlier, in 1950, by a similar overture to Pune's best girls' school, the Convent of Jesus and Mary. Although this school was started much before the Loyola school for Boys, it acquired importance only after the latter was established — probably because it then became a school exclusively for girls. The NCL's relationship with this school was always smooth.

The NCL's active interest in children's education went beyond establishing schools. It also periodically arranged for visits from children to enable them to learn about modern scientific methods. A picture of the NCL's school along with another showing some children in an NCL laboratory appears in Figure 15.6.

Figure 15.6: The NCL in the education of children

The NCL school

Pune's children in an NCL laboratory

Other Major Activities

A few other major activities of the NCL are worth noting**.** Starting with Mrs. McBain, the wives of all subsequent directors evinced keen interest in the social life of the ladies of the colony. A Ladies Club was formed with the director's wife as president and a few elected office bearers. Mrs. Venkataraman held frequent discussion sessions with wives of the Class IV employees to impress upon them the need for birth control and family planning. Mrs. Tilak encouraged religious discourses and visits to temples as part of organized picnics. Mrs. LKD organized fairs, had a TV installed in the common room (*bhajana samaj*) in the area of F-type quarters (for lower income staff), and prodded the director into having a shopping center established. Mrs. Mashelkar and Mrs. Ratnasamy continued the good work of the previous presidents. Mrs. Sivaram gave a larger meaning to the role and participates in several social activities including cancer awareness among the colony ladies.

A children's park, planned jungle, and a few other garden-related facilities were also established. The evolution of these was briefly described in the section on horticulture.

A City Within a City can be a Relief from Boredom

In today's world it is difficult to imagine the conditions in the days of planned economy, with all its faults and benefits. Public-sector institutions, created not only to meet the expanding industrial and other needs of India's growing citizen body but also to cater to the other wants of everyday life, are now things of the past. Their demise is all too evident from the powerless remnants of their once dominant presence, linked by a fragile thread of continuity. Those that were gobbled up by the giants of the free market continue to be a significant sector of the industrial scene but only as faceless components of larger enterprises.

In the context of this dramatic shift in India's style and structure, the NCL has managed to stay vigorously alive, in fact doing better than ever in some respects. But the everyday concomitants of life, created to meet the needs of a new society rising in the outskirts of the historic town of Poona (renamed Puna and later Pune), soon became increasingly accessible through the surge of globalization that took the borders of the town far beyond those outskirts. The "city within a city" became part of the city, and the old facilities are fast becoming a memory — history in fact, so relevant to this book. I see this happening with amazing speed during my annual visits to the NCL, and soon it will be no more than a metropolitan campus with nothing distinctive about it save itself. Some facilities remain, like the shopping center, children's park, open-air theater (all modernized by Ratnasamy and Sivaram), but the aura of a distinctive, almost self-contained, society is no longer to be sensed. While this is perhaps inevitable, one will do well to remember the admonition of a master builder:

> *There seems, on the contrary, to be no natural limit to the size of a functional zone; the boredom which befalls man while driving a car has made him forget any sense of physical limit.*
>
> Leon Krier, 1977: 69–152

❄

Part VI
This and That

The brain is a wonderful organ; it starts working the moment you get up in the morning, and does not stop until you get to the office.

Robert Frost, 1874–1963

INTRODUCTION

This concluding part combines many features of the NCL but has no specific feature of its own — which, in many ways, accounts for its caption. The first of three chapters comprising this part attempts to place in a nutshell the high points, positive and negative, of the NCL's evolution, as viewed by me personally. All previous parts were largely if somewhat unsuccessfully kept free of opinion and were based on facts, although one really does not know what the word "facts" actually stands for. According to an unknown author, *A fact merely marks a point where we have agreed to let investigation cease*, nothing more — an interesting thought. The chapter also recalls interesting anecdotes that, one hopes, add some harmless spice to the narrative.

There is nothing original about the second chapter (except perhaps the brief reminiscences of the directors' children or next of kin), but I have tried my best to take it away from the popular realm of retirement compendia containing letters from scores of admirers.

And finally, in the last chapter, I indulge in a bit of reverie which, let me hasten to add, is no idle dream or mad conversation with myself, but an attempt to unburden myself of some of the thoughts I have had on the future of the NCL. I thought I owed it to myself, to the institution I was associated with for the better part of my life, and to the director who initiated this attempt and offered the fullest cooperation, to look at the road ahead, winding its way forward through a wondrous panorama of dream, part lingering still as hesitant promise, part turning to firmer reality.

16

ROSES AND THORNS, SHOUTS AND WHISPERS
PERSONAL OPINIONS, INTERESTING ANECDOTES

The time has come,' the Walrus said,
'To talk of many things:
Of shoes — and ships — and sealing wax —
Of cabbages — and kings —
And why the sea is boiling hot —
And whether pigs have wings.

Lewis Carroll
The Works of Lewis Carroll, by Blackburn and White, 1871

The caption *roses and thistles* is a regular item of comments in a nationally renowned newspaper in the USA, *The Des Moines Register*. Under this caption the editors give their views on recent events, a rose for something they approve and a thistle for something they do not. In my adoption of the modified term *roses and thorns*, approval and disapproval may be substituted by less definitive sentiments, removing any trace of personal bias.

The NCL also has had a history of several non-technical and human incidents that have added color and perspective to it. Some of these are events that one would like to shout about; and others, one would like to forget or perhaps just whisper about. The caption *shouts and whispers* seems most appropriate for such events. If it sounds provocative, it is no thanks to the author. Any reader of the *New Yorker* would find *shouts and murmurs* a generic item in its contents with interesting episodes. I use a modified phrase here to pen a few episodes that the laboratory would like to dismiss as murmurs or magnify as shouts. They were all historically relevant, however. Several other episodes were related in the course of the earlier historical walk through the laboratory. They merited neither shout nor murmur but were just interesting anecdotes that lent a human face to the narrative.

Roses and Thorns

The matter does not appear to me now as it appears to have appeared then.

Attributed to Baron George Bramwell, 1872

True to Bramwell's saying, opinions change as the years pass by and the impacts of earlier decisions are revised. Stated below are the opinions consolidated over a period of 60 years:

- All directors, right from the outset, laid heavy emphasis on building a pool of talented scientists. The appointments of J. Gupta, M. Damodharan, S. C. Bhattacharya,

V. Jagannathan, C. SivaRaman, K. K. Chakravarti, A. B. Biswas, Hiralal, K. P. Sinha, J. C. Sadana, A. P. B. Sinha, M. K. Gharpure, S. B. Kulkarni and a few others gave a flying start to the laboratory. All of them did outstanding work and many published papers in reputed international journals. Their appointment was followed by that of Sukh Dev, A. F. Mascarenhas, Ranjini Nadgauda, K. V. Krishnamurthy, M. C. Srinivasan, H. B. Mathur, L. K. Doraiswamy, K. G. Das, P. Madhavan Nair, A. V. Rama Rao, R. B. Mitra, H. H. Mathur, A. S. Gupta, S.C. Sethi, and later of R. A. Mashelkar, S. Rajappa, N. R. Ayyangar, Paul Ratnasamy, John Barnabas, P. Ganguly, B. D. Kulkarni, V. K. Jayaraman, V. Ravi Kumar, M. G. Kulkarni, Sourav Pal, V. Ramaswamy, S. Sivasankar, S. Sivaram, K. N. Ganesh, J. D. Yadav, S. Devotta, B. C. Subba Rao, T. Ravindranathan, C. Gopinath, U. R. Nayak, S. Ganapathy, S. Krishnan, R. V. Chaudhari, V. R. Choudhary, Murali Sastry, Vivek Ranade, M. K. Gurjar, B. L. V. Prasad, S. Ponrathnam, Rajiv Kumar, Ashish Lele and a few others at a more junior level. The laboratory's pre-eminent status today is entirely the result of the vision of the NCL's directors that regarded talent as the central pillar of the laboratory and made great accomplishments possible. A big rose to the directors who made these appointments.

- Directors McBain, Finch, and Venkataraman initiated academic type research as a thick underlayer to a thin veneer of industrial research. This was a reversal of Bhatnagar's agenda but proved to be for the greater good of the laboratory. They also started flourishing schools of research. Some might think of a thistle for them for their ignorance of, or relative indifference to, industrial research, but as far as I am concerned they deserve a blazing red rose.
- Although the laboratory was created to further the Indian chemical industry, most of the directors regarded basic research as a necessary concomitant to applied research. Some even encouraged basic research in its own right and not necessarily as a spin-off from the applied work or an effort leading to it. The resultant high standard of basic research has given the laboratory a position unmatched by any other chemistry oriented laboratory of the country and has earned international esteem. Definitely a rose to the scientific leaders of the laboratory.
- In the early 1980s, Director-General G. S. Sidhu offered the NCL the first rejection of his plan to have a project engineering section with hefty financial support from the CSIR. Tilak, who was then the Director, left the matter to Doraiswamy to decide. LKD felt that the NCL should stay fully oriented to research and not diffuse its efforts into areas for which expertise could be bought from private sources. The offer was therefore rejected. IICT (then RRL-Hyderabad), to which the offer was then quickly redirected, did not lose a moment in accepting it. As a result, that laboratory has today a very efficient project engineering group and is in a position not only to develop a technology but also to make turn-key offers. The reasons that prompted the NCL's rejection of the offer are even more valid today than at the time. It was therefore perhaps the right decision. But there are many who do not think so. Neither a rose nor a thorn to LKD for this decision.

- Development of compounds for the control of water evaporation from lakes was a major laboratory study of the NCL right from its inception. Some excellent basic research was done and the results were published in prestigious journals including *Nature*. Tilak at first did not fully realize the importance of this project but when he did, he pursued it as a major project of the NCL. He even arranged field trials by having the NCL compound sprayed over the surface of one of the lakes in Maharashtra. The results were not very satisfactory. Even so, there was no let up on this project when LKD became Director. The results continued to be discouraging. No outside funds were forthcoming and it was concluded that available resources should be deployed for other, state-of-the-art projects of the NCL. Hence work on this project was terminated. Considering the immense potential of this project, it is not clear in retrospect whether that was the correct decision, budgetary pressures notwithstanding. Perhaps a thorn for this decision, one of the most important in the history of the NCL.
- All arrangements were under way. Ratnasamy was soon to join the NCL. Even as the modalities of his move from the IIP to the NCL were being finalized, thoughts of a catalyst for a major petrochemical process were buzzing in his mind — and mine. Almost immediately after his arrival, work was under way for what was to be the first Encilite, for xylene isomerization. The development was completed with the greatest expedition and single mindedness. The various stages of its trial at the IPCL, its final acceptance by the IPCL Chairman Subroto Ganguly, its loading into the isomerizer, and phenomenal success (loaded in 1986, it is still performing with undiminished activity, a record by any standard), are now a matter of history. No single event at the NCL has combined such novelty, single mindedness, cooperation between three organizations from different cultures; the IPCL (a public-sector undertaking), the NCL (a CSIR laboratory), and ACC (a private sector company) (see Chapter 11). The NCL, in particular Paul Ratnasamy and the director, deserve giant roses for this accomplishment. I pin the *Rajalaxm*i, a new variety of rose created by the NCL's garden supervisor Jana, on Ratnasamy's lapel.
- Process development in the NCL was an ongoing activity since the early 1960s, when Tilak joined the laboratory. If it was also practiced earlier, it was not as a team effort but that of a single division. Tilak changed all that and recognized process development as a specialized activity and an integral part of the Chemical Engineering Division by renaming the division as Chemical Engineering and Process Development Division (CEPD). He also made it clear, almost mandatory, that for all major processes developed in the laboratory, the process development group should be actively involved before it was considered ripe for transfer to industry. This stopped the dangerous practice of every scientist declaring a process complete according his/her own light. Tilak deserves full credit for this new philosophy but it is also true that he had the advantage of being a chemist, which shielded him from any accusation of professional parochialism. Taking advantage of this development, although it was seen by some senior organic chemists as an intrusion of chemical engineering, LKD, a chemical engineer, carried this even further by creating a

separate Division of Process Development — and earned an increased share of criticism from the dissenters. Eventually, all scientists accepted this as a healthy practice and supported it fully. A big rose to NCL, particularly to Tilak and LKD, for introducing this change.

- The NCL had been in existence for 15 years and no major project had seen the light of day. This was at once a harping point for the NCL's critics and a sore point for Tilak. An opportunity for visible redemption arose when tenders were floated by HOC for a plant for acetanilide. Tilak seized that opportunity and decided to make an offer through a firm of project engineers, R. L. Dalal and Co. Crossing many hurdles, he had the NCL offer accepted by HOC. One can argue whether the process was complete in every respect before it was offered but then one would miss the point. It would have been a no-win situation had he waited for the process to be complete in every detail, for the mindset of HOC was such that it would find fault even with the most complete of processes if it was not from a reputed Western company. The NCL had broken new ground and in the process, Tilak had introduced for the first time in the entire CSIR system, the concept of making turn-key offers through an outside firm of project engineers. (It was precisely the success of this philosophy that later prompted LKD to reject the concept of establishing a project engineering section within the NCL. Because of the mixed reception of this decision, it rated neither a rose nor a thistle.) But, for introducing the concept of turn-key offers to the NCL/CSIR, through the offer of the acetanilide plant to HOC and making a success of it, the NCL deserves a big red rose, pinned on to Tilak's lapel.
- As envisaged at the start, chemical engineering was a hard discipline concerned exclusively with plant design, the pots and pans and stills and nuts and bolts of a chemical process. This image changed when Tilak brought in chemical engineering to finalize a process, but even to him it was a hard discipline. It was during his period, thanks mainly to LKD, that the concept of chemical engineering at the NCL underwent a major change: it became chemical engineering science. And then, when LKD took charge of the laboratory, every major discipline of the NCL was associated with its engineering science counterpart. The NCL had bioscience and engineering, catalytic science and engineering, and polymer science and engineering. For making significant contributions in the first area LKD received major awards of the American Institute of Chemical Engineers and was elected to the National Academy of Engineering. Mashelkar too received many prestigious recognitions for his contributions to polymer science and engineering: he was elected to the Royal Society, and the National Academy of Engineering and the National Academy of Science. This transformation in the NCL's philosophy deserves a big rose.
- The globalization era had arrived. The NCL was still largely dependent on the CSIR for its budget. The CSIR had made it clear that it expected its laboratories to earn their own keep. It was at this juncture in 1990 that Mashelkar took charge of the laboratory. He decided that instead of ruing the lost protection of the CSIR, the NCL should take advantage of this opportunity to break from tradition and enter

into alliances with corporate giants in India and abroad. He began with GE and DuPont and his successors did even better by considerably extending the list of alliances. He also had the NCL respond to the international tender for consultation floated by a provincial Chinese government and had the satisfaction of seeing the offer accepted against competition from such giants as DuPont and Arthur D. Little Inc. A very big rose, the NCL's own *Shakuntala* (another product of Jana's creative talent), to Mashelkar.

- As part of the globalization drive, business-rooted research, and a desire to inject industrial culture into the NCL, Mashelkar went beyond the call of the government. Thus, when later he became Director-General of the CSIR, he carried the idea farther and declared the CSIR a virtual corporate entity and saw himself as the CEO. He made this declaration in his interview with *Business India* in June 1999. A somewhat similar move by an earlier Director-General, Varadarajan, but less articulately, had met with stiff opposition. To this day it is not clear to me whether the NCL should shift to such a totally industrial culture. But one thing is certain. There are many who applauded this sentiment and an equal number that did not. In any case, he had given punch and push to a concept that was once aired as early as at the beginning of the CSIR (see Chapter 3) that may or may not grow to a stable permanence. It will never be a rose but it is too early for a thistle. This does not in any sense take anything away from the *Shakuntala* pinned on Mashelkar in the previous paragraph.
- The NCL had begun its first modernization in the early 1980s with the establishment of a sophisticated Instruments Laboratory and the beginnings of the computer era in the laboratory. This was accelerated in the 1990s but it was only in the first few years of the 21st century that the laboratory became truly modern, with the complete computerization of all its operations and facilities. More than anything else, several resource centers were established with a whole range of competencies and modern experimental facilities. A walk through the laboratory and a look at its facilities would leave no doubt that the NCL is now a state-of-the-art center of research in every way: talent, instruments/equipment, communication, management. The up-scaling of the laboratory had been in progress for over two decades, particularly in the last decade under Ratnasamy and Sivaram. Much of the credit for bringing it to the 21st century, for creating resource centers, must go to the most recent Director, Sivaram. A large bright red rose to him.
- No regime in the NCL had to contend in its closing phase with the belittling phrase, "there is life in it yet." Thus no director was a lame duck, or just faded away like the proverbial old soldier of General Douglas McArthur. He was fully involved till the very end of his tenure, with no disrespectful comments about him either immediately preceding or following his departure. This made for a smooth transition of leadership. The laboratory as a whole deserves a rose for this orderly conduct.
- The pursuit of excellence was never barriered or constrained. Emphasis on it was certainly not uniform but even the minimum was enough to raise it far above most of the CSIR clan. It became the defining feature of the lab starting from 1980. A rose to the unknown scientist for his/her silent practice of excellence.

- The NCL started out with a strong divisional structure with weak interdivisional collaboration. Around 1980, this structure began to break with the formation of units consisting of scientists drawn from different divisions. The weakening of the laboratory's monolithic architecture and its progressive replacement by cross-divisional heterogeneity by LKD, Mashelkar, Ratnasamy, and Sivaram gave new strength to the NCL's creative muscle. A rose to these directors.
- There seems to be an increasing disconnect between the leaders and the led in the laboratory. Creative conversations involving scientists at all levels and the directors' more personal involvement in divisional programs and affairs are not an intrusion but a necessary vehicle to dispel the lingering vibes from the Arthur D. Little report. A thorn to the directors responsible for allowing this to happen — and persist.
- Many senior appointments were made in the 1980s. All those appointed did remarkably well and have occupied positions of leadership in a way that was the envy of most other CSIR labs. They earned international honors for themselves and the laboratory in good measure. Some have retired and many more are soon to retire. No replacements of equal merit are in sight. This is a failure of leadership and those responsible deserve a thorny thistle.
- The apex committee of the NCL (Executive Council/Research Advisory Council/Research Council) has been uniformly well served by its chairmen and members over the years. And yet it cannot go unnoticed that some of its members, including chairmen, have continued for unusually long periods of time, much more than the unstated, but usually practiced, three-year limit. To say that other suitable persons were not available is an insult to the country's scientific body. For the NCL to pass the blame on to the CSIR is to abrogate its own responsibility and lower its status as an institution with its own voice and will on issues of this kind. Some mandatory limits need to be set. A thorn to the NCL and the CSIR.
- I have talked at some length about the shifts in domain in the NCL under different directors (see Figure 6.1). How many of these were real paradigm shifts generated by the NCL leadership, and how many were responses to policy shifts in the country? The domain under McBain, Finch and Venkataraman gave the laboratory as good a start as any organization could have hoped for, and involved no shifts. Tilak introduced a major shift when the very culture of the laboratory was changed from semi-academic to semi-industrial. This was partly because of his own personal industrial bias, but more because the prevailing climate of the country demanded nothing less practical. But for this change, the NCL might well have become a failed experiment in the country's industrial development. The shift under LKD was equally significant; it was fully internally generated with no external compulsion, save the realization that, in the fast changing world of the day, for a laboratory like the NCL to even exist was to excel. This increasing assimilation of excellence found expression both through articulation and performance. Then came the last of the shifts in the NCL's history to date: globalization of research in the free market era that was swiftly engulfing the country. The novel approaches adopted by Mashelkar, Ratnasamy and Sivaram to bring about this transformation were described in the earlier chapters.

This again was a shift engendered by external pressure, indeed by necessity, rather than by internal motivation and urge. It is difficult to say which of these qualify as true paradigm shifts, and naive to suggest that they would not have occurred but for the men at the helm at the concerned times. How much longer would it have taken for these changes to have occurred is a more pertinent question — and a different story altogether. The best I can do is to recall some famous facts from history as an endnote.[1]

Shouts and Whispers

Often a purple patch or two is tacked on to
A serious work…to give an effect of color.

Horace, 65–8 BCE

- ***Science versus mysticism***: The NCL's scientific basis was not always strong enough to overcome the influence of the country's beliefs in the non-scientific, the mystic, the occult. The laboratory also showed itself ridiculously capable of getting into politically charged situations. Here is a whisper. During Finch's regime there was a question in the Lok Sabha about a person in Pune who could create fire in rubbish merely by gazing at it. Apparently, many members of India's Parliament, the Lok Sabha, were convinced about the veracity of this individual's claim. No amount of persuasion by the CSIR's representative, probably the director-general himself, would change their minds. Finally the DG had to agree to have this matter investigated. And since NCL was in Pune, the task almost naturally fell to it. It was one of those unfortunate occasions when I wished the director had less confidence in me than he did, for he promptly assigned the job of checking the claim to me. The moment I got a call from his secretary that the director wished to see me immediately on an important matter, I knew I had had it! The Lok Sabha members would look askance at a young fellow daring to contradict the claim of a person with obvious higher powers. Armed with the company of two of my assistants, I went to Deccan Gymkhana, where this miracle was purporately being performed. To this day I do not know how the man did it, but he did create the semblance of a small fire! All three of us ran around him looking for some give away clue, like a hidden match box. There was none. What was I going to tell this Englishman who had already indicated to me that all this was utter nonsense and that he would accept no less than a total rebuttal. When I told him about my observation, he looked at me almost sadly through his monocle, which he often used to good effect, and asked me to send a report saying that the whole thing was a fake. When I reiterated my observation, he said he would see me later and apparently asked the head of DTS to inform the CSIR that the claim was a fake. A few days later, when I had rehabilitated myself with him, he advised me that I should never let anything cloud my reason. And so the matter passed but my personal embarrassment persisted for a while. Apparently the miracle man had heard about the investigation and thought the better of it to decamp.

- ***Get rid of all those high pressure plants for ammonia***: Talking about Lok Sabha questions, here was another one. A "scientist" from Uttar Pradesh had reported that he had formulated a mixture of herbs which when sprinkled into a glass of water would release ammonia. Scientists were turning into miracle men! Somebody in the Lok Sabha found out that the NCL was working with substances that could carry out extraordinary conversions (meaning catalysts, I suppose). And so the matter was referred to Tilak. True to his style, he straightaway asked the DTS to inform the CSIR that the whole idea was nonsense. Without some advice from the DTS, he might have used stronger words and might even have asked New Delhi not to waste his and his scientists' time with such trivia! A weak shout perhaps!

  Apparently the kind of skullduggery mentioned in the previous two items is not exclusively an Indian issue, had Finch but known it (perhaps he did and chose to ignore it).[2]
- ***Shakuntala Devi confounds Finch***: But Finch was not always right. Anything he could not understand he dismissed as impossible and attributed to "Indian mysticism." Shakuntala Devi's rare powers in arithmetic proved this point, much to his embarrassment (and annoyance, I am sure), but his intransigence in these matters would make him seek every avenue of reasonable escape. Shakuntala Devi had an all-India reputation for her ability for astonishingly quick manipulation of numbers. For instance, she could compute additions, subtractions, multiplications of square roots, cube roots and nth roots, and combinations thereof, of a whole lot of huge numbers in less than 10 seconds. Finch personally attended the demonstration and actually instigated some of his students to test her with really complicated problems. When she came out with the right answers, he was graceful enough to applaud her but complained later that he had somehow been had! This certainly had the decibels of a shout.
- ***Tilak silenced by a watchman***: Another incident involved Tilak personally and was even more odd. Although Tilak did not relish anyone questioning his word, he was once actually forced into silence when blatantly accused of lying by a Class IV employee! In those days, the director lived in a flat on the third floor of the laboratory. Any visitor to the flat had to pass a watchman at the entrance to the main laboratory (after passing the first scrutiny at the main gate). On one occasion, when Tilak was returning with his wife from a dinner at night, he found the watchman fully intoxicated and rude. Tilak was actually asked to prove his identity before he was even allowed to enter his own flat! On reaching his flat he called up the Administrative Officer, R. P. Phatak, and asked him to take disciplinary action against the errant watchman. Two days later, when he had had no word from Phatak on this matter, he sent for him and demanded an explanation. Phatak, an efficient officer who was seldom ruffled, replied: *Doctor saheb, if I were you, I would forget this incident.*

  Undeterred, Tilak pressed for an explanation. Hesitatingly Phatak replied: *Sir, the watchman says you were drunk! If you wish to proceed with the charge, an enquiry has to be held at which you will be called to testify*.

  Tilak quickly dropped the idea! For those of us who liked and admired Tilak, this was just a whisper that went nowhere.

- **How a minister announced he was "boss" and Gupta was silenced**: It was announced that V. K. R. V. Rao, Minister in charge of Science and Technology, who was visiting Pune, would like to spend a couple of hours at the NCL. Dr. J. Gupta, the Deputy Director, was in charge of the laboratory in the absence of Tilak. As I was next to him in hierarchy, he and I received the minister at the entrance and took him round the laboratory, ending in the main conference room where he was to meet the senior scientists. After all were seated, Gupta began: *Hon. Minister, on behalf of all of us here, it is my pleasant duty to welcome you…*

  There was something like a roar from the minister: *Mr. Deputy Director, stop right there! As you know, I am your minister and hence the CSIR is mine. The NCL is mine. So, who are you to welcome me to my own laboratory*?

  Thus rebuked, Gupta did not take part in the proceedings any further and it was left to me to absorb any further jibes. After speaking for about 10 minutes, the minister declared that he would take questions for a few minutes. One of the scientists raised his hand for permission to speak. After a pompous nod from the minister, he began: *Sir, I would like to know…*

  Again there was that angry interruption by the minister: *How dare you speak to me in that tone*!

  The unfortunate man had a severe cold and a hoarse throat and couldn't help his voice! When I explained this to the minister, he grunted and asked him to proceed. After that there were no more questions! At the end of the meeting neither Gupta nor I thanked him and he left — imperiously. There were scores of people standing outside to greet the minister, whose manner suddenly changed. With folded hands, a nodding head, and the fixed smile of the politician on his face, he walked through the corridors all the way to his car, Gupta and I closely behind not knowing how to send him off. He saved us the trouble by simply saying *namaste* and drove away.
- ***LKD's naivete***: The above instances spoke for Finch's inflexible views and Tilak's propensity for getting into trouble, not always of his own making. The one given here speaks for LKD's lack of simple political sense bordering on stupidity or managerial suicide! They were the days when the rhetoric for a uniform language for India was at its loudest. A committee of the Lok Sabha was formed to ensure the adoption of Hindi in all government agencies and departments. This committee had wide ranging powers including the inspection of government institutions to determine the extent to which government policy was being implemented. The NCL was chosen as one of the institutions for inspection. The committee corresponded with the CSIR directly (ignoring the NCL) on the dates and other details and LKD received instructions from New Delhi on how they should be received and treated. The seating at the meeting was so arranged that the Controller of Administration (COA) of the NCL, who was responsible for implementing government policy in this regard, sat facing the committee chairman and LKD sat next to him. When the members arrived and the chairman was taken to his place by the COA, he looked at him and asked, *where does the director sit*? When told that he would be sitting next to the COA, he was visibly upset and, raising his voice, said that he would like to face the director across the

table when he spoke to him and implied that he would not like to sit face to face with anyone lower than the director. He then looked at LKD and said in Hindi, *I think you should know, Director Saheb, that as chairman of a powerful Lok Sabha committee, I can discipline you if I find your conduct unsatisfactory*.

He then sat down right across LKD at the table. He was pleasantly surprised that LKD could speak good Urdu, which is very similar to Hindi. After a series of questions and inspections of files, which revealed a whole lot of notings in English and none in Hindi, he had some angry comments and instructions for the future. As this was going on, the NCL committed its biggest *faux pas*. The invitations to lunch handed over to them were in English! He took this almost as an insult and warned LKD that he would make an issue of it. During the sumptuous lunch that followed, he calmed down and was actually quite pleasant. A Tamilian member of the committee took LKD (who happened to be a Tamilian) aside and remarked in Tamil, *I don't think you should take the chairman's comments seriously. Yes, he has the powers, but so do I*!

The post-lunch proceedings were unremarkable and the meeting ended on a relatively happy note. Fortunately, this ended as a whisper.

- ***A telephonic duel between secretaries***: An episode that throws an interesting light on the concept of prestige and protocol in those days, and is odd in its own way, is worthy of note. The director of a major military establishment in Pune (which is the Southern Headquarters of the Indian Military) wished to talk to the director of the NCL. His secretary got on the line and asked LKD's secretary to put him on the line. LKD's secretary told him that he should put his director on the line first. After a prolonged altercation over the telephone, LKD's secretary concluded bluntly: *It is your director who wants to talk to mine. So, let him come on the line and wait*.

  And then he added, rather unnecessarily, *I doubt if my director will ever need to call yours*!

  Soon the other director was on the line and waiting! No more than a whisper, this!
- ***Was LKD kind or ignorant?*** A gardener had put up an unauthorized hut in the NCL campus. The AO wanted to demolish the hut before the gardener claimed some kind of a permanency for having been allowed to remain there for a certain length of time. It was to be demolished on a certain evening. A few hours before the appointed time the gardener and his family of wife and a few children came to the director's house pleading for mercy and extension of just 24 hours to enable him to find a place for his family to sleep in the night. The AO was sent for and he arrived along with the security officer. The gardener appealed to the director's wife for sympathy, which unfortunately he got in ample measure: *What kind of a director are you that you cannot give this poor man an extension of 24 hours to find accommodation for his family*?

  The argument was powerful enough but not reasonable. The AO strongly opposed it but the director overruled him and extended the demolition time by 24 hours. The next morning around 4 a.m., the doorbell of the director's house rang. When the director came down to open the door, he was confronted by the same gardener whose demeanor had somehow changed. Quietly, he handed the director a sheet of dirty brown paper with a lot of official words and stamps designed to effuse authority, an unmistakable communication from a thrift-conscious government. It was a stay order issued by a local judge! On seeing this order later in the day, a sympathetic AO did not say a word but his broad smile and a twinkle in his eyes said it all. It took more than two years of legal wrangling to throw the gardener out! The gossipy lot of the laboratory was divided in its assessment of the director on this issue. A very kind man, some said. Downright ignorant and unfit to lead, others shot back.

- ***Killing by postponement***: Another episode begins with the visit of a director-general to the NCL. On the morning of his departure, he checked out of the NCL guest house, and after a call on the director, left for the airport. On the way, he realized that he had forgotten a certain item in the guesthouse and stopped to pick it up. On entering the open room, he found the guesthouse supervisor lying on the bed with a glass of scotch on the center table along with the ruins of a hefty morning repast. It is not clear who was the more startled. An angry DG, on reaching the airport, called the director and told him bluntly to have this fellow removed. He did not realize, as Tilak had not in an earlier instance, that dismissal was not a sensible option. An enquiry would have to be held at which the DG would have to be called to Pune to testify. LKD hedged the issue for several weeks till the calls became fewer and eventually stopped. The matter had slipped from the DG's mind or wiser counsel had prevailed. Again a whisper.
- ***Demonstrating the need for firmness***: This one is decidedly in the category of a shout, hailing the decisions of Tilak and LKD. A middle level scientist (whom we shall call Dr. G) of the Polymer Chemistry Division was up for promotion. He appeared before the Promotions Committee and after a long and contentious discussion was rejected. Hit to the quick, Dr. G responded with a scientific indictment of all those who sat in judgment. With a tabulated statement of the accomplishments of the committee members along with his own for comparison, he proved that he had stronger credentials as a scientist than any of them and accused the director of bribing the committee just to make sure that he was not promoted. When the CSIR refused to accept his contention, he turned to the courts. The ruling went against the Director (Tilak). By that time, Tilak had retired and LKD had take over as Director. When the matter was brought to his attention, LKD decided that there was no intention on Tilak's part to pack the committee and he therefore instructed the COA to take the case to the highest level, all the way up to the Supreme Court if needed, for a final verdict. He strongly felt that the biased view of a single scientist should not be allowed to impugn the motives of many of the country's senior scientists and of his predecessor Tilak. As the case was making its way through the courts, Dr. G decided that it was time to back off and sought an interview with LKD for a compromise. LKD agreed to meet him but with no promises of compromise. But Dr. G's suspension was revoked and he was allowed to resume visits to the library and the use of the other facilities of the laboratory normally granted to retired scientists. Dr. G was a good scientist and the laboratory was happy to welcome him back as a retired user of its facilities. A shout, this.

- ***An angry Finch versus a bus driver***: Here is an incident that showed the tough side of Finch, tough in favor of the staff. They were the days when a majority of the NCL staff that stayed in the city had no personal transport beyond a bicycle and hence depended on the city bus service to come to work. The bus usually dropped off/ picked up the staff at the main gate of the laboratory. In order to avoid the walk from the main building to the gate, Finch was requested to approach the Pune Municipal Service which ran the buses to provide a halt at the main entrance within the gates. This was agreed to and the service went ahead smoothly — till Finch observed one day that the bus was traveling at a speed more than the stipulated 15 miles/hour within the campus. Next day he decided to stand on the mezzanine and observe this closely. He found the driver speeding into the gates of the NCL and going on merrily at the same speed thereafter. He was furious, sped down the stairs, out on to the laboratory road, waving his hands for the bus to stop. The sight of a tall Englishman running right in front of the bus angrily waving his hands signaling the bus to stop must have been an unnerving experience for the driver who managed to come to a screeching halt within a couple of feet of the director. Finch then shouted the driver down and asked him to get out of the laboratory instantly. He also called up the Pune Municipal Service, told them what he thought of their service, and forbade them from entering the NCL. When some staff members complained to him, he was apparently quite annoyed, saying: *I would rather save your life than some walk — which, from the looks of you, you can all use.* End of discussion. Who can deny that this qualified for a shout!
- ***The mild mannered KV accused of military rule***: An incident that must stand out as a unique event in the history of the NCL occurred during KV's regime as Director. The laboratory had grown indisciplined. The staff came and went as they pleased. There was no check at any point. The divisional heads refused to interfere. The director felt he had no option but to take the matter in his own hands. The laboratory timings were 9 in the morning to 5.30 in the evening. He therefore had all entrances to the laboratory closed at 9.10 a.m. and opened at 5.30 p.m. This improved the situation slightly but not very much. In the morning there would be an unsightly rush at the gate outside the laboratory to sign in. In a city that, in those days, looked upon NCL scientists as people of whom they should be proud, this must have been somewhat of an unpleasant awakening. In the evening, lines would form behind the gates that extended all the way to the buildings. As soon as the gates were opened there would be a rush that would put to shame a bunch of kids jostling to be the first to be gone from school! Had the discipline improved? No, but the scene of indiscipline had shifted to the gates. The matter came up for discussion at the Senior Common Room meeting. S. K. Subramanian, who had just joined the NCL as head of DTS (he came from ICI, India, and left within a few years to join the Department of Science and Technology at New Delhi), raised a vociferous protest and accused KV, that quiet, well-meaning professor who liked this disciplinary measure less than anyone else in the laboratory, of high handedness and military rule. KV was less angry than hurt and allowed a free rein of opinion. He was more relieved than

any other member of SCR when there was an almost unanimous vote to do away with gate closures. In turn, the divisional heads decided not to shirk from their own responsibilities. Just as they shared in all the decision-making processes of the laboratory, they would also share in the discharge of responsibilities. This was a good epilogue to an action that brought out the worst and the best in the laboratory but ended with a great big shout in my reckoning.

- ***Mission accomplished* (No, not George Bush's!)** While the ill-fated vitamin C project was going through swings of perceived success and failure (see Chapter 10), an incident occurred that was not widely known but that brought a momentary smile to an NCL project group. Vitamin C was being produced at the Alembic Chemicals in Baroda (now Vadodara), and KV had casually asked a senior scientist, who was going to Baroda on some other work, to find out what he could about the Baroda plant. A few days later, when this informal discussion had faded from his mind, KV received a crisp 5-word Bond-like telegram, fortunately not coded, with the mysterious message "mission accomplished will report personally," with no name! More alarmed than stunned, KV sent for me to find out what it was all about. It took me several hours of investigation to get to the bottom of this, for I knew nothing about the conversation between the concerned scientist and KV. When the scientist kept his word and personally re-delivered the message to KV, the director was left helplessly hesitating between rebuke and silence! This calls for neither a whisper nor a shout but a mysterious silence on my part as well!
- ***What a German professor thought of Indian cuisine***: Professor G. V. Shulz, an internationally renowned polymer physical chemist who was a pioneer in his field and was largely responsible for the post-war renaissance of polymer research in Germany, visited the NCL in 1960. Shulz, who was also responsible for the founding of the Max Planck Institute of Polymer Forschung at Mainz, refers in his autobiography *Fulfilled Life of a Scientist* to his NCL visit in terms at once pleasing and disquieting. He remarks:

> *On the way* [from Mumbai], *we traveled through a lovely valley partially covered with high deciduous trees and small houses with red tiled roofs. The scene was really a heavenly joy… Subsequently I visited the laboratories, discussed vivaciously with the interested, mostly the younger generation, who were well aware of the recent developments in their respective scientific area. Their work was also properly documented. But when I asked them about their professional prospects, I received disappointing answers. They told that in the country, industry did not have any interest in the scientific research, and, from this point of view, their prospects were also narrow. At the most, they could get jobs as teachers in the colleges. However, they were all interested in going to foreign countries* [an interest that has grown over the years in spite of great strides in the national scientific structure].

And then came the lines undeniably hurtful to the national culinary pride:

> *At the end of my visit, the Director of the Institute invited me for a dinner in his comfortable official residence. Almost a dramatic event! It was really an Indian food full of surprises. Extremely bitter fruits (after consumption, one gets breathless). This was followed by extremely*

> *sweet oily dishes and then when one has carefully chosen the next item, it was tasteless. Such was my culinary experience in this modern institute.* [The succession of dishes he talks about does not seem Indian!]

The first statement clearly deserves a shout while the second must settle for a muffled murmur.

- **The dog that ate shoes and the master who smiled**: The NCL has had many Administrative Officers (AOs), each with his own brand of administrative leadership. One particular AO was a very religious man and organized *bhajans* in his house at periodic intervals. Many residents of the colony attended these open-house occasions. As shoes were not permitted inside the house, they were left out in the verandah. Now this AO had a huge dog and nobody could accuse the fine man of starving this dog — in fact the animal looked well fed beyond his normal dimensions. Even so, he seemed to have a great fascination for the shoes left there in the unsuspecting AO's care. He chewed them delightfully leaving the remnants to half cover the feet of the departing guests. Others were less fortunate because the obnoxious creature would drag the shoes onto the streets, leaving them there for the less fortunate members of his species to make a meal of. Nobody dared to complain because the AO was a powerful man and the loss of a shoe was not worth inviting his displeasure. To those who mustered sufficient courage to bring this to that fine man's attention, the only response they got was a broad smile followed by the words: *He loves shoes, doesn't he*? A whisper for the AO.
- **A scientist's generosity exceeded only by his patriotism**: It was 1965 and the Indo–Pakistan war was raging fiercely. Prime Minister Nehru had just issued an appeal to every Indian to donate handsomely to the war effort. S. C. Bhattacharya and his wife lost no time in donating their substantial possession of gold and diamond (mostly in the form of jewelry) to the Prime Minister's fund. Any statement of praise will only detract from this act of pure and magnanimous patriotism; hence I will just leave it there.
- ***The two faces of bureaucracy***: This incident concerns another AO (or perhaps the same one, I am not sure). Tilak wanted the CSIR's approval for a certain proposal and left it to the AO to take appropriate action. A strong letter from the AO had no effect on the presiding officer at the CSIR headquarters in New Delhi. A second, even stronger, letter fared no better. A third one elicited a detailed response explaining why the proposal could not be approved. Around this time the AO was transferred to Delhi and an annoyed Tilak asked the new AO to pursue the matter vigorously. His letter to CSIR attracted an equally strong refusal and was signed by none other than the AO who had just departed from the NCL! Surely, no more than a whisper for the AO.
- ***Cigarettes: Charminar up-scaled***! Finch was a reasonably heavy smoker and he liked strong cigarettes. In those years no brand was stronger than Hyderabad's Charminar. Finch loved them. If they also happened to be cheap, so much the better. On the other hand, he had no desire to be caught smoking that cheap brand. It would not do for an NCL director who was also an Englishman to be so espied! He found a brilliant

way out. He bought a packet of Gold Flake cigarettes, one of the most expensive varieties available then, emptied it out and filled it up with his favorite brand! His friends often wondered why he never offered them cigarettes!

Here is an interesting incident, unconnected with the NCL, that throws Finch in a double jeopardy for, if he felt that, being a renowned professor, he could not smoke Charminars, he perhaps did not reckon with Lord Todd's smoking fiasco, as recorded by him in his autobiography (1984).[3]

- **A novel way of looking at *lost and found***: As the NCL's presence in Pune was increasingly felt, a guide was appointed to take visitors round. A reference was made in Chapter 3 to the novel way in which this guide explained simple scientific principles to visitors. He also was very honest, in a novel way if I may add! He once found a 10 rupee note in some obscure corner of the laboratory. He took it to the receptionist for safe keeping and asked her to put up a note on the bulletin board announcing this fact and asking the owner to contact him. When nobody came forward, he asked the receptionist to put up a reminder. He waited for another week and, seeing that nobody had yet come forward to claim the find, he took back the note from the receptionist telling her, *I will put it back where I found it so nobody can claim it and thus cheat the person who actually lost it*!
- ***Sri Prakasha was appointed Governor to teach him how to govern***! A witty man was Governor Sri Prakasha. Soon after taking office as governor of the state of Maharashtra, Sri Prakasha was invited to visit the NCL. He agreed to speak to the staff and an overflowing auditorium saw him climb up the podium with folded hands. In faultless English he began to briefly sketch his career, till he came to his appointment as governor. And then, with a poker face, he admitted that he never knew what a governor's job involved, for instance speaking at the NCL, and went on to relate the following story. George Joachim Goschen had just been appointed England's First Lord of the Admiralty. He confessed to the Prime Minister that he knew nothing about the sea, to which the P. M. seems to have replied that that was precisely why he was being appointed Lord of the Seas — so he could learn! And Goschen became famous for the following lines that were repeatedly spoken:

  Goschen [pronounced Goshan] *had no notion*
  Of the motion
  Of the ocean!

- ***Culture versus Culture***. It was mentioned that the NCL operates the National Culture Collection Center. The director of the NCL decided that the head of this center should be deputed abroad to visit similar centers in other countries. When the file was sent to the appropriate scientific ministry, it was promptly returned with the remark that it should be sent to the Ministry of Cultural Affairs for clearance!
- ***These Indians are normal!*** Madusudhan Goswami, a former senior scientist of the NCL, told me several years ago of an incident that occurred during his visit to Germany in the 1960s. He was a member of a team that visited a number of factories in Germany. True to their well known efficiency in planning, the host institution

would pass on pertinent details of the visiting party to the next host. Goswami (since deceased) swore he overheard the following message being telephoned by a current host to the next: *Don't worry about their food habits. These Indians are normal human beings*!

This was obviously a step to ensure that, if there were any vegetarians in the team, their needs would be taken care of.

- ***Chemicals versus superchemicals***.[4] As I had mentioned in an earlier chapter, a program of research on superphosphates was to be a major part of the NCL's research effort soon after the laboratory became functional. When this matter was discussed at an informal meeting in Delhi, it is reported that a very senior official (it is even alleged that he was a minister) remarked, almost sarcastically: *Let them do the phosphates first, and then think of superphosphates*…
- ***Humor in corruption***!

> *No question is so difficult to answer as that to which the answer is obvious.*
>
> George Bernard Shaw

Corruption — of every shade and manner — is unfortunately an almost natural part of every human enterprise. There is usually nothing distinctive or anecdotal about it, except perhaps its extent and ominous influence. To the question: *Is there any institution without corruption*? Bernard Shaw's answer is intriguingly clear. However, some types of corruption add a touch of humor, of the bizarre. Here are two such pertaining to the NCL (with no names mentioned), culled out of the usual number associated with any endeavor.

It was brought to my attention that a piece of land at the back of the NCL campus was being used to grow vegetables that were never sold to the NCL staff (see Chapter 15). Investigation revealed that the garden staff was ordered to attend to the patch, which had been 'sold' by a senior administrative official to a local businessman! It was quite an effort to redeem that piece of land because the businessman insisted that it belonged to him! A shout no doubt.

The second, with the same decibels, happened during an annual auction of the late 1970s. A jeep (I forget if it was a jeep or a truck) was put on the list. A senior administrative official, who wanted to acquire it at junk rate, had the vehicle exhibited with worn out tires, malfunctioning breaks, and other visible evidences of a highly damaged property. It was reported that he had the tenders opened in private and arranged for an agent to make the highest bid (exceeding the next highest by a few paltry rupees). When, a few weeks later, a fully reconditioned and painted jeep drove out of the campus, no immediate connection could be traced to the jeep with damaged tires, scratches, dents, peeled paint all over its body, and its engine shaft noisily arrhythmic !

Points to Ponder

Every institution has points to ponder, stories to tell, history to be proud of, facts to forget. Many of them give it its character, its defining moments, and shape its destiny. Some are irrelevant, add a sense of the bizarre, and bring laughter. The material of this chapter is a *potpourri* of what, in my view, were the great and weak moments of the NCL, and of incidents that have added humor and color and lent it a lore all its own.

A typical thorn (or thistle), for example, is an unambiguous expression of a negative opinion:

> *A thistle to the University of Iowa College of Public Health for sacrificing a $15 million gift in pursuit of pointless academic principles.*
>
> Des Mines Register, July 15, 2007

Personally, I would not call this a thorn or a thistle but it illustrates one. I would call it a rose. None-theless, my roses and thistles have the same general connotation.

Anecdotes of persons or institutions enrich their memory. There are many such in the history of mankind. One of my favorites is Caliph Abu Bakr’s reaction to praise. After the man who praised him had left, he is reported to have said:

> *O Allah, You know me more than myself, and I know myself more than these people who praise me. Make me better than what they think of me, and forgive those sins of mine of which they have no knowledge, and do not hold me responsible for what they say.*

These illustrations fully define the choice of opinions and anecdotes of this chapter.

❄

17

REMINISCENCES
MEMORIES MATTER

Is something that doth live
That nature yet remembers
What was so fugitive!

Wordsworth, 1798–1806, "Ode: Intimations of immortality from Recollections of Early Childhood" 1815

Any history that is written when most of the events pertaining to the subject of the history occurred during the living memory of the historian has some special features. These features become even more special when the historian was directly involved in the history. "Historian" is a grandiose description of a writer with implied claims to knowledge in a wide variety of fields, in spite of being severely limited to a narrow field, "thus making a fool of himself" (see Preface; Schrödinger, 1967). On the other hand, any such writer has the advantage that he can elicit the views and reminiscences of some of the most outstanding persons associated with the subject of the history. Dropping all anonymity and moving from the general to the specific, my personal association with the NCL dates back almost to its inception. The NCL has had contacts with scores of people from the academia, industry and the government, who have been involved in shaping the laboratory from within and without. The views of M. M. Sharma (a Fellow of the Royal Society), who was closely associated with the NCL for over four decades and is familiar with all aspects of the laboratory, are reproduced.

In shaping an institution like the NCL, all its scientists are involved, in one way or another, to a greater or lesser degree. And yet, it is the director who sets the tone, controls the pace, and calls the shots. While true in most countries, it is particularly so in India, where the institutions tend to be more director-oriented. Thus the role of each of the eight directors so far was brought out in considerable detail in the preceding chapters. However, little was said about them at a personal level. I thought it best to leave this to their children or next of kin to do. Thus, their views are also included under Reminiscences.

The chapter ends with brief writeups from first Indian Director (K. Venkataraman), and two retired senior scientists.

Reminiscences

M. M. SHARMA, PROFESSOR OF EMINENCE, UNIVERSITY OF MUMBAI

My Enjoyable, Rewarding and Exhilarating Association with the NCL for More Than 40 Years

I first visited the NCL towards the end of 1958 when I had joined the UDCT, Matunga (now ICT) as a full time research student. I did consider the NCL, particularly the Chemical Engineering Division, as an outstanding center for research as research papers were published in learned journals and Dr. L. K. Doraiswamy (LKD) had published some nice papers on thermodynamics which was my favorite subject at that time. I was, of course, very impressed with their activities and we in the ICT had strong connections and our own Director, Prof. K. Venkataraman, a doyen in Organic Chemistry and author of several books on Synthetic Dyes, had moved, in 1957, to the NCL as their Director. Since then we had my teacher, colleague and a life long friend Professor B. D. Tilak as the Director of the NCL from 1966 onwards till his retirement, and he was succeeded by the outstanding Chemical Engineer Dr. L. K. Doraiswamy, with whom my life long association started in 1966. Indeed, we wrote the two-volume book, *Heterogeneous Reactions — Analysis, Examples and Reactor Design* which was published in 1984 by Wiley — Interscience, USA. This required many get-togethers and my spending a significant part of the summers in the NCL, when a number of his students doing Ph.D. interacted with us and they later became outstanding researchers and specific mention may be made of B. D. Kulkarni, R. V. Chaudhari, V. R. Chaudhary. This book, first of its kind from India and also of a unique kind by global standards, was well received and interestingly by the industry as well. LKD and I continued to interact fruitfully all along and even today we exchange emails.

The NCL saw an orientation to industry in a remarkable way with Professor B. D. Tilak as the Director and a number of technologies were commercialized and some got the coveted Indian Chemical Manufacturers Association (ICMA) Awards, with which I had association as a jury member.

L. K. Doraiswamy (LKD) had a penchant for excellence and succeeded admirably in getting outstanding scientists to join the NCL and mention may be made of Paul Ratnasamy, who made truly outstanding contributions in catalysis and whom I fondly call Mr. Catalyst, S. Sivaram (from the IPCL, R&D) who is the current Director and who has made outstanding contributions in Polymer Science and Technology and John Barnabas, who made great contributions in Biological Sciences. LKD also played an active role in getting R. A. Mashelkar (RAM), from Salford, UK, who is my former undergraduate as well as my doctoral student, who later succeeded him first as the Head of the Chemical Engineering division and then as the Director. RAM has created history as DG, CSIR, becoming the most versatile and functional scientist in that politically hyperactive Delhi. RAM took the NCL to the status of ICL, International Chemical Laboratory.

S. Sivaram is combining excellence in research with business in an admirable way.

It will thus be obvious that my association with the NCL has been of more than four decades and I have had the pleasure of seeing the NCL in its glory. The NCL has a unique character, free from petty politics, nibbling, etc. There is an aura of excellence in science and technology. During the last few years as Chairman of the Research Council, I am having yet another phase of association.

The NCL sometimes gives an impression of “academic” arrogance which must be curbed. Research excellence, measured by any yardstick, continues to flourish and will continue to make a mark but the delivery to the market place needs to be strengthened. The global Chemical Industry is going through a drought of breakthrough technologies in last 15 years and the NCL can play a pivotal role.

I am more than convinced that the NCL will go places and will have the maximum number of Ph.Ds. in chemistry, biological sciences and chemical engineering in coming years and will simultaneously commercialize difficult and rewarding technologies. As a predominantly “Chemical” Laboratory, the NCL is doing outstanding work in Biological Sciences and with chemistry and biology coming closer we can expect even more rewarding contributions from the NCL.

CHILDREN OF THE DIRECTORS OF THE NCL ON THEIR FATHERS

It was not possible to obtain reminiscences from the children or next of kin of the NCL’s first two Directors, McBain and Finch. These are therefore substituted, much less appropriately, by their brief biographical sketches.

James William McBain

James William McBain was born a Canadian and did his doctoral studies under the direction of H. Quinke, a distinguished colloid chemist at the University of Heidelberg. He then began a 20-year career at the University of Bristol, England, originally as Lecturer and then as the first holder of the Chair of Chemistry endowed by Lord Leverhulme, the founder of the Lever Brothers industrial empire. McBain had broad interests in physical chemistry, but his studies on solid surfaces and his elucidation of the properties of detergent solutions were largely responsible for his fame as a scientist.

McBain and his students made extensive studies of the adsorption of gases on charcoal and other solids of large surface area, obtaining relationships between the weight of gas adsorbed and the equilibrium gas pressure. Such knowledge was of direct, practical importance in the manufacture of gas mask canisters in World War I, and also provided a framework in which an understanding of heterogeneous catalysis was built. It is interesting to note that his studies on adsorption formed the first basis for the well known ideal adsorption isotherm, which would later be extended to non-ideal isotherms by a future Director of the NCL (LKD) and his students. McBain’s work on detergents was mainly concerned with the unusual physical properties of soaps and soap solutions. In particular he devoted much effort to working out the complicated phase diagrams of a number of metal alkanoates and to characterizing their aqueous solutions.

McBain also invested considerable effort in developing the opaque, air-driven-top ultracentrifuge, the concept of which was simple — a rapidly rotating metal top driven by a turbine attached to a high-pressure air blast — but one which required extreme nicety in machine shop work. By dispensing with the elaborate auxiliary optical equipment of the Svedberg's analytical ultracentrifuge, the McBain spinning top enormously reduced the space required for sedimentation measurements, but the instrument never became as popular as it deserved to be.

For his time, McBain was unusual in that he succeeded by dint of much effort in obtaining sizable gifts from the US industry to support his researches, and he was much ahead of his time in gathering around him a group of post doctoral scholars who, although informally, added much to the education of his graduate students. All this experience came in very handy when he took over as the Director of the NCL in 1950.

The appointment of McBain to the Stanford faculty directly at the rank of professor is regarded as a marked aberration from the normal pattern, as is clear from the fact that between 1903 and 1960, McBain was the only person appointed at tenured rank in the department. From the 1960s onward, this pattern changed radically: now the more common entry to the established faculty of the department appears to be at the junior level (mostly as assistant professor).

McBain earned many awards and recognitions for his outstanding contributions, the most notable being his election as Fellow of the Royal Society in 1925, the award of that Society's prestigious Humphry Davy Medal in 1939, and the award of honorary degrees from a number of universities.

> Retirement was fundamentally unthinkable to a man with McBain's temperament. Although he looked forward to the freedom for travel when he became emeritus, the notion of discontinuing his research was far from his mind. He planned to move some of his work to the fledgling Stanford Research Institute in Menlo Park, New Jersey, but before that move had proceeded very far he was invited by Prime Minister Jawaharlal Nehru to build, and to serve as the first Director of India's National Chemical Laboratory. Overcoming great obstacles in the construction of the laboratory in Puna, he quickly assembled a competent group of scientists who, with the initial assistance of a few young chemists who accompanied him from Stanford, soon settled down to a program of research on problems of economic importance to the nation. To quote from his biographical sketch: *In three years McBain provided a base for the economic development of India on a scale which rarely falls to the lot of any individual. When he left India, his successor, G. I. Finch, inherited a thriving scientific laboratory*.
>
> McBain 1954:604–09

George Ingle Finch

Born an Australian, Finch was privately tutored in Europe. His desire to pursue a career in medicine took him to Ecole de Medicine in Paris. Soon his interest shifted to physical science and he studied at the Eidgenossische Technische Hochschule in Zurich, where he won the gold medal of the diploma course. He later joined the E.T.H. as a research assistant and then moved to the University of Zurich. As a consequence of his discovery of an improved catalyst for the synthesis of ammonia, he became associated with the Badische Anilin Sodafabrik (BASF) in Germany, and spent a period as manager of one of its units. This interest in technical application of science, aroused and stimulated by his period in Zurich, remained a permanent feature of Finch's later years. Coupled with his eminence as a professor, this was no doubt a factor in Nehru's acceptance of Bhatnagar's recommendation to invite Finch as successor to McBain as Director of the NCL.

Finch returned to England in 1912 as a research chemist at the Royal Arsenal. Soon he became a demonstrator in Professor Bone's group in the newly formed Fuels Department housed in the Chemistry Department of the Imperial College in London. This later became the Department of Chemical Technology. The outbreak of the Great War in 1914 caused a break in Finch's academic career. He served with the Royal Field Artillery and the Royal Army Ordnance Division in France, Egypt and Macedonia with the rank of a captain. He was frequently mentioned in the dispatches between London and these field offices, resulting in the award of M.B.E. He then returned to Imperial College and was appointed Lecturer in Electrochemistry in 1921, the year in which he got married, and soon became an assistant professor. His extensive contributions were recognized by his appointment to the Chair of Applied Physical Chemistry in 1936, a position he held till his retirement in 1953 and appointment as the second Director of the NCL.

Finch's scientific accomplishments were recognized by his election to the Royal Society in 1938 and the award of the Hughes Medal in 1944. He spent a year in Brussels as Franqui Professor, was President of the Physical Society in 1947 and delivered the Guthrie Lecture of the Society the following year. There was not an area of physical chemistry he touched that he did not embellish. His main contributions were in the fields of electron diffraction and electron microscopy. The first electron diffraction unit in India was built by him and his students at the NCL.

Finch was the first person to prove the great value of supplementary oxygen for climbing at extreme altitudes. He did this during the 1922 Everest expedition when he and his companion, Geoffrey Bruce, reached an altitude of 8,320 m, higher than any human had climbed before. Finch was well qualified to develop the oxygen equipment because he was an eminent physical chemist. Many of the features of the 1922 design are still used in modern oxygen equipment. Finch also demonstrated an extraordinary tolerance to severe acute hypoxia in a low-pressure chamber experiment. Remarkably, despite Finch's desire to participate in the first three Everest expeditions in 1921–24, he was only allowed to be a member of one. His rejection from the 1921 expedition was based on medical reports that were apparently politically biased. Then, following his record Himalayan ascent in 1922, he was inexplicably refused to participate in the 1924 expedition. From available reports, the undeclared reasons were complex and related to his Australian origin, his forthright and unconventional views, and the fact that some people in the climbing establishment in Britain saw Finch as an undesirable outsider. This aspect of Finch's personality came through, wholly undiluted, to the entire staff of the NCL: an absolutely straight forward and brilliant individual, who expressed his views with vigor and candor, irrespective of the recipient audience, a rare quality indeed in today's world of political adjustments (see the lines from Truesdell, 1984 in Chapter 18). This perceived lack of sensitivity was seen as a major factor that placed his predecessor above him on the likeability scale. On the other hand, unlike McBain who brought his own American/European colleagues to the NCL, Finch brought his Indian students from Imperial College and left a flourishing school of research in solid state physics, surfaces, and films. For example: his studies with A. P. B. Sinha (one of his students from Imperial College who would later become a distinguished scientist of the NCL) stimulated a number of investigations, in various countries, into the unusual magnetic properties of hematite; and his papers with Anil Goswami (another student from Imperial College) brought thin films research to the fore in India.

K. Venkataraman, by daughter Dharma Kumar
(excerpts from an article written before her death)

My father was unique in his dislike of money. He never handled it if he could help it — caught in a shower he would take a bus, and often could not pay for the ticket, but luckily for him, he looked so honest that bus-conductors always forgave him. He was abnormally offended by any connection between money and the things he valued such as affection and learning. When I did unexpectedly well in the matriculation examination, my mother gave me a sari. A perfectly ordinary action, but it upset my father who explained to me that I could have a sari whenever I wanted one, if we had the money, but that learning was its own reward.

Psychologists may well find a connection between my father's attitude to money and his fastidiousness about cleanliness, a family joke. He took several minutes each time to wash his hands; he always carried six handkerchiefs, since the same one could not be used to wipe his hands, his spectacles and his face, and of course not to blow his nose. At the end of the day, six clean handkerchiefs would be put into a separate bag, to be boiled at home once a week.

A lie was the worst uncleanliness of all — I was very rarely scolded and generally for some form of untruthfulness. Even something which I still consider as harmless as signing the attendance register when I had not attended a class, earned a lecture at home — but one considerably shorter and more interesting than the college lecture I had missed, since my father had the family habit of terse and pointed speech. He shared the family power of biting sarcasm.

Two things made my father's absorption in chemistry possible: my mother and his own nature. My mother took over all household responsibilities, from paying the bills to meeting visitors, however important, at the station or airport. He was surprised when a colleague took a day off to help his wife shift house — *we are not all married to Mrs. Venkataraman*, came the reply. She provided a calm courage he badly needed. My father was easily depressed, often over-sensitive, and he himself felt he would have achieved nothing without my mother. This was an exaggeration; he certainly would not have been as happy, but he was fundamentally dogged (and extremely well organized) and would have managed to work under the most difficult circumstances.

The last two years of his life were badly clouded by ill-health; he grew feebler as he lost weight and when he died, he weighed only 32 kilos, nearly half his normal weight. Yet the last four of his 84 Ph.D. students completed their theses in the last year of his life. In the last two months in Delhi, his health improved somewhat and he immediately began to plan new books — one on vegetable dyes, and another — a kind of scientific autobiography. Luckily his final illness and stay in the hospital was short, and when

I returned to Princeton after his death, I found a cheerful letter waiting for me telling me of his plans for work (Kumar, 1982).

B. D. Tilak: Kaka's memories, by daughter Vidya Nagarkar

BDT was affectionately known as Bal, Dr Tilak, Professor Tilak, The Director, Sir to the whole world. He was simply Kaka to us. Being a joint family, there was already a Baba (his elder brother) in the family. Since Baba's children called my father Kaka, we also addressed him by the name Kaka.

I was very attached to Kaka from the beginning. Even when he was busy as a professor in UDCT, I loved being in his room sitting with a whole box of colored chalks, drawing on his board while he discussed the various intricacies of chemical formulas with his students and colleagues. I was the youngest and, as I am given to understand even to this day, the most pampered one. As I had known him the way he was towards me, I could not fathom he was any different towards anyone else!! Does that mean I could get away with just about anything? In a chorus, the elders in the family would agree.

He believed in importance of education. When my husband Ravi's proposal was being considered, he was working in Navin Fluorine, right after his graduation from IIT, Mumbai. This did not impress my father and he refused to consider this proposal for his daughter. It was only when he was informed that Ravi had plans to do postgraduate studies that my father reconsidered. It did not matter to him whether he had a job or not.

His absent mindedness was famous. After my marriage was fixed, he happened to run into my would-be father-in-law at the airport. When he was approached, he was so engrossed in thinking about his next set of meetings that he had completely forgotten who this nice gentleman was!! My father-in-law, although taken aback at the time, soon realized that this is how Kaka was!

Even after 10 years of marriage, my husband could never forget the day when Kaka called him in his office at Color-Chem to pass on the message to me, 'Tell Vidya, I will come to her house to visit her on Friday.' Needless to say, Ravi did not appreciate it and was a little cool towards Kaka. However, Kaka did not realize that what he had said would tick Ravi off until Tai, my mother, pointed out his gaffe.

His enormous affection for his grandchildren is well known. I remember, in 1993, he had declared that Nandini was his favorite grandchild at her wedding. All other children were aghast at this but it so happened that each of them had no doubt in their mind when they believed that they individually were his most favorite one! Such was his affection towards them.

> *His protective nature extended to his children and his grandchildren. Even when my sister was in her 40s, he took upon himself to personally escort her from Mumbai to Puna every time she visited India. This was not something that anyone could argue about. It did not matter that my sister was born and raised in India and was at the time going around the world due to her work.*

After I was married and on my way to join my husband in the US, he accompanied me right up to Rhode Island, just to ensure that I was in good hands! Upon leaving me in my husband's care at Rhode Island, I was told that the emotions got his better of him.

For years, Kaka and I enjoyed making wine every spring. It was a ritual for both of us to get huge baskets of grapes from Gultekdi and like any chemical process, my father would ensure the end product was a crystal-clear red wine. Once, when we failed to make the white wine with the clarity that was needed, his experimental nature made him treat it with activated charcoal which resulted in clarity that made the wine look like gin and not wine! We laughed at the end product but my father ensured that not a single drop was wasted.

I remember his 80th birthday when his extended family (his students) had gathered at our house in Pune from all over India. I was scheduled to attend the festivities but his joy had no bounds when he saw my brother with me. A cricket match was going on at the time. Kaka had promised his students that he intended to hit the century just like Sunil Gavaskar and Sachin Tendulkar and he would have all of them again. His health was failing and all of us knew he was on borrowed time. His determination to lead a meaningful life had already extended the statistics of life after bypass surgery from 10 years to 20 years. He was convinced that his work was not yet complete. There was a lot to be done for rural India and as a scientist he owed it to the people.

To me the ideal world always consisted of one with Kaka in it. I did not know what it was like not having him as part of my life and had never given it a thought. After his passing away, to me, it was like an era coming to an end. It has been more than nine years now and the vacuum is still there.

LKD, by son Deepak Doraiswamy and daughter Sandhya Raghavan

As an illustration of our father's (Appa's) whimsical humor, he sent two separate requests for this article to us addressed to: *Sdaenedphayka* and *Dseaenpdahkya* (constructed from the first letters of our respective names)! This was a playful reminder of the times when, as children, he used to send us postcards addressed alternately from the various conferences he attended round the world to ensure that we were treated identically in absolutely all respects.

Although Appa is the consummate workaholic, family has always come first and he has been available to us during emergencies without exception. An especially poignant memory concerns him spending hours massaging our sick mother late into the night. He would drop everything and rush to her aid every time until her final moments. More recently, when one of us (Deepak) had a serious car accident he was at his bedside in the US within 24 hours and literally nursed him back to health almost without sleep for days on end. Appa's sometimes grim appearance also belied a playful and tender side with friends and family. On one, now legendary occasion (a selection committee meeting at the Indian Institute of Science in Bangalore), while peering over his reading glasses to return to an interviewee to ask a question, he was perplexed to find that the candidate had disappeared. On closer inspection by the committee and after much consternation it was discovered that the unfortunate man was overcome by the appearance of our father and had passed out on the floor. He was revived and promoted!

Appa was addicted to comic books and loved discussing them with us. He could identify every comic character with the greatest ease! He used to often invite his students home for meals and our mother loved making *masala dosas* for them, which were her specialty. He enjoyed back massages and, as children, we and our friends were encouraged to walk up and down his back in single file — it must certainly have been quite an amusing sight!

Appa is meticulous about English usage. We have often seen him ponder for ages over the placement of a comma or the selection of just the right word during the writing of his book on 'Heterogeneous Reactions' (with Prof. M. M. Sharma) and, more recently, during his historical survey of the NCL. Sharma uncle, as he is still known to us, and Appa would stay up late into the night discussing various aspects of chemical engineering in India after the sumptuous meals provided by our mother — while we valiantly tried to stay up with them. Even as a boy his English teacher (Mrs. Garden of the Methodist Boys High School in Hyderabad) once seems to have told him that *chemistry need not be the only subject in which you could excel; you would do even better in English*.

Appa was very dedicated to the quality of life on the NCL campus and often used to take evening walks with our dog — an occasion when he used to talk to people and identify issues of concern to his colleagues. His eye for detail was legendary and he worked hard to ensure that the colony was kept clean and aesthetically pleasing. One of the nice conveniences he brought to the colony was the shopping center which was later named after our mother Rajalakshmi by Dr. R. B. Mitra, Deputy Director of the NCL, and other senior NCL scientists, to commemorate her memory. This is a good time to mention a few words about our mother who played such a key role in defining our personalities. She was snatched from us at the young age of 49 after undergoing a painful and stoic battle with lupes. She was an extraordinarily patient person with no airs what so ever about her. There was an innocence and down-to-earth nature about her that was so refreshing that nearly everyone was at ease with her — ranging from laborers to esteemed visitors. She was a gentle influence on all of us — someone who was always there to cheer for us during our victories and provide the emotional strength to help us pick up the pieces when things went wrong.

We have known all along that Appa was helped by a whole lot of people in managing both his official and personal affairs, so we were quite apprehensive when he moved to Ames to live entirely on his own. He has been doing a remarkable job in spite of recent problems with his health — sometimes serious ones. He showed remarkable composure on one occasion when he managed to get to a hospital on his own after a serious head injury. He is one of the lucky individuals for whom his work is also his hobby and he greatly enjoys the intellectual stimulation of his department. He helped mentor a great graduate student group which continues to stay in touch with him. He ran a "Nonsense Club" for several years with his students to discuss various philosophical issues on a regular basis (accompanied, of course, with meals!).

He is almost never late for an appointment and his tendency to provide for a large buffer when going to the airport is a standing joke in the family! One of his key strengths has been his ability to listen to people and not dominate conversations — a rare virtue in today's world. Appa's tendency towards quiet understatement, firmness in his decisions and an old-world ability to always provide the "losers" in an argument with a graceful, face-saving exit have always been his distinguishing features. His ability to exude strength and leadership while maintaining gentleness is perhaps what describes him best. He has always led through gentle example and, right from our childhoods, never had to threaten either of us in any way.

Appa, an insouciant perfectionist, loves the NCL passionately and in many ways has nurtured it almost like another child. His wry sense of humor, intellect, strength, and above all, a profound sense of personal ethics have always been and will continue to be a tremendous source of inspiration to us.

Ramesh Mashelkar, by daughter Shruti Borde

It is always difficult to write about one's own father — especially when there are so many memories. Many people that I have met in the past have said- *You must have really missed your father, the busy man that he is.* I must emphasize, it is rare for a man to reach the helm of his career, devote his life to the upliftment of the country and still find time for his family. We have been the fortunate ones. Whether it was teaching us late into the night after a hard day's work at office, or wishing us on our birthday wherever we are or he is in the world, enquiring about his grandson's progress, advising us on important issues and at times just giving us the patient ear — he did it all.

With a busy schedule that is second to none, he would always have time to attend fam-ily functions, being there for the most important puja in the house, to spend quality time with my mother — recognizing that she has also sacrificed a great deal for him, still gaining wisdom from his mother, watching India play cricket and then often cry when India lost and whenever his grandson is around, to be a 4-year-old himself.

I still remember how he brought innovation in his teaching by using props such as balls to teach geography, flowcharts to teach history and many more. What also amazes me is his ability to clearly communicate his message and make the other person comprehend him. He often discussed work with the family in the evenings but it was the most exciting time for us — we would sit there and listen to him for hours, mesmerized in the process. He also enjoys the time that he gets to spend with his son-in-law — dreaming together about a technology-led future.

He has always been a great pillar of support — together with our mother, always guiding us in the process. He is a man who always believes in forgive and forget and that was good enough to discipline all of us. Of course this comes probably from the kindest heart that he has — whether it was sitting by the bed side through the night when we were ill or making a phone call at 2 in the morning to enquire about his grandson's broken leg.

He signs with his initials R.A.M — and that is what he is to all of us. He is our RAM.

Note: Shruti perhaps does not know that it was I who christened him RAM.

Paul Ratnasamy, by daughter Sylvia Ratnasamy

When Dr. Doraiswamy first contacted my sister and myself about this article, I must confess that our initial reaction was tinged with a slight dismay. Writing has never been our forte — could our words ever do justice to our dad?

Across different time-zones, we ruminated over the essay frequently and at length (our phone bills attest to this!) we laughed — *Remember when Pa came to our school*

PTA meeting wearing black shoes, green socks, brown pants and a blue shirt? — smiled fondly — *Do you know that Pa will still step into the middle of Fergusson College Road and stop the traffic so that Maman can cross the street*? and resurrected innumerable precious memories that had been collecting dust. Hilarious tales, only-my-dad anecdotes, bittersweet memories, all tumbled forth and, in our minds, we wrote page, after page, after page. Trepidation gave way to unbridled enthusiasm. Step aside Rushdie!

And then comes reality. Pen to paper. Fingers to keyboard. I've been sitting at my computer for hours now but the screen remains blank and the "delete" key looks somewhat the worse for wear. This is not, mind you, for lack of material! On the contrary, unruly memories push and shove inside my head, jostling each other to get ahead like rush-hour commuters on a Mumbai local. I try, but fail, to bring them to order. Where does one start? With the gentle father who told us bedtime stories about Mowgli and Sher Khan? Or the young-at-heart father who played "pretend" cowboys with us? (For those curious, Pa played the role of Dirty Harry, my sis was Bronco Billy). How does one proceed? To the proud father who bragged unabashedly about his daughters to anyone willing to listen? Or the protective father who could rival an Inquisitor in his interrogation of every male friend his teenage daughters brought home?

They say that memories appear as images, visible only to the mind's eye. I believe that. But when I close my eyes, I see a veritable cascade of images from our childhood. I wade through them, rifling through, picking this-or-that one up, setting it aside. Here is one of Pa taking our dog (Sophie) and cats (Mao and Rustam) on their nightly walk through the NCL campus — a tall and too-skinny figure followed by a lazy Labrador struggling to keep up with Pa's brisk pace. Here is another of my dad trying (repeatedly and unsuccessfully!) to cook plain rice. Looking, hunting, exploring, reaching — and slowly it dawns on me that the overwhelming impression my collective of images convey is one of color.

Bright, bold, happy, exciting, vibrant color — that is what my father brought, and continues to bring, into our lives. When Pa came home from work, the tempo picked up. Suddenly, our discussions were a little more animated, our debates a little more spirited, our laughter a little louder, lasting longer. It is hard to break such charm into its component causes but there are three key "dad characteristics" to which would attribute Pa's ability to invigorate any room he enters.

The first is that, in his thoughts, Pa recognizes no barriers. Instead, he is constantly exploring new directions, seeking new ideas, turning things inside out. The result can be exhilarating and Pa's attitude infected us all. Growing up, our house had few rules and regulations. Instead, we were encouraged to question everything. And we did! No topic was off limits, no thought inadmissible, no person too venerated or custom too sacred to be opened up for scrutiny. There were times, I am sure, when my parents regretted this! On most topics, we would find ourselves with four different opinions, each of us vociferously defending his/her point of view. Consensus could be slow to arrive at, but this culture sure made for delightful meal time discussions — lively, stimulating, rich in color and spice. Just like the idli-sambars and fish curries Pa so enjoys.

The second secret to Pa's colorful personality is, I am afraid, somewhat less intellectually worthy — when Pa tells a tale, he is prone to embellishment. There is one tale in particular over which we constantly pull his leg. Apparently, in his student days in Madras, Pa participated in some political demonstration. I first remember hearing about this when I was about 6 years old; in that version Pa was a "participant" in the demonstration. When I was about 8 years old, Pa and his co-demonstrators were responsible for "major political upheaval" in Madras. At 10 years, Pa and his partners in crime had "held up a train" as part of the demonstration. At 12, Pa had "instigated and led" the demonstration. At 14, Pa had laid down on the train tracks and single-handedly stopped the train. At this point, we asked my uncle (Pa's elder brother) for the truth. And indeed, there had been a demonstration, a train had been stopped and my dad had been around. No evidence exists as to who stopped the train. We remain skeptical. What we do believe though is that Pa's love for a juicy tale stems from his love to entertain and bring joy and laughter to those around him. And, in that, he is incredibly successful.

The third reason is, very simply, that he cared. To his home (wife, daughters, dog, cats and even the stray dogs we would adopt on occasion), Pa brought the same attention and enthusiasm that he did to his work. I have no doubt that my dad was frequently up to his ears in work and had innumerable work-related issues and deadlines to worry about. And yet, we never saw this. Pa was always home by 6 p.m. — ready to play with us, accompany my mom shopping, or just sit around on our front steps watching the sun set and partaking in the everyday family gossip and banter.

But color is not all. A remarkable facet of Pa is that the outer dynamicity is accompanied in equal magnitude by quiet thought and introspection. I would often come across Pa sitting out on the porch, the book he was reading set aside. I would ask him what he was doing and he would say *Thinking. What about*? *Things*. was the brief response. And then, switching to his teasing mode, *You should try it sometime*. We would routinely see Pa spend hours in this manner — contemplating some unseen scenes.

Did I mention that Pa is a really terrible driver? We fear for the lives of innocent Puneites every time he gets behind the wheel. He is, however, a really snazzy dancer. He can jive with two partners at the same time — the price one pays for having two daughters, I suppose. My mom's cute twist is the perfect pairing to Pa's smooth jive and they hog the limelight every time they take to the dance floor (which, by the way, they still do — long after their children have set aside their dancing shoes).

I could go on.

The above is but half the tale, I am afraid. One side of a coin. The other is Maman and the picture could not be painted without a few words on that front. If my dad was the bold reds, my mom was the pastels that soothe. If my dad makes us burst into boisterous laughter, only my mom can bring out our Monalisa-like smiles with her rare but oh-so-subtle jokes. When my dad tests our patience by going on a little too long about the teachings of Krishnamurthy, my mom reminds him that the trash is waiting to be taken out. My mom is the one we would crawl to, tail between our legs, after a fight with a friend at school or an exam failed. Pa understands the importance of a paper accepted by that prestigious journal, or the delicacy of politics in the workplace, but Maman understands the importance of finding the perfect dress for that "special" party, the appeal of a trashy book, the joy of aimless walks through foreign cities, of aesthetically pleasing rooms, of rainy afternoons, and myriad other little indulgences. The colors blend together in perfection. Differences in harmony, harmony in differences. Smooth jive with dainty twist. The drama of Gauguin, the serenity of Botticelli. Exuberance with patience. Intellect with compassion. Non-materialism with a taste for beauty. Optimism with wry cynicism. Love, affection, humor and honesty. My sister and I could not have been more blessed.

S. Sivaram, by son Sushil Sivaram

NCL, Dad and Me…

Sitting at the departure lounge of an airport I read a poem to Father about another son writing to his Dad. He liked it and spoke to me about Robert Frost, Wordsworth and some of the other poets he liked when he was younger and before he was "wedded to his polycarbonates." I guess images like this stay permanently stippled in forever recollections as compared to more concrete "things" which a father does for a child.

I was young when I moved to Pune. I overheard father and mother talking to each other about his need to pursue research. His partial dislike for the corporate world which made him migrate from Baroda and my own initiation into a new town. I felt bitter sweet.

But we made the move nevertheless.

Pune was different. The first impression of the National Chemical Laboratory was that it was a huge aircraft with a long green central hull and wings sprawling on either side like a giant bird in flight. It was mythical and I looked down in wonder many a time when I used to spy the building from atop the hills, behind the colony. Similarly in one of our evening conversations I learned that the "directors" used to live at one time on the top floor of that monstrous fuselage. I had dreams of aristocratic driveways the length of small islands, for months.

The initiation was rapid. I spent considerable time in the Division of Polymer Chemistry as an apprentice to science. Dad's schedules were beyond my little understanding and even today I wonder if man should be as one-tracked and possessed by his profession. But now I understand the enigma and have come to terms with the fact that he is simply wired that way. In fact, in all my innocence I even imitated his schedule, carrying school work to his room and sitting and working with him as he ploughed through his day's hard labor till late at night. Thinking back now, I remember going to the laboratory was almost a family affair! Maybe as I grow older and more mature I will understand his single minded devotion towards work, his elixir, his manna, the "chemical abstractions" which govern his life and the dedication towards a cause and an institution.

I met interesting people (a nice professor in khaki shorts who tried teaching me material science as I tried hard to understand what they were talking about), interacted with his students (who told me they studied for 16 hours a day during examinations!), sat on stacks of The Journal of Polymer Science and the Aldrich Catalogue and did my home work, drew pictures on his white board, practiced titration in some basement lab which reminded me of haunted catacombs in a medieval castle, stared in amazement at little white magnetic stirrers which moved magically at the bottom of Pyrex conical flasks and tried learning organic chemistry from the man himself.

And one book in his vast collection which I can never forget was a book on the science of rubber bands which I read and reread a number of times.

The National Chemical Laboratory for all the real reasons became a part of our lives. One man's dedication to his work and institution changed perceptions; not only in his own life but also in all the lives he seemed to touch. The lab skulked like a familiar shadow over all our beings and today having tried looking at the circumstances from both sides I cannot draw any conclusions. There were good times, there were bad times, but growing up in that particular environment is what has made us what we are today, what he is, what I am and what we are...very different individuals with very different interests but still a father and son.

Much that is natural, to the will must yield.
Men manufacture both machine and soul
And use what they imperfectly control
To dare a future from the taken rout!.

Thom Gunn, 1929–2004, "On The Move 'Man, You Goa Go'"

CHILDREN OF TWO OF THE MOST INFLUENTIAL CHAIRMEN OF THE NCL'S RESEARCH COUNCIL

Prof M. M. Sharma, a.k.a. dad, by son Vibhu Sharma

Dad has been a genuine inspiration as I was growing up. Since his work kept him away from home quite often, we would cherish the time we spent with him on evenings and weekends.

He continues to be a highly energized molecule and inspires everyone he touches. One of the exciting events I remember while growing up was when there would be these business meetings with industry stalwarts. As a kid, I would sit in or listen in to the conversation. It would be a big attraction to hear the business leaders talk about big new projects and investments and hear dad's animated discussions. This was a big reason for me getting into my own business today. Noteworthy also would be his extended technical discussions with Dr. Doraiswamy at NCL, and Dr. C. N. R. Rao over the phone as well as during visits to Pune and Bangalore.

We took so many walks around the campus & around beaches. Walking (brisk walking, I might add), is one of his big passions. Come rain or shine, you can find him walking around the campus at 6 p.m. every evening. As a family we were a close knit one and would enjoy eating dosas from the nearby Anand Bhavan. Dad would pick up these piping hot dosas and bring them in for an evening snack. This would initiate an impromptu family get together. We took several family trips around the country. Pune used to be a regular haunt, not to mention the comfortable setting of the NCL guest house. I especially remember the wonderful hosts there and their gourmet cooking.

While he was quite strict with us as far as education was concerned, in all other matters he was a "softie" at heart. He epitomizes the saying "keeping your ears open" since he has this uncanny ability to be listening in on multiple conversations at the same time. He would have unusually deep knowledge in Bollywood movies and Indian music (especially old hits). It would not be fair if I do not mention his voracious reading habits. He could read for hours on end anywhere from movie magazines to technical journals.

All in all, he is just a magnetic person to be around. He instills excitement and inspires me every day. He is a task master and keeps me on my toes and pushes me to be the best that I can be. For this and for being my father, I would always look up to him.

My father, C. N. R. Rao, by daughter Suchitra Ganesh

I should begin by saying how lucky I am and feel proud to have a father like him. He is a wonderful and caring person, simple and young at heart. One must really get to know him to realize his true loving qualities.

He is totally a family man. Even though he used to travel a lot for professional reasons when we were children, yet he found a lot of time to spend with us when he is at home. This is because he never carried his work home and so he could spend quality time with us. In his absence, my mother was the backbone of our family. My father has tremendous faith and confidence in my mother's abilities and very much encouraged her to pursue a career of her own. But all this never came in way of family life and my brother Sanjay, my parents and I together were a small, well-knit and simple family. My father and mother understand each other very well and know each other's wants and needs.

He is a wonderful, dedicated and an affectionate father, who always superbly supported me in my life. He always appreciated even my little successes and never discouraged failures. Apart from his profession as a teacher-scientist, he has a lot of other interests to relax all of us at home. He loves listening to music, (hindustani, karnatak and western) voracious reader of novels and fiction while at home and traveling, very fond of cooking authentic and delicious meals for us — in particular Chinese and Italian — and a great lover of sports (tennis and cricket). A favorite past time in the family was to watch a movie on television every Sunday evening at home. He also loves taking us for eating out in his favorite restaurants. My father likes gardening and looking after pet animals. He has a green thumb — whatever he plants, it happily grows. Above all, he is a great traveler with the family during holidays. Even now he enjoys taking us along with Kartik and Suguna to exotic tourist places such as Simla, Nainital, Jim Corbett park and also to several cultural places. He enjoys watching plays and I often fondly remember our Cambridge days in 1983 when he took me and Ganesh to London theaters almost every fortnight to watch hit plays such as *Hello Dolly*, *Mousetrap*, etc. He is a great conversationalist and has a great sense of humor; he can make any party burst into laughter with his jokes and wisecracks.

My parents are really made for each other and are very exemplary for me in managing my own family, with my husband also being a scientist. My father has been very successful not just because of his excellent science, but also because of his sheer uncompromising determination in anything he does, his focus and hard work and most importantly, my mother's dedicated support. As a child, I too used to have arguments and small fights with him, but looking back, I had a lovely childhood, adolescence and grown up life due to his many-sided personality. My mother always said *with him there never is a dull moment.* I always look forward to visiting my parents and brother during holidays with my husband and children and when we are all together, it is like old times — good food, music, travel and fun with my father and mother.

Snapshots in History

THE FORMATIVE YEARS: REMINISCENCES OF EVELYN MCBAIN, WIFE OF THE FIRST DIRECTOR OF NCL

Mrs. McBain's article is readily available in *Chemical Engineering News*, 1954, and therefore will not be abstracted or summarized here. This article introduces the NCL to the international scientific community in a DeBona way. It is a combination of fact, historical perspective, and exposure of friendly foreign eyes to practices and procedures common to India but delightfully new to them. It also recaptures with telling simplicity the birth of a future enshrined in a structure of Italian marble and local masonry. The following extracts tell their own story:

Motley labor force on duty: Furthermore, building in India is not mechanized; a building is a hand-made affair... All cement was watered down by a water carrier who squirted water from a goat skin. He also served as a drinking water boy. Many women brought their tiny babies to work with them, and they took time off for feeding. Older children played in sand piles or on swings hung from scaffolding... The work went forward but never fast enough. However, Indian workers can always be relied upon in an emergency. For example, a Science Congress was to be held in Pune in January 1950, and Prime Minister Nehru, who is himself a scientist, wished to have the NCL opened at that time when so many distinguished Indian and foreign scientists would be assembled. This meant a mad rush for everyone night and day even on New Year's Eve. By the morning of January 3, everything was ready...

Democratic ideas introduced: In India, office buildings and laboratories have a peon seated on a stool outside each doorway to act as messenger boy. It was always embarrassing to walk down one of our corridors in the early days because every peon would rise and salute *memsahib*... We put the peons inside the rooms in useful occupations and installed an internal telephone system.

Cafeteria a social center: I was told that self-help will not work in an Indian cafeteria. However, on opening day, Dr. McBain and I fetched our coffee and returned our cups, and no one thereafter questioned the procedure... This had the effect we wished of making each member of the laboratory feel that he or she was someone who counted and that all were members of the NCL family.

Ceremony marks every undertaking: You would think it a simple thing to plant a potato or even a row of them, but it is not as simple as it sounds. I had to lay the potato on the soil, partly cover it with earth, sprinkle it with petals and red dust, and then "water" it with coconut milk. Then I had to put pellets of camphor around it, light them, and while they burned my instructress chanted a yearning melody...

SILVER JUBILEE: REMINISCENCES OF K. VENKATARAMAN (ABRIDGED FROM HIS ARTICLE ON THE OCCASION, *NCL SILVER JUBILEE SOUVENIR*, 1975) (VENKATARAMAN 1975)

My own association with the NCL goes back a few years earlier as a member of the Planning Committee and the special committee for the choice of the site. We asked for a plot of land across the road from Government House, now the Pune University campus, but the Governor, Sir John Colville, thought that the stinks from the laboratory might drift into his residence a mile away, and the present site near Pashan was then chosen.

The oldest member of the NCL staff still in service is driver Dagdu. He has continued to be a dependable chauffeur, but his reputation as a water diviner is more doubtful as I found to my cost. After drilling deep enough to strike oil at a point he indicated in my bit of land to which I moved after retirement, we found no water. My old friend, Dr. B. D. Laroia, whom I succeeded in the Forman Christian College, Lahore, in 1929, occupied an office at Nos. 1 and 3 in Ganeshkind Road in Pune in 1947 to look after the construction of the laboratories and all the other administrative work. A group of biochemists (Drs. M. Damodaran, P. N. Rangachari, S. S. Subramanian, J. C. Sadana, C. SivaRaman), Dr. S. K. Kapur (the monomer who soon became a sizable polymer), and an Oils and Fats group (Dr. J. S. Aggarwal, P. G. Sharma, S. C. Sharma, S. C. Sethi, A. S. Gupta and H. H. Mathur) started work in the basement a few months before the official opening. G. V. Kulkarni, a Lab Assistant in Biochemistry, joined in June 1949; I discovered his unexpected talent as a linguist with a good knowledge of German, French and Russian when I was looking for recruits in 1966 for my PL-480 project. Dr. J. L. Bose, Dr. K. K. Chakravarti, and a few other organic chemists, who were already working in the CSIR labs in Delhi, shifted to Pune early in 1950.

Professor J. W. McBain, the father of colloid chemistry, took charge as director in September 1949. A little later the McBains happened to be guests in my home on top of the Department of Chemical Technology in Mumbai. A kind friend in the University Senate once spoke of the nice apartment I had built for myself with a few labs underneath, probably as an afterthought; and the McBains were so taken up with my apartment that they decided to give up the bungalow allotted to them in the NCL campus and convert the top floor of the laboratory into their residence.

Professor McBain was succeeded in 1952 by Professor G. I. Finch, famous for his work on electron diffraction and the electron microscope. When Dr. Bhatnagar mentioned his appointment to me, he indulged in one of his characteristically atrocious puns that Finch was on the very fringe of chemistry. Finch vigorously developed solid state chemistry at the NCL. He discovered R. V. Kulkarni, A. U. Momin and Niranjan Singh, thus providing the NCL with excellent workshop, instrumentation and glass-blowing facilities which were further improved when new buildings for the workshop and glass-blowing were constructed in my time. Finch's fame as a chemical physicist was equaled by his fame as a mountaineer. He was probably the first to get to a thousand feet of the peak of Mount Everest, and to climb Mont Blanc was an almost routine exercise for him. It is a sad thought that his successor was an asthmatic who regarded with awe the top of Chaturshringi.

Professor Finch was a man of strong likes and dislikes. Another failing, at least in my eyes, was that he regarded organic chemists as mere bottle washers. He had perforce to make exceptions of Emil Fischer, Kuhn, Karrer, Robinson and a few others at the Nobel prize level. Dr. R. C. Shah at the head of the Organic Division was a very competent chemist, whose new reagent ($ZnCl_2 + POCl_3$) for instance found application in the synthesis of phenolic ketones and xanthenes; but he was not a fighter who could stand up for himself and his division. Professor Finch thought highly of Dr. S. C. Bhattacharya and as a result the NCL became an active centre of research in Essential Oils. One of my first tasks, when I joined the NCL in 1957, was to develop areas of organic chemistry outside essential oils. Dr. Sukh Dev took over from Dr. Shah in 1960 and rapidly established a flourishing school in the chemistry of natural products which attained an international status. Dr. B. C. Subbha Rao in selective reductions and experimental techniques, Dr. C. R. Narayanan in stereochemistry, Dr. P. M. Nair in NMR spectroscopy and Dr. K. G. Das in mass spectrometry helped in restoring organic chemistry to its rightful place. At the same time Dr. Bhattacharyya's work in essential oils was encouraged to expand by building a new wing devoted solely to this group of natural products. Synthetic organic chemistry was represented mainly by perfumery materials and somewhat desultory work on synthetic dyes, but an ambitious program with special reference to heterocyclics, pharmaceuticals and pesticides was undertaken after 1965 when Dr. Tilak joined the NCL. One evidence of NCL status in organic chemistry was the award of the Bhatnagar prize to Bhattacharyya, Sukh Dev and Tilak.

The day before the Finches left India, my wife and I met them at dinner in Dr. Hamied's house. Finch took me aside after dinner and for over three hours gave me a vivid picture of his impressions of the senior scientists at the NCL. He spoke of his many "finds." Two of them were Drs. A. P. B. Sinha and K. P. Sinha. He has provisionally arranged with Dr. Bhabha for their transfer to the TIFR because he was apprehensive of their future in the regime of an organic chemist. The Sinhas stayed on of course at the NCL because I told Finch somewhat tactlessly that the balanced development of chemistry as a whole would be my endeavor. A. P. B. Sinha continued to provide solid support to the progress of the NCL, but K. P. proved to be a renegade who deserted us for reasons best known to himself.

Not long after I came to Pune my attention was drawn to the comment of some cynic that the NPL had become famous for its cafeteria and its garden. This hurt me deeply, and I took immediate steps to build a new cafeteria.

My chairmanship of the Development Council for Drugs, Dyes and Intermediates gave me the chance to get a resolution passed recommending the creation of a Division of Dyes and Intermediates at the NCL, and to use it for speedy implementation by the CSIR. One object was to make Dr. L. K. Doraiswamy an A. D. and to give full scope for his outstanding ability as a chemical engineer. He proved to be a tower of strength to my successor who expanded LKD's domain to the vast Division of Chemical Engineering and Process Development and made LKD his second in command.

A broad assessment of our record during the period I am covering must be that our published work was impressive and the NCL was without question the leading Indian centre for chemical research; but our impact on industry was marginal. Although many useful products and processes were developed, their translation into commercial production was beset with difficulties. This is hardly the place for discussing the relevant reasons or apportioning blame; but the chequered history of vitamin C might be worth briefly recalling. The multistep process from glucose was released to Hindustan Antibiotics in 1960 after a team from the company examined it in detail and made a favorable report. In p. 16 of the Annual Report of the company for 1961–62 it was stated:

> *Sanction of the Government of India for Vitamin-C project at an estimated cost of Rs. 60 lakhs has been received in April 1962. A foreign exchange of Rs. 30 lakhs in Yen currency has also been released. Steps have been taken to procure the plant and equipment, the designing work having been completed. The building designs are also ready for taking up construction work.*

As of today vitamin C is not in production at Pimpri! [see Chapter 10 to find out why.]

My most useful contribution to the NCL was to create a post of joint director and to persuade Dr. B. D. Tilak to accept it, because he was the obvious choice for the next director.

One reason for the steady progress of the NCL to its present position in India and its international reputation is the absence of any upheaval with a change in the post of director. A common phenomenon in our country, when a new person takes charge of an institution as vice chancellor, director, etc., is that he quickly proceeds to demonstrate that his predecessor was an unusual combination of congenital idiot and crook; and to turn things upside down. Fortunately, the NCL has been undergoing a natural and health process of evolution based on tradition, an understanding of earlier problems and difficulties, and a pride in past achievements. All of us associated with the NCL can look forward with confidence to a future in which it will play an increasingly useful part in the advancement of both chemical science and the chemical industry.

THE NCL OF 1962: REMINISCENCES OF A SENIOR SCIENTIST C. GOPINATH

This laboratory was only 12 years old, the trees around much shorter, and the main building absolutely shining when I joined as JSA in the Inorganic Division which had a strength of about 75 at that time.

Since there was no immediate hostel accommodation available, I was staying in a lodge in Deccan Gymkhana. Conveyance was not easy; there were very few scooters, motor cycles or cars. Auto-rickshaws were very rare; cycle, bus, taxi and tonga were the only modes of transportation.

There were two special PMT (Pune Municipal Transport) buses plying between Deccan and the main gate of the NCL every working day, morning and evening — one via Shivajinagar and the other via Fergusson College Road. The passengers always outnumbered the seating capacity of the buses, and only a few standees were allowed. Hence there used to be long queues at the NCL entrance at 5 p.m. itself. Some intelligent scientists reserved their positions in the queue by keeping lunch boxes, newspapers and umbrellas. The bus fare for the non-stop trip of 25 minutes was 20 n.p.

Buses from Pashan were very rare, and just as crowded as they are now. If one missed the special bus at 5.30 p.m., the only feasible way to reach home was to walk up to the University Gate and catch some other PMT bus. There was one good thing at that time. The multi-storied flats at the NCL were just completed and there were only a few aspirants.

So all those who had dependents or declared to have them (on paper only) were given quarters immediately after joining the NCL service. For bachelors, the old hostel was the only relief.

There were no shops nearby; the Coop timings were very short and not too convenient. One had to go up to Ravindra's at the University Gate to get a match-box, kerosene or any such provision.

Research was given top priority at the NCL. Most of the work was done by regular employees only; research fellows were very few. Junior Research Fellowships were awarded by the director to all candidates with First Class M.Sc.; those who had only Second Class had to go to Delhi for an interview. The JRFs got a monthly stipend of Rs. 250 (US $ 35, using the then conversion rate) only, but this was sufficient for a fairly decent living.

There was a shortage of funds for everything in the laboratory — glass apparatus, chemicals, writing paper or notebooks. Small round-bottomed flasks with standard joints and stoppers were considered to be a precious possession.

Research Fellows worked as hard as now; those in Organic Division had to wait in queue to carry out gas chromatographic and NMR analyses of the pure samples they had isolated after days of struggling with spinning band columns or thin layer preparative chromatography. Only two gas chromatographs and one small NMR unit were there in the whole of the NCL. The Research Fellows worked late in the evenings; the head of the department had the practice of visiting the staff at their work benches at least once in a day (mostly after 5.30 p.m.), and this made the juniors feel happy and enthusiastic about carrying out their research.

Some other memories are raising their heads... There were no identity cards or attendance registers — the staff could come and go at any time of the day... Saturdays were half working days... Tea and snacks were always available in the privately-run cafeteria which was clean and tidy... The director used to host dinners for newly-weds... There were very few ladies working in NCL — some divisions were not blessed with a female at all.

Yes, the NCL of 1962 was certainly different. And yet, in many ways, it is the same.

(Note from LKD: The last sentence is interesting.)

RECOLLECTIONS OF THE 1980s, BY R. N. SHARMA, A RETIRED SENIOR SCIENTIST

The NCL, the oldest CSIR lab established before independence, has been fortunate in having a vast, sprawling campus which included a well-planned residential colony, a medical dispensary and schools almost right from the beginning. This enabled development of an almost filial culture and atmosphere in the campus, separate from the official work of the lab. The directors were usually patriarchal figures who took a keen interest in the welfare of the staff and upkeep and improvement of the colony. The NCL boasts of a Staff Recreation Club, and a Ladies Club. The serving director is the president of the NCL SR Club, and usually the director's wife is the President of the Ladies Club. This serves to involve the leading figures of the community in its activities and welfare. All senior functionaries including the director usually participate in colony functions mostly geared to local or national occasions or festivals.

By the 70s, admissions to the prestigious Loyola School for boys had been made deliberately difficult especially for NCL staff by the school management, despite the land for the school having been donated to it by the NCL. All NCL directors were usually quite conversant with nearly all situations affecting the NCL and its staff and colony. They were also generous in helping new comers. I was one such, being entirely new to Pune. Dr. Tilak offered to help me in securing admissions to my children despite having sworn not to speak to the Loyola school management ever again. He assigned the task to the Administrative Officer (AO), Mr. O. P. Khanna, a crusty, no-nonsense Punjabi refugee from Pakistan, settled after partition in Delhi. One fine day he called me on the phone and told me to go to Loyola and pay the fee for my younger son who was seeking admission in the first standard. The child had passed the interview but was denied admission because his handwriting was not satisfactory. The NCL knew that it was a deliberate affront to it since it had become the school policy for some years to deny admissions to wards of new NCL scientists to force the NCL functionaries to plead. The then Principal had not reckoned with Mr. O. P. Khanna. On going to the school, I was shocked to find the high and mighty Principal literally in tears. In a broken voice he begged me, *Tell me Dr. Sharma, is this the way to talk? Your AO threatened to throw me out of the school and to close the school and to shut off the water supply* … Having no sympathy for the boorish Principal, and being fresh from Delhi, I curtly asked him where I was supposed to pay the fees. The poor man came to the door to point the way to the cashier's office. Regretfully, the situation did not improve as expected after this episode too, and NCL had to opt to allow another school in its premises with the strict codicil that wards of the NCL staff would have to be admitted — an undertaking not taken from the other two schools.

A few years after Dr. Doraiswamy took over as Director, a situation arose when some NCL scientists found that the then AO wanted to get elected as vice president of the NCL Staff Recreation Club, a post always by tradition held by a senior scientist. The scientists found a diplomatic way out by requesting me, already known for my cultural activities for the club, and with a dubious reputation for many confrontations with the administration, to offer my name for the VP's post. The AO quietly withdrew his candidature. The Security Officer, Mr. Mohan Das, a fine, upright and sincere man was elected the Secretary. Both took their assignments seriously, and were pleased to find the President, Dr. Doraiswamy, enthusiastically supportive of their proposals and plans when he found them genuinely striving for doing something for the Club and the community. He agreed to fund the purchase of two community TV sets, one each for the Community Center and the colony for Class IV workers. He also approved ambitious plans for a children's park complete with the usual swings, see-saws, bars and other paraphernalia. The work was assigned to the NCL workshop, the expenses were to be borne by the NCL. Unfortunately, the work did not quite take off as planned and it was some years later that a real garden with a children's park annexe eventually came to be developed in NCL Colony. Dr. Doraiswamy also gifted Rs. 25,000 to the club. This was the amount obtained when a deposit with the new NCL school matured on its being taken over by the Deccan Education Society.

For a long time, Saturdays were film show days — two shows of films being organized by the NCL SR Club in the NCL Auditorium in the main building. This was an occasion for community gathering in a happy mood in the imposing premises of the main NCL building. Later, due to various reasons, an open air theatre was built in which, with its larger capacity, one evening show could accommodate the whole colony viewers. However, the shifting of the cinema from the main lab to the open air theatre did signal the end of an era and the *bon homie* that was unique to the NCL auditorium venue.

Till the time of Dr. Tilak, the NCL director's residence was on the top floor of the main laboratory building. Dr. Tilak would sometimes humorously remark that that made him a sitting duck for errant lightening strikes, but also rendered him available and accessible to his scientists at any time of day and night. His successor, Dr. Doraiswamy probably felt claustrophobically cramped in that location (but more so because his wife wished to live among the colony residents and not separate from them within the lab premises), and opted for renovation of an A-type bungalow into a permanent director's residence. Dr. Doraiswamy had a huge Alsatian which he would take out for evening walks around the colony. This kept him in personal touch with the colony, its maintenance, cleanliness (he had a penchant for cleanliness), and above all its residents.

Till the 80s, NCL staff residing in the colony had to go to the city by rickety municipal transport, or their own vehicles for almost all shopping. Dr. Doraiswamy, the 5th Director, was instrumental in planning for a regular shopping center in the colony. With the help of the dynamic and resourceful AO, M. M. Sharma, he had it largely funded by NCL. Today, trips to the city are no longer essential. The NCL shopping center commemorates with a marble plaque the late Mrs. Doraiswamy, a warm, familiar and lovable lady, who unfortunately passed away after an illness.

The Stuff that Reminiscences are Made of

The word reminiscences evokes strange thoughts, often lending a touch of fiction, making up in drama what it is presumed to lack in reality. David Kurzweil's uniquely written book *The Age of Spiritual Machines* comes apparently close, but is really far from it. It is a vibrant piece of work with reminiscences strewn all over, although, strangely, the word itself never appears anywhere. My reminiscences (along with others') narrated above are equally real and, in a sense, recall the sterner stuff NCL is made of, and give the lie to the half-humorous assertion:

> *The young have aspirations that will never come to pass, the old have reminiscences of what never happened.*
>
> H. H. Munro, 1860–1917

And yet it is just a memory. It is not the stuff to be lived again, but a pointer to changes that enliven and enhance life. What better way of saying this than *reminisce* the words of a great writer:

> [When I talk of reminiscences], *I am talking of a space, of moments and discontinuities. For even if months and years appear here, it is in the form they have in the moment of recollection. This strange form — it may be called fleeting or eternal — is in neither case the stuff that life is made of.*
>
> Walter Benjamin, 1892–1940

❄

18

WHERE DREAMS COLLIDE WITH REALITY
A REVERIE

Whereof what's past is prologue, what to come
Is yours and my discharge.[1]

William Shakespeare *The Tempest*, first published 1623 (Folio)

I like the dreams of the future better than the history of the past.

Thomas Jefferson, 1816

The makers of today's NCL owe it to themselves and to Indian science to continue the seeding of yesterday to yield a richer tomorrow. The morrow of this chapter is a derivative realization of today's vision and is inseparable from it. As Kalidasa, the great Indian poet of the 5th century CE, who was listed as one of the giants in Charles Murray's classification (see Figure 1.3 of Chapter 1), has said in his *Salutation of the Dawn* (English translation of the original Sanskrit):

For Yesterday is but a Dream,
And Tomorrow is only a Vision:
But Today well lived makes
Every Yesterday a Dream of Happiness,
And every Tomorrow a Vision of Hope.
Look well therefore to this Day!
Such is the Salutation of the Dawn!

Stevenson, 2004

The essentials and the etceteras of the NCL were described in the preceding chapters, in an attempt to present a complete picture of the laboratory. Its emphasis on excellence was not pressed beyond a point, nor were its failures stymied. The attempt was to present a totality of the laboratory over its period of existence without being a traitor to the scholarly imperatives of search. It is certainly true that the NCL, along with a few other research institutions like the IISc and TIFR, has given a fresh life in India to the meaning of excellence, taking it away from the realm of the popular to one of the beautifully specific. The votaries are many — with a gift for articulation unspoiled by even a pretense of selectivity — but the true practitioners are just a few. The general refrain of this esoteric trait has given it a commonness that insults its rarity. Excellence has become what someone says it is and the guiding expression of every institution, depending on its own generous interpretation of it. I do not wish this chapter to be a dissertation on this fascinating subject, but rather a somewhat personal description meant to be no more than a starting point for the separation of performances into categories that describe the NCL, one of which — the dominant one — is excellence.

Excellence apart, the NCL has taken many decisions over the years that together have forged a direction that has brought it to the present state. It is doubtful whether the change of a single decision would have caused more than a minor ripple in its path, but changes in many might have caused a directional change, for better or worse. There is always a movement with time, and whether this is a natural progression of events or a consequence of a planned earlier decision is difficult to tell. To borrow the inimitable words of Samuel Johnson,[2] *One should not mistake subsequence for consequence* (Quoted in Ferrari, 2003), as one often does, but a clear-cut separation too is impossible. In my personal judgment, the changes were more often a consequence than a subsequence.

I would like in this chapter to put excellence at the NCL in perspective, considering its interpretation and practice by its successive directors. Many of my friends who were aware of the writing of this book have suggested that I end it by offering my personal solutions to the problems that confront the laboratory as it passes through the first difficult years of the new century. I cannot summon the temerity to offer solutions, but I can certainly dream of a few options — with the full realization both of the objectivity resulting from my absence from India since 1989 and the somewhat personal status my close association with the laboratory for 35 years confers on me. What behoves me is to operate in the zone of dynamic neutrality created by their interactive influence. I start with the general observation that the NCL has been free of the disastrous displacement of one concept by another. No doubt new concepts were introduced from time to time. The new succeeded the old but without disturbing the equanimity of the lab and with a full understanding of the need to conserve commitment. The superseding concepts were not without creative pains but they were often not at the expense of the displaced ones and were a consequence of their own insertion into a stubborn status quo in need of repair, not expulsion. All these interpretations and conclusions may easily land the discerning reader into a scientific quagmire for they are not founded on replicated laboratory experiments. However, as Jared Diamond points out:

> *The word science is not derived from the Latin word for "replicated laboratory experiment," but from the Latin word for "knowledge."*[3]

It is this understanding of knowledge that gives any historical science, as the present effort claims to be, a credibility that is exceeded only by the truthfulness of its content.

My opinions and suggestions will be brief and to the point:

- *Continuing rejuvenation.* Scientists of very high merit were recruited in the 1970s and 80s, and they have been the torchbearers of the laboratory till now. For one reason or another, very few appointments at that level were made in subsequent years. As individual merit is the single most defining feature of an institution's excellence, a barren patch looms ominously — one that does not bode well for the future. Unless this patch is seeded, nourished, and imaginatively cultivated, by *wrapping it in cotton*, as Finch seems to have remarked to K. Venkataraman (KV) while handing over charge to him, the future might be beyond redemption. Talent in the NCL is central and must be part of its architecture, an a priori property woven into its very fabric, and not an aesthetic dye applied to it, painted and repainted in different shades.

- *Pre-emergent nourishment.* In continuation of the above suggestion, it is more important that talent is caught while it is still flowering than after it has expressed itself. A nourishing pre-emergent regimen can do much to further enhance quality. It would be wrong in the world of today to quote instances from the past of talent flourishing under adversity, because migratory opportunities for high talent are too numerous to be ignored. The NCL has yet to fully realize and implement such a course of action. The field of science abounds in examples of talent gone awry or driven to cynicism, and the NCL should move fast to arrest talent from turning into deadwood. There are also cases where a repentant senior tries to make up for his neglect of talent when help was crucial by excessive help after the talent has fully expressed itself, probably to curry favor at an opportune time.[4]
- *Weaning catalysis from bulk petrochemicals.* Heterogeneous catalysis, principally catalysis by solids, has been the NCL's major strength, particularly since the early 1980s. It became internationally renowned through its development of the Encilite series of catalysts for petrochemical reactions, which are invariably large scale processes. Catalysis by solids should continue to be a major area of research, but emphasis should shift to smaller scale reactions. With the advent of globalization, there is little the NCL can do in the conventional petrochemicals industry.
- *Making drugs directly with no separation problems.* Homogeneous catalysis, i.e. catalysis in a single phase of liquid, has not made its presence felt at the NCL in terms of new processes that have been commercialized (although it has made significant contributions to its understanding). Efforts should be intensified to effectively address this situation. Homogeneous catalysis can play a significant role in selectively producing drugs of the desired optical structure without the need for extensive separation.
- *Emphasizing the new rather than improving the old.* Catalysis (heterogeneous and homogeneous) should become a vehicle not just for carrying out known reactions more efficiently, but to discover new process routes.
- *Prospecting for knowledge.* Efforts should be intensified in the areas of combinatorial chemistry, chemical biology, materials science and engineering (nanoscience in particular), chirotechnology, nano-biotechnology, bio-polymer science and engineering, plant science and engineering, and discovery of new molecules. In fact, a modern discovery laboratory must soon be in the pipeline. The IICT in Hyderabad was the first to conceive of such a laboratory, and the NCL should have no qualms about being the second, remembering that IICT's discovery laboratory was the brainchild of one of its own scientists, Rama Rao, a former head of Organic Chemistry (Natural Products).

- *A wider program on plant science.* Plant tissue culture has been a major strength of the NCL right from inception, when it was new the world over. It is no longer a central technique of plant propagation, and many exciting modern methods have emerged. The NCL should seriously think of starting a more inclusive research program in the general area of plant science. I suggest that the Division of Plant Tissue Culture be renamed Division of Plant Science, with tissue culture continuing as an important part of it. This merits urgent consideration, as advances in this area are taking place at an incredible pace.
- *Strengthening the hyphen.*[5] A large proportion of breakthroughs in science will almost certainly occur at the interface of disciplines. The culture of interdisciplinary research, exemplified by hyphenated programs such as bio-nanoscience, bio-polymers (involving biochemistry and materials chemistry), should be considerably strengthened.
- *Honoring the originals.* Some areas have been the NCL's continuing strength and have brought international recognition to the laboratory. Biochemical sciences, organic chemistry, catalysis, chemical reaction engineering, and polymer science and engineering are the most visible of these. Polymer science and engineering has been singled out for particular attention and a state-of-the-art building will soon be coming up. The first truly modern building was constructed around 2002 for housing the newly created Digital Information Resource Center. Similar modern buildings should be planned for chemical reaction engineering and a couple of other carefully chosen areas. (Note: Separate buildings for existing disciplines were built in the 1970s and 80s, but as funding was meager and strict rules dictating the choice of the materials of construction were in force, these constructions lacked the quality of those constructed later in the free market era.)[6] These new, and some old (renovated), laboratories should be "name-laboratories," honoring the individuals who started the areas, such as Jagannathan for tissue culture (or biochemical sciences in general), Mashelkar for polymer science and engineering, Ratnasamy for catalysis, and Sivaram for DIRC. Appropriate names should be chosen for organic chemistry and chemical reaction engineering. Other areas have yet to make a lasting mark. This is an excellent academic tradition and the NCL should take the initiative in creating it in the CSIR.
- *Moving to discovery oriented research.* Analysis, process improvement (mainly new routes for known commercial chemicals), and the skilful use of sophisticated instruments have been the NCL's forte. While this strength should be nourished, discovery-oriented research should increasingly become its new forte. The pharmaceutical industry, in particular, has been in the forefront of discovering new molecules. The Indian pharmaceutical industry (mainly Reddy's Laboratories, Lupin Laboratories, Ranbaxy's, Nicholas Piramal) has recently joined this race for discovering what has come to be know as a New Chemical Entity (NCE) (see C&EN, 2008). With the chemical industry in India becoming increasingly sophisticated, the NCL should, as stated more then once earlier in this book, turn to NCE discovery. At the same time, it must be recognized that companies like CIPLA, which specialize in

manufacturing generic drugs more cheaply than the originals and are not involved in NCE discovery, have a major role to play in the Indian chemical industry, and laboratories like the NCL should do everything possible to help them sustain their high standing in the production of large volume drugs (like its top selling anti-AIDS drug and the newly developed generic version of Roche's lung cancer drug, Tarceva). It is worth reiterating that the NCL should not fully give up its traditional strength of developing new, competitive routes for known drugs, but with a full realization of patent obligations. This might cut into the profits, but the game must be fairly played.

- *Creating formal centers of excellence.* The concept of creating centers of excellence should be explored, with provision for naming outstanding scientists as directors of these centers, within the overall administrative jurisdiction of the director of the NCL. In time, the NCL could well become a conglomerate of such centers, conceptually a mini-CSIR. Catalysis, polymer science and engineering, plant tissue culture (or, better, plant science), catalysis, and chemical reaction engineering are obvious candidates for such distinction to start with.
- *Strengthening ancient science with the tools of today's research.* Natural products chemistry has been an abiding strength of the NCL over the decades, a strength that seems to have lost momentum since the departure of all senior scientists working in this area. This trend should be reversed and increased focus placed on ancient-modern concordance, as so beautifully brought out by Sukh Dev (1999). This is one area where two scientific cultures can meet, and the traditional Vedic methods revitalized through the language and tools of modern chemistry. Such an approach will lead to the identification, extraction/synthesis and more effective use of traditional curatives. This will not replace the work under way on drugs and pharmaceuticals, but supplement it. In the work-a-day market-driven world of today, such a facility would be unthinkable in the industrial laboratories of India, and most universities are too ill equipped to even think of it in a modern setting.
- *Maintaining the strength of a hallmark identity.* Apart from natural products, drugs, and dyes, organic synthesis in general has been one of the NCL's major strengths from inception. Although this strength has oscillated between a narrow range of high and low, even the low has always been much higher than the average in major centers of research. With the retirement or resignation of practically all senior organic chemists, only a few bright spots remain. The conversion of one of the organic chemistry divisions to chemical biology is commendable, but the vacuum this has created in mainstream organic synthesis must immediately be filled, for there is danger here of losing one of the NCL's hallmark identities.
- *Going hugely instrumental.* Instrumental facilities should be constantly replenished. As an example, I mention the following for quick action. Combinatorial chemistry, not quite a mantra yet but a surging field, should be greatly strengthened. Many schools in the world can claim excellence in this area, but only four in the USA (including the Chemical and Biological Engineering Department of ISU) have the kind of microscope that can split a material into astonishingly minute sections and actually view

its atoms in the raw [Local Electrode Atom Probe (LEAP) Microscope]. This can provide enormous muscle to research in this and other areas. The NCL should make every effort to procure one of these instruments (which, with all its accessories, can cost up to 5 million), by itself or in collaboration with the Indian Institute of Science Education and Research located in the larger NCL campus.

- *Finding new directions in contract research.* Contract research with multinationals should be undertaken not just to help them carry out development studies on clearly identified parts of a technology but also with the object of building up budgetary resources for conducting basic research.
- *Scale-up with a difference.* Routine process development should become increasingly the industry's responsibility. It has had its day at the NCL, having helped close a yawning gap of the earlier years. With the tools of traditional chemical process development now a common possession of the chemical industry, the NCL must move on to other related areas. For example, the methods of scale-up as practiced till the mid-1990s would not be relevant to such fields as nanotechnology for which no rational methods are yet known. Pharmaceutical chemistry has become a major component of the NCL's research program. Only a handful of engineering schools in the USA, such as the University of Michigan, have a program in pharmaceutical engineering. The NCL should join this number and explore new methods of scale-up and optimization.
- *Miniaturization is the way to go.* Use of micro-reactors in process development and optimization is becoming increasingly popular in the USA and a few other Western countries. This trend, already under way at the NCL, should be fully encouraged, and the NCL should strive to become one of the world's centers of excellence in this fascinating area.
- *Confronting a seemingly unsolvable problem.* It is pertinent to note that processes are being continually improved. It therefore becomes necessary for the NCL to be always associated with its processes in commercial production, which, for obvious reasons, would not be possible. The concerned firm would not be wanting in readiness to discard the NCL's technology and replace it with a new one, thus permanently eclipsing the laboratory from the picture. This is a difficult situation and must be handled sensitively.
- *Breaking from recent tradition.* A new idea should be tried and patented internationally. Its industrial exploitation should be fully left to the buyers of the patent.
- *From apology to prominence.* The NCL should never apologize for its interest in theory. In fact, this interest should be boldly inlaid on the center piece of its research program. Success in real theory is rare — so rare that funding agencies, genetically programmed to reject most such proposals, find a ready deterrent in the great, and often uncertain, length of time normally needed for a new theory to be experimentally validated. Admittedly, I am not talking of mathematical theories of the class of Euler's, Einstein's or Feynman's, but of lesser mortals. And here I shall repeat what I have said many times before (starting from the 1960s),

but by quoting Truesdell who expressed the same thoughts later much more authoritatively — a situation that might, in a lighter vein, brand me as an "*anticipatory plagiarist*" (see Chapter 2):

> *I do not suggest that other theories have been or are or will be as successful as Euler was in creating good mathematical theory of physics which was to lack abundant basis in experiment for two centuries. I do suggest that it may be not only naïve but stupid to proclaim and in effect to enforce a schema of scientific research that excludes an approach like Euler's.*
>
> Truesdell, 1984

- *Unfixing a fixation.*[7] The guru fixation is rampant in India, particularly if the guru happens to be a famous and/or influential person. Even some hackneyed scientific statements, in the category of clichés, made by him/her, and repeated in almost every lecture, are treated almost as sacrosanct. I am sure there are many instances of this kind where a famous or aging senior, in danger of exposure by a brilliant but voiceless minority, has torpedoed a really original idea or observation by a young scientist.[8] Our younger scientists must resist the pull of this halo, with which some of our famous scientists have bedecked themselves.
- *Learning some basic lessons.* Most departments in Western universities organize special lectures on patents and plagiarism.[9] The NCL recently took steps with regard to patents by appointing a patents specialist. The NCL does not seem to have given any thought to plagiarism. This is wrong, because, at one extreme, one may be plagiarizing even without being aware of it, and, in the other, one may be almost shamelessly doing it.[10] Corrective coaching is of the essence and should be taken up soon.
- *Why should "clean" be "unclean" and "order" not be "the order of the day?"* I have talked at some length in some earlier chapters about the merits of cleanliness and order, conspicuous by their absence in many Indian laboratories. I am personally greatly devoted to order; but I concede that it need not always be an indispensible virtue. In the mid-1970s, I was guest of a Professor Tartarelli in Italy. His secretary had warned me to tread softly in his office to avoid stepping on scores of files, loose papers, empty soda cans, cigarette stubs and the like strewn all over the floor, on desktops and shelves. I had not expected the *quality of disorder* that greeted me! However, when during our discussion I referred to a certain paper, he made an unerring beeline to the spot where it had lain and put it in my hands in a matter of seconds. Apparently there was mental order in his physical disorder. I cite in the endnote another instance involving a much more famous and revered name, J. B. S. Haldane.[11] I mention these instances to emphasize the importance of the ability to quickly locate what you need, irrespective of the method adopted. Things are of course very different in the computer age of today. During my visit to the NCL (in 2006), I noticed that scientists at the working level could speedily lay their hands on information with which they were directly concerned. Things were not so good at the organizational level, however. Reports on even some of the major projects of earlier years were not available. Sivaram is doing his best to correct the situation that had worsened over the years. This is not just a desirable step, it is a necessary step.

- *No change for the sake of change.* Change has been the guiding principle of all modern institutions, and largely rightly so. It is equally important to remember that too frequent a change leaves nothing permanent.
- *Recognizing failure as a temporary stay in the progression of knowledge.* Most research directors balk at failure. They should indeed, if it were a routine failure due to cognizable inadequacy or deficiency. There could be occasions where the mediocre would have succeeded in a less arduous project while the gifted would have failed in a more challenging one. This should only be regarded as a temporary setback and efforts redoubled to meet the challenge. Evaluation of scientists of that caliber should not be left to a routine committee charged with the responsibility of deciding based on a form-intensive yes-or-no system operated long distance. Rather, it should be left to the discretion of more imaginative discerners of talent, unfettered by bureaucratic bonds. The ability to recognize certain failures as positive knowledge is the hallmark of an imaginative director. In any case, one has no existence in the absence of the other. Even Einstein's final years were ruined by his failure to unravel nature's universal force. To those who dare to fail grandly, the following beautiful lines of Anne Rice (1990) must come as a comfort:

  Is there a God, Lasher?
  I do not know, Rowan. I have formed an opinion and it is yes, but it fills me with rage.
  Why?
  Because I am in pain, and if there is a God, he made this pain.
  But he makes love too, if he exists.
  Yes, Love. Love is the source of my pain.

- *Correcting a mistake.* No institution or director can claim that mistakes have not been committed. Often there is a propitious moment to own and correct a mistake, such as choice of a project or choice of leader for a particular project. Even when there is not, it is good to remember Pearl Buck's advice:

  Every great mistake has a halfway moment, a split second when it can be recalled and perhaps remedied.

  There has been at the NCL, a tendency to let a project die by neglect, and not to terminate and give it an official burial. This is wrong and a clean closure is necessary.
- *Caution.* There is always the danger that scientists might take advantage of a perceived unaccountability arising out of the freedom to indulge in the highest class of research. This can largely be avoided by adhering to the 5P principles mentioned elsewhere. If there are no papers in top journals, funding must be stopped. Magnificent failures must be evaluated by a special committee, and not by routine methods, as mentioned earlier.
- *Education versus training.* A discussion I had as a young man with Professor H. Kramers in Delft has been permanently etched in my mind. He said: *We educate students, we do not train them*.

This must be the guiding principle of every university in India, but, alas, it is not. They all want to produce finished products that can be harnessed straightaway by the captains of business to make money (advisedly, I do not use the word wealth, for it means much, much more than money). In other words, they are trained and are incapable of asking basic questions. Only the educated mind can do that. The trained mind is just what the word says, a train: a little off-track, it ceases to function, and is often wrecked beyond repair. On the other hand, an educated mind rejoices in off-track excursions. That is precisely why we in India, while we go high up in the ladder of discovery and invention, never quite make it to the top. What is worse, we treat the educated and the trained minds equally and produce numbers without quality. There are about 300 universities and over 15,000 affiliated colleges churning out about 2.5 million graduates every year.[12] And the faculty? Good or bad, excellent or mediocre, they are all subjected to the same rules of promotion in a system of vanishing selectivity. Unless the government can muster up the courage to generously fund blue sky research in selected universities, or outstanding persons in a given university, mediocrity will prevail. That is perhaps the reason why only a handful of universities from India (out of nearly 300) find places in the top 300 in the world. China has taken the lead and decided to encourage the highest class of research in selected universities. Could not India have done this, with its history of Nehru's vision in creating the IITs? Unfortunately, even in the case of IITs, many more have been created or are planned, probably on a political basis. Soon, they too will be drowned in the game of numbers, and the distinctive worldwide reputation they now enjoy could be at stake. This discussion is not irrelevant to the dream of this chapter. It is equally applicable to the CSIR and NCL. As stated elsewhere, equality seems to have won at the expense of excellence in the CSIR. It has not happened so far at the NCL, but the invisible writing on the wall must be erased before it emerges as a visible symbol of decline. Excellence is not built by a fiat but only through sustained effort starting from the foundation: the educational system.

- *Heed Al-Biruni's comments, nearly 10 centuries ago.* Our educational system has immunized us to the importance of detail and the richness of error free writing. As mentioned in Chapter 1, the famous Arab traveler mathematician, Al-Biruni, made a pointed reference to this Indian failing in his writings. This genetic component of the Indian genome seems to have come through intact to its progeny a millennium down the line, though with this difference. Even some of our more famous scientists project an aura of flowing language by glibly using contemporary terms and phrases but give themselves away in the connecting sentences. Never mind the tense or article, or even the lowly colon, full or semi-, entire sentences tend to be ungrammatical. Many colleagues of mine at Iowa State University have drawn my attention to this persistent deficiency so noticeable in the theses received by them from Indian universities for evaluation. The remedy is simple: as in American universities, every graduate student should be required to have his/her thesis whetted by the English department for correctness, format, consistency, and other aspects of good writing, including the ability to spot and correct errors of any kind. As over a hundred theses are submitted by the NCL research fellows every year, a similar system should be followed in the laboratory. The communications unit of the NCL should recruit a couple of persons thoroughly familiar with English in the most formal sense, and should be given a free hand in correcting NCL reports, theses, etc. Addressing this deficiency at the school and college levels is even more important.

- *Dealing with asymmetries.* This is a subject on which my views were non-specifically dispersed in some of the earlier chapters. I would like to conclude the present section by making a specific point of this as forcefully as I can. Asymmetries in quality are a part of any human enterprise. They can only be eradicated by lowering the peaks, an unacceptable remedy. As stated in a previous chapter, a judicious encouragement of selectivity without infringing on an individual's right for equality in treatment is the director's unenviable task and his supreme challenge. The language of management is replete with words to address this problem. These kinds of linguistic gymnastics that do not recognize the role of personal judgment and are meant to shield the director from accusations of intrusive encouragement is a sure path to nowhere. There are situations where judgments emanating from a pre-wired architecture of management must be boldly dispensed with and scientists of exceptional merit recruited from outside the normal channels and also promoted from outside these channels.[13] It has been done at the NCL before, albeit with much resistance from the CSIR, but why should it continue to be so? NCL's director can play a very useful role in initiating such a procedure in the CSIR system of recruitment and promotion.

I now come to a point that happens to be chronologically the last. It is intentionally the last but only because I wanted to leave this section of suggestions with this point lingering brightly in the mind. It has been expressed in different ways throughout this book, but I now give it a concrete assertion, a "permanent present." It is simply this: never, never retreat from a lofty enquiry just because most such quests are dismissed as "useless" by the evaluators of the NCL. Nothing is useless if it aims at a higher understanding of things. It is for the management (I am not particularly fond if this word, but I do recognize its inevitability) of laboratories like the NCL to lead this pursuit of the useless. The other day I was listening to a lecture by a professor on the life and works of the Indian genius Srinivasa Ramanujan. The professor talked at length on the theory of numbers, which has always been regarded as "useless" by the commercially-oriented research community. All this confusion arises out of the acceptance of "effect-follows-cause" principle of Aristotle. We are now moving towards the awesome concept of a multi-verse (infinite number of universes) that consists of interacting spacetimes, in which all events are irrevocably etched and the perceived alternating order of cause and effect thrown into disarray, with neither past nor future. In such a world, the effect of Ramanujan's concepts are already present. This was beautifully demonstrated (not in the space-time context) by Prof. George Andrews (discoverer of Ramaujan's 'Lost Notebook'), who showed how this phenomenal theory can be of practical use. Through the help of Professors Krishna Athreya and Tim Huber (of ISU's Department of Mathematics), who directed me to a New York Times article on Ramanujan, I learned about the increasingly phenomenal practical importance of this troubled genius's scibbled equations (considered once of no practical value) in the recently found The Lost Notebook.[14] Let us, by all means, be very, very selective about such work, but, for heaven's sake, let us not shy away from it. Keep it on the agenda — always, and wait for the opportunity to grasp it, this scientific equivalent of the Brave New World of Aldous Huxley.

Having stated clearly and point-wise my suggestions for the future (with somewhat diminished exactitude in a couple of points), I now indulge in a bit of soliloquy, a reverie to be exact, which, unlike Charles Lamb's in *Dream Children — A Reverie* (Essays of ELIA, 1823), is rooted in the possible and stretched to the probable — with dream, potential, and reality vying with each other to usher in a future where discovery is king, analysis is queen, and the rest of the pack play their own roles.[15]

THE ROVING MIND DREAMS AND HAVING DREAMED ROVES ON[16]

It is a funny thing about life; if you refuse to accept anything but the best, you very often get it.

W. Somerset Maugham, 1874–1965

The NCL should desist from doing what the industry is increasingly becoming capable of doing, by itself or in collaboration with multinational companies. Available competencies that can be bought at a price should not be the NCL's to do. The NCL should be a generator of new knowledge and not a salesman for the old, repackaged with its trademark. In other words, the vision of the founders should find a new expression consistent with the needs of a changing world. This turnaround from Bhatnagar's charge (Box 3.5) should be viewed not as an affront to the first dreamer of the CSIR but as a necessary paradigm shift from prosaic continuity.

That is the only way, as I have said in previous chapters, that the NCL can retain its *raison d'etre* and continually renew itself. The NCL should forever champion by example a change where the initial need of rediscovery is constantly yielding place to the grand thrill of discovery. It should reduce its size, employ only scientists of the highest talent and, along with the Indian Institute of Science, The Jawaharlal Nehru Center of Advanced Scientific Research, and the Tata Institute of Fundamental Research, should be the pace-setter for the country. The student population, comprised mostly of research associates, should dominate the working landscape, providing an atmosphere infused with the adventure and enthusiasm of youth.

It is a fact of life that brilliant scientists often prefer to work in an academic atmosphere. It is therefore of the utmost importance that the NCL should not only foster an academic culture as mentioned above, it should move a step forward and offer academic designations like professor, associate professor, etc. to deserving candidates. TIFR already practices this and the NCL should act quickly to incorporate these designations. It should also create chairs through industrial and other sponsorships, and offer the designation of distinguished professor to its most meritorious scientists. The possibility of joint appointments with universities and/or sister institutions should be vigorously explored. It is likely that some of the top scientists may not be great teachers or lecturers, but this should not be an impediment, as noted by Sir. J. J. Thomson.[17]

The Director-General of the CSIR presides over 38 of its constituent laboratories covering practically all disciplines of science and engineering. In addition to the varied programs of these laboratories, it has over the years carried out multi-institutional programs in which the director-general has been personally involved. These programs have flourished under different names: national missions, task forces, inter-laboratory programs, and the like. Water Mission, for example, was a program in which the CSIR evinced particular interest. From what I can recall, nothing substantial came of these programs; some would even argue that they were failures. The most recent rendition of this central initiative has the same objectives but is more regularly monitored and is heavily funded — orders of higher magnitude. The future of the CSIR will depend, at least in part, on how these programs fare. Huge sums have been earmarked and targets have been laid out, but no significant results are visible; perhaps it is too early. Although the NCL has the ability to attract part of its budget from outside sources, the CSIR is still its single major financial benefactor; and it is only with the CSIR funds that long-range research is possible. And as any convulsions in the CSIR will have their own ripple effect in the NCL, it is imperative that the laboratory plays its role effectively in ensuring the success of these national missions. All this casts a heavy burden on the DG and directors of the CSIR. Clearly, they feel that the goals are achievable within the framework of time and money envisioned by them. Knowing them, I would be inclined to agree, even if I have not looked at these programs. But my audience is the future leadership. It would inherit enough material to be able to distinguish between the do-ables and the undo-ables and present a more streamlined program that would avoid any huge year-end financial surrenders that erode confidence. The initial projections both in terms of achievable ends and financial requirements are usually the result of enthusiasm overshadowing pragmatism. With time a greater balance is often seen and hence my suggestion to the future leadership is to carefully revisit these claims and requirements with a more pragmatic frame of mind.

The CSIR today is a goal-centered organization, with some of its lofty goals in sight of fulfillment. It has learnt to think big and to infuse confidence in the country's leadership. It has suffered in the past with many of its goals, though less lofty, often unrealized or silently killed by disinterest or calculated neglect. The question of setting goals for a more distant future of dream and reality rarely arose. As I have stated in an earlier chapter, where would a nation, an organization, be without a vision, a dream diminished by its own realization? This is a shortcoming that has been most skilfully addressed by the CSIR's recent leadership, particularly R. A. Mashelkar. Talk, accomplishment, dream, bravado, apart, the CSIR received a few years ago a much-needed shot in the arm. The resultant immunity from criticism cannot last long. Down-to-earth booster shots are needed from time to time both to enthuse and to accomplish — and to remain the beacon light of scientific and industrial research in the country that it has been striving to be. Every attempt should be made to keep the organization from drowning in the enveloping sea of globalization.

I am strong on silence and have studied it in depth, both the good and bad aspects of it. Where else can this find a more appropriate opportunity for expression than in a soliloquy, to drive home the view that neither loud self-espousal nor contrived silence can by itself be beneficial? Thomas Carlyle's *Under all speech that is good for anything there lies a silence that is better*, will not do. Neither will George Eliot's *Blessed is the man who, having nothing to say, abstains from giving us wordy evidence of the fact.*

True, real greatness can express itself with opposite accompaniments: the gregariousness of an Ernest Rutherford (Snow, 1967) or the taciturnity of a Paul Dirac (Infeld, 1941), both Nobel Laureates.[18] The NCL should devise an optimal strategy to propagate its performance, neither chasing nor shunning the popular media. There should never be an overdose of the former, a rather common occurrence in India. Trumpeting is for an institution making up in noise and print what it lacks in quality and achievement. I submit that CSIR's scientific publications and industrial achievements should largely, if not alone, be its noiseless trumpeters, even if a subdued overlay of self-exposition in catalytic amounts may not be entirely out of place.

As we all know, increased noise distorts the message, often leading to ridiculous cacophony. The solar cooker of infamous memory is no subtle reminder of the CSIR's promotion of its ware. Instances involving other scientific agencies did even greater damage to government-supported industrial enterprise in India, such as the construction of hundreds of thousands of small-scale gobar gas plants (plants for producing methane from human wastes) throughout the length and breadth of the country. The CSIR had learnt its bitter lesson of premature publicity fairly early in the game. A calculated combination of bravado and technical competence was needed to restore credibility and find a respectable niche for relative haste in a fast changing environment. The NCL, CSIR and the Indian chemical industry as a whole owe it to B. D. Tilak for bringing about this transformation — this nexus between urgency and accomplishment. The India of the 1950s was too unprepared for this change and the NCL of the 1980s too advanced for it. As a member of the US House of Representatives so aptly put it:

> *A clear strong statement of a case made too soon or too late fails.*
> *If well made at the right time it is effective.*
>
> Swith,1925

Tilak was neither a prophet nor an anachronism. He appeared on the scene at the right time, with the right ideas, and had the right personality. The result was immediate and dramatic, a paradigm shift in the NCL and CSIR. The CSIR's accomplishments have been most effectively articulated in recent years by Mashelkar. The onus of the CSIR's promotional articulation must now be passed on to others — the recipients of its knowledge and largesse.

From the era of known technology development, boldly prefixed "new" because it was indigenous, to the era of comfort zone research where failure was not an option and results would be in line with conventional thinking, to the era of challenge zone research where no surprise would be the biggest surprise and failure is part of the game, the NCL has experienced all these phases of research in the 60 years of its evolution. As challenge zone research gets more firmly established, quality and not quantity would be the guiding criterion. The most serious challenge would be to find researchers of the greatest merit and to have the courage to go back in time and revisit methods to fund blue sky research as Rajiv Gandhi famously called it. In the fast changing research scenario of the country, only this will persist. All else will be irrelevant, or only fleetingly relevant, depending on the political dispensation of the day.

Quick success in finding an answer to a difficult problem may not always equate to brilliance. Perhaps the mind was not challenged enough. It should be put to the severest test. In this sense, failure would be a measure of the "overreach" than of the reach (and not "of the reach over the grasp," as expressed by the famus poet, Robert Browning). I hope the NCL will not be satisfied with the reach and aim for the overreach — at once a challenge and a mocking invitation to failure. This will redefine its uniqueness — as other institutions in India, always on the hunt, begin to close in. It is better to have tried and, if it so happens, failed magnificently than not to have tried at all. But the quest for unlocking the doors to nature's myriad secrets must go on. As Edgar Guest so eloquently put it in 'It Couldn't be Done:'[19]

Somebody said that it couldn't be done,
But he with a chuckle replied
That "maybe it couldn't," but he would be one
Who wouldn't say so till he'd tried.
So he buckled right in with the trace of a grin
On his face. If he worried he hid it.
He started to sing as he tackled the thing
That couldn't be done, and he did it.

TRUTH, FACT, AND FUTURE: AN INTRIGUING NEXUS

A fact is what we know to be — by sight (through visible or invisible light), observation, or evidentiary proof.[20] Unfortunately (though to a lesser extent) it is also averred through axiomatic statements coming forward from years long past. It can be qualitative or quantitative. That the sun revolved around the earth was a fact for centuries. Then, with one of the most monumental discoveries of all time by Copernicus, it was overturned and the reverse became the fact: earth revolving around the sun. The age of the universe jumped around from one fact to another: a few thousand years (by no less a luminary than Lord Kelvin), to a few millions, and now to the purportedly final figure of 14.5 billion years. The weight of the earth also jumped around for quite a while, till Cavendish settled it once and for all. How many of such facts become eternal truths? A truth is not just a scientific fact invulnerable to change with time. It is frequently an unverifiable religious or moral assertion attributed to a religion. The latter is no more than a conviction converted to a truth through force of religious authority, a statement shielded from challenge by implied threats of retribution from an all-knowing being. This is as controversial a concept as a fact — which remains a fact only so long as it is not overturned (see Preface), and may even come in the way of those flights of imagination that have dramatically influenced humankind's progress, a situation so admirably expressed by Emerson:

> *Facts encumber* [men], *tyrannize over them, and make the men of routine the men of sense, in whom a literal obedience to facts has extinguished every spark of that light by which man is truly man*.[21]
>
> Emerson and Porte,1983

In what way is this excursion into an irresolvable argument germane to the NCL? It is — and very much so. The NCL is India's foremost chemical research laboratory. True, individuals matter more than institutions and have often produced their best under the direst circumstances, but in the world of today, money, environment, and quick appreciation are the ingredients of a nucleus that can burst into convulsions of discovery. Laboratories like the NCL, created in the dream of yesterday's world, should initiate the dream of tomorrow's. They can and should no longer look to other countries for discoveries that will fashion future thought. They should strive to be ranked alongside the best. Let me now go back to the first few pages of the book, where I talked about the context, and stated that we are not in that class yet. But I am talking about the future now, in which the NCL will be a major player, where we have the opportunity to rightfully equate ourselves with the best — not through politically oriented assertions but through truths or final facts, placed in context on a broader canvas and etched in the enduring pages of history.

THE FINAL WORD: IS DETACHMENT JUST ANOTHER WORD FOR VICARIOUS INVOLVEMENT?

Are these fanciful thoughts the offspring of the fractured imagination of one in whom detachment is just what the caption says it is — vicarious involvement? Yes, partly. Are these the reflections of a mind too fully occupied in the intellectual pursuits of his adopted country's affluent academia? Yes, partly. These two parts, joined together into a whole, describe at once the confusion and the clarity of my final thoughts on the NCL.

In Figure 6.1, I represented the stages of the NCL's evolution through the years. What happens now, after the first surge of globalization finds its own level in the scheme of development? The NCL has only two options:

- To fall in line, compete with the rest of the pack for money, and make its presence felt as the smartest money making machine of the country's research system.
- To evolve a completely new paradigm that boldly contests the newly settled philosophy and is embedded in a purer panorama of research that will place it among the best in the world.

In following the first course the NCL will reduce itself. It is only the second alternative that will help the laboratory survive with dignity and grace in a drastically changed world. A completely new philosophy would be needed, a cultural shift that must bring back a discarded concept. To stay relevant will be necessary but not sufficient. And so, a culture is needed that encourages (but not through destructive displacement, as explained in Chapter 5) the new and the novel, that does not, in the spirit of the founders of Princeton's Institute for Advanced Study (see Context), shy away from the pursuit of useless research that someday might be useful, and that does not place a heavy premium on quick exploitation of results. More importantly, the cultural shift in the NCL must first redefine its coordinates, in order that it may more gloriously look forward and not replay the catch-up game of the earlier years. In other words, the academic culture that several political and industrial leaders did their best to curb must be strengthened — but with a difference. The maturity of 60 years and the advantages of a shrinking world must be fully exploited to fashion a future of discovery. This may take decades, but the NCL must not lag, must not always follow.

With this vision in mind, I sketch in Figure 18.1 my recipe for the future, stage 5 of the NCL's evolution. As this figure is self-explanatory, I will not discuss it further here — but I hope that it will be viewed, not as a one-sided affront to reality, but as something that makes sense to others too. If Indian science is to truly fall in step with the Western world, the scientific foundations built by Nehru need to be strengthened. Structures and superstructures on the same foundations will not do. A self-regenerating foundation that continually questions and replaces old concepts with new, and that does not shrink from the most basic questions (answers to which keep changing), can alone make these lofty goals achievable and stage 5 a reality. Such questions are asked only when imagination turns to what is perceived as useless. To differently state what I have said previously, we must learn to distinguish between useful, valuable, and useless research (C. V. Raman, see endnote).[22] And herein lies a contradiction, a reason for scientists to be themselves and not just blind votaries of a current thinking. As Truesdell puts it so eloquently in his *An Idiot's Fugitive Essays on Science*,

> *In the effects of the popular attitude toward science in the* (French) *Revolution, we may read the first example of the now-familiar pattern of a "people's" government suppressing "pure" science in favor of the "useful," against the equally familiar background of the stupidity and cowardice of the scientists.*
>
> Truesdell, 1984

Strong, harsh words with which one may or may not agree! But in a reverie where free rein to thought is its defining feature, they certainly provide food for thought. If in some measure they buttress the need for the highest form of originality, where the ancient creators of that *numerical creature* called zero would be challenged by their distant progeny, India may yet emerge as a dominant force in science. I would like to see our scientific institutions, the NCL in particular, anchored to a future of spirited inquiry where lukewarmness has no place and the Eureka of an unclothed Archimedes is more than just an entertaining roar of discovery from an ancient world.

If these statements leave the disquieting impression that what I propose is a dream world removed from reality, I would not deny an element of truth in it. And yet I would argue that we should learn to appreciate the limitless, notwithstanding Shakespeare's immortal words (in *Troilus and Cressida*):

> *The will is infinite and the execution confined. The desire is boundless and the act is a slave to limit.*
>
> Shakespeare, 1609

Irrevocable facts tend to set limits to human imagination, and yet only attempts to burst out of these confines, instead of being a *slave to limit* (Shakespeare), *make man truly man* (Emerson). The reader can discern in these words an attempt on my part to make a single far-reaching recommendation that epitomizes lessons from thinkers that transcend time. This, like white light, is split into more specific suggestions in regime 5 of Figure 18.1. This may not be practical enough for those who desire a more narrowly defined agenda of action. To set such an agenda is for the laboratory to do, hopefully within the broader framework of the suggestions contained in the table. This will perhaps be dictated by the logic of the possible and the useful, notwithstanding Henri Poincare's admonition,

> *Logic sometimes makes monsters.*
>
> Schechter, 1998

Logic is a necessary prerequisite to being practical. It is interesting to note that Kurt Godel (Pickover, 2002), perhaps the greatest mathematician of the last century and the greatest logician since Aristotle, has proved that God exists. Bertrand Russell and a few other equally great thinkers propose, quite logically, that God does not exist. These conclusions are not based on belief but on profound logic. Hence one cannot completely disagree with Poincare's assertion! The point of this clash of conclusions reached by the same logical methodology, seemingly irrelevant to this book, is that there is room, or indeed room must be made, for useless proposals, provided they emanate from a gifted, imaginative mind. For a laboratory like the NCL, routine application of management dicta, cost-benefit analysis, and use of such other criteria as quick acquisition of exploitable results in framing an entire research agenda will be self-diminishing. A reasonable part of it should be aimed at pushing the frontiers of knowledge and be independent of the pushes and pulls of a current market. Research based on fluctuating market demands, its importance undeniable, is for the industrial laboratories to pursue. My assumption that the NCL is not an industrial laboratory but a discovery oriented one, thinly but adequately peppered with profound (as distinct from routine) industrial associations, will perhaps be disputed. But to me it is its *raison d'etre*, its very life blood. If the prevalent climate of scientific advice refutes my assumption, then some of my recommendations may be irrelevant. Even so, I adhere to my thoughts in the hope that the collision between dream and reality will not altogether vanquish the dream.

POINTS OF COLLISION

I would like to end this chapter and the book by identifying, in the simplest language I can, the points of collision between dream and reality.

- Indian science has long been the preserve of a few durable sultans of science (and dispensers of cash), honest and well meaning but detainees in the cells of their own ideas — convinced of their invulnerability to wrong judgment. Being powerful, all major positions are filled by their devotees, leaving little room in government controlled institutions for meaningful deviations. Hence any dream on the NCL's part that collides with what they consider, often very honestly, to be in the best interests of the country is usually foredoomed. Examples are: induction of a top university culture; passing on the exploitation of an idea, after it has been internationally patented, to outsiders, with no further involvement save as consultants. Continuing with the same idea and making incremental improvements should not be for the NCL, which should be freed to pursue other ideas. The realist would see in this a

Figure 18.1: The four domains of the NCL's growth extended to include the fifth domain representing the suggested future

DOMAIN 1	DOMAIN 2	DOMAIN 3	DOMAIN 4
Laying the foundation and creating schools, recruitment of outstanding scientists	Transition to applied research, turnkey projects, rural development, involvement at national level	Emphasis on all-round excellence and state-of-the-art technology, recruitment of outstanding scientists	Switch to globalization, emphasis on international alliances, accelerated sophistication
McBain Finch Venkataraman	Tilak	Doraiswamy	Mashelkar Ratnasamy Sivaram
1950–65	1965–77	1977–89	1989-present

DOMAIN 5 FORWORD

WHERE DREAM COLLIDES WITH REALITY

- Get away from what the industry can increasingly do.
- Concentrate on discovery and original theory
- Create a top class academic culture with academic designations, including endowed chairs For the most outstanding scientists
- Do not shy away from esoteric research or magnificent failures
- Do not judge EXCELLENCE by money or results
- Attract funding by addressing the future
- The NCL has served its intended purpose; time now to Move on to the unknown, with no promises Save an assurance of unrelenting effort
- Make the NCL a center for visiting scientists of the highest caliber, including Nobel Laureates
- Do not be afraid to dream big and collide with an extrapolation of the known — that all too familiar managerial/political mantra called *Realistic research*
- In an era where universities are increasingly becoming industrial R & D centers, and decreasingly committed to unfettered inquiry And puristic knowledge, let the NCL of India join like-minded centers of the world and dare to create a new paradigm.
- In the final analysis, let us remember that outstanding work needs no trumpeting; on the other hand, Silence is not always golden; deliberate destruction of decibels is for the crafty, not for the genuinely silent.

Note: Domain 5 forward contains suggestions that are purely personal and may even be regarded as wishful thinking. Even if the NCL agrees with them, they are difficult to implement, but may be viewed as the ultimate challenge the laboratory is not afraid or hesitant to accept.

wasted chance of catering to the market and increasing financial reserves. Financial reserves should be increased, but through new ideas and not incremental gains through older ones. There is bound to be collision here.

- Many of the old guard would always like any research proposal to be linked to practical utility. While this should certainly remain one of the indicators of performance, work without thought to immediate utility has the potential to stimulate some bright young minds to unprecedented levels of originality. But this would be considered a dream not worth funding by the aging elite, and will almost certainly lead to a collision, and leave yearning young minds limp and lacerated.
- The first collision has already occurred, between an earlier dream and bureaucracy's unfailing challenge to the promotion of scientists of exceptional merit by the simple process of identifying them and letting their international peers of the highest distinction make the judgment. That is how the NCL became the only lab in the entire CSIR in the 1980s to have had three outstanding scientists promoted to this level. CSIR then was not an intrusive participant. In today's climate, it should play its role by being an oversight body for such recognition, and nothing more.
- Ratnasamy divided the NCL's performance indicators into 4 Ps: Publications, Patents, Ph.Ds, and *Paise* (Hindi for money). To this I would like to add: *Par excellence*, denoting excellence in general in any field of concern to the NCL. These are the only five non-colliding lines that must define the NCL.
- The NCL has sound performance indicators, progressively improved over the years (particularly during the regimes of Ratnasamy and Sivaram). There, however, is no marker for rewarding scientists daring to attempt a "big one" and failing in the process. The management would all too soon write them off as non-performers. The dream calls for research that will enhance understanding and become part of the architecture of science for tackling problems of practical relevance, but by itself would not be directly exploitable. There is danger here of collision of an extended reality with the dream of the daring.
- In the increasingly market-driven world of today, and probably of many tomorrows, incrementalism will hold sway, and leave intrusions of thought into the secrets of nature in the hands of a select few in the West. The future will no doubt reveal their usefulness.[23] Laboratories like the NCL must not be afraid to collide with such an unremarkable extrapolation of reality.
- There have been some very good appointments at the middle levels but none at the senior levels since the late 1980s. If this situation is not corrected immediately, an uncertain — probably bleak — future looms. There will be no dreamers to dream and no opposites to collide, only a bunch of moneymaking machines to feed and fatten the hungry markets. There would be no collisions but only mergers: dream with reality, or reality with dream. The dream being very much the smaller will be subsumed by the colorless reality, resulting in an all too familiar scene: the brightness of a vision dimming into the lusterless sight of a diminished institution. I have every confidence that the present leadership that has so well sustained, indeed enhanced in some cases, the laboratory's excellence will quickly retrieve the vision and keep it bright and glowing.

Beware the Professors Emeriti

The future is always a doubt, for the small and the big, for the lofty and the not so lofty, including the loftiest of all: Godhead and the universe, of which we are but a "nanocosm." This is perhaps best expressed in Bhagvad Gita's Hymn of Doubt, regarded by many as the loftiest tribute to doubt, in which the doubt and the doubter are one. Doubts at various levels have existed through all phases of life. I would like to conclude this book by supporting Professor Eric Chaisson's doubt regarding the intellectual condition of professors emeriti, particularly their facile assumption that they can still write a book:

> *Even today professors emeriti seem to be a good deal more metaphysical (and even occasionally teleological) than younger colleagues or than they themselves were in their youth. Whether it is wisdom or senility, I have not yet been able to judge.*

Now comes the wish part, following which I take leave of my readers. A wish is not necessarily something that does not happen. It is the mad excursion of the mind that does not. Chaisson allows for the professors emeriti a twilight zone between wisdom and senility, and I hastily grab that zone before settling permanently into senility. I make the following wishes (some already expressed in a different form in Figure 18.1).

- Foster a thinking where thinking itself is supreme.
- Facts, experimental findings, unimpeachable in the timescales of their existence (for even the most stubborn of them change in the larger timescale of Nature), can often be rebellious; discard any theory that would sideline them as exceptions.
- Let globalization play its inevitable role, but insist on leaving your own stamp, the stamp of your institution and of your country. Do not consider any venture where facelessness is the price one pays for money.
- Introduce science in the architecture of the thought process and in strengthening the foundations of the laboratory, and not in building fleeting superstructures that change with the created demands of consumerism. The finest example I can think of is the chain of Neutron Research Laboratories established by Exxon-Mobil, Dow and other companies at various universities, which underlines the thinking that "uses will follow if you understand the basics."
- Build an innovative NCL and not an imitative one. This is important to remember in today's "global world," where imitating the superstructure has become the *sine qua non* of progress.

Dream? Maybe. But man is not truly man if he is not also a dreamer. And the closing words of a book on the NCL would be beyond redemption if they did not echo the beguiling drumbeat of a dream. As David Schwartz has so admirably said:

> *Every challenge we face can be solved by a dream.*

❄

EPILOGUE

Every man or woman, the moment he or she gets an opportunity, intensifies the decibels that brought him/her to that position, till a major part or whole of the agenda is implemented. I came in riding the chariot of NCL's excellence, little realizing that no unidirectional approach that subverts all others can be successful. I recall with no great pride my summary non-countenance of strong suggestions by some of the topmost scientists of the country not to ignore scientists who were doing outstanding research but were disdainful of NCL's charter that had the words, "public good," strewn all over it in spirit if not in actual words. Instead, I chose to stick by those who stuck by an invariant charter. Little did I recollect that the charter itself was a creation of the times and subject to periodic assessment and change in the overall interest of science in the country. This led to underperformance by some gifted scientists and over-recognition of some not so gifted.

I was also consumed by the perceived overreaching excellence of NCL. This created a distance between NCL (me personally) and CSIR that sometimes became embarrassing. But this situation was short-lived, for there were planners in CSIR like Professor A. Rahman who saw merit in my ideas, and funded the lab to the fullest extent possible, thus always keeping it ahead of the pack. One of the Directors-General, Dr. A. P. Mitra, was as committed to excellence of NCL itself, and never once flinched in extending a hand of friendship and help to one of his most recalcitrant directors. He and his successors never failed to give NCL its due credit, even as their predecessors had not to Venkataraman and Tilak.

My successor twice removed (Paul Ratnasamy) is said to have further asserted his determination to keep NCL "different," without seriously impacting the flow of finance from New Delhi and other perks of a good relationship. But thanks to the advent of the free market era, this flow became increasingly unimportant, though still very relevant. Mashelkar in particular, through his brilliance, managerial skill and dynamism, built relationships that took NCL to a position of enviable financial stability and strength.

All through these 60 years of its existence, NCL has lived the dreams of its makers, neither hobnobbing with nor ignoring the powers that be. It has been a marvelous march marked as much by smooth transitions of power as by the genuine willingness of every head of NCL to recognize and respect the contributions of his predecessors. New orders displaced the old with a smoothness that was wonderful to behold, neither complaining nor crass, overreaching nor negligent in praise. It was an emotional and intellectual continuum that addressed emerging problems and did not cavil at the old.

Sivaram has continued this tradition magnificently, mostly by bringing in his own brand of management and creating a number of resource centers in the lab. He is trying his best to disprove Werner Heisenberg's uncertainty principle by precisely defining when and where a certain thing will happen!

No account of today's NCL would be complete without a reference to its Number Two, B. D. Kulkarni, who has managed to bring in his own brand of confusion between numbers! Without in any way questioning the absolute authority of Number One, he has managed to elevate Number Two to a level that dances merrily between One and Two.

One and Two are in great hands, but how about the rest? Retirements and resignations have left their mark and taken their own toll. Endless opportunities in the private sector for the talented, with remunerations hitting the ceiling, are creating in government laboratories a talent and leadership vacuum that must be causing Sivaram great concern. Solution does not lie in timid changes at the lab and higher levels. There must be a total shift in emphasis that would restore the supremacy of research, where the boundaries of profit are more broadly defined and temporal fluctuations are accommodated on the unidirectional wings of coordinated progress.

Distance and disengagement make it impossible for me to offer solutions, but a pervasive attachment to the lab does draw on the unflagging temerity of receding youth to make some far-reaching (far-fetched?) suggestions. I have done just that in Chapter 18, and would like to conclude this book by suggesting a re-visit to that chapter, in particular to Figure 18.1. On a health- and age-driven course for some years now, I still entertain the compulsion to seek out this temerity and offer it as my last bit of service to a great institution. Thank you, Sivaram.

LKD

AFTERWORD

History and Dream, The Stuff of this Book

To be ignorant of what occurred before you were born is to remain always a child.

Marcus Tillius Cicero, 106–43 BCE
Roman senator and orator (Cicero, 1817)

Yet, to be blessed with the wonder of that very child experiencing the unfolding magic of its own universe is like the dream of an incomparable Godel

transfigured by the notion of the infinite eternal varieties lying suspended beyond all the human imperfections, the confoundments and obfuscations and distortions … He will dream, silently and audaciously, of proving a mathematical theorem the likes of which has never been seen … And then he will do it.

Goldstein, 2005

NOTES

Introduction: Stating the Context

1. http://www.hrf.gov/news/speeches/lane/nl96icsu.htm
2. Gödel's theorem suggests that once the ability to represent all phenomena has reached a certain critical point, that is the end. That "certain point" here is the limit of knowability of any meaningful matter within our universe where our axioms apply. There will always be certain axioms and things that cannot be proved within that macro-system or universe, and can only be proved by going outside the system. This is Godel's theory of incompleteness within a system of fixed axioms.

Part V

1. There is something more complete in the archaic *compleat* than in its modern version *complete*. To those with a sense of nostalgia, this comes through with remarkable clarity in Izaak Walton's *The Compleat Angler* (1653), a book about fishing — about how to dream — often regarded as the contemplative man's best recreation. To put things in perspective, my dream, described in Chapter 18, is entirely land-based and not inspired by hapless fish pulled out of their watery habitat for culinary purposes!

Chapter 1

1. It is difficult to be exact about the beginning of British rule (the Raj) in India. In 1670, King Charles II granted the East India Company the right to acquire territory, raise an army, mint its own money, and exercise legal jurisdiction in areas under its control. By the last decade of the 17th century, the Company was arguably its own nation, possessing considerable military might and ruling three presidencies. The British first established a territorial foothold in the Indian subcontinent when soldiers commanded by Robert Clive and funded by it defeated Siraj ud Daulah at the Battle of Plassey in Bengal in 1757. The company then took control of Bengal's *diwani* (tax system) — somewhat like Wal-Mart running the Internal Revenue Service in today's United States (Robins, see website under Reference). The company looted India (Nehru, 1946), and in the process, enriched the English language by acquiring the word loot. Also, as Nehru has remarked, it was one of the first instances of commerce turning into conquest, and is significant in today's context of globalization, with no holds barred on economic conquest by multinational companies. A few years later (1773), Warren Hastings, an upright gentleman, was appointed the first Governor-General of India — a welcome change from Clive's mercenary, despotic rule.
2. It is interesting to note that this accomplishment has hardly been noticed by Western writers, largely because there is no desire to go beyond the borders of Western thought. A similar accomplishment (more correctly, an appreciation of such an ability) a millennium and a half later by President Woodrow Wilson, undoubtedly a great scholar, has become a quotable quote (see Daniels, 1946, in Fred R. Shapino (ed.) *The Yale Book of Quotations*). Wilson replied to a question: *If I am to speak ten minutes, I need a week for preparation; if fifteen minutes, three days; if half an hour, two days; if an hour, I am ready now*.
3. It is interesting to note that a few Indian scholars seem to have been adept at transmitting their knowledge to their daughters through books, as exemplified in more recent times by Jawaharlal Nehru, who wrote from his jail innumerable letters to his daughter Indira on Indian history, a compendium of which was later published as *Discovery of India*, 1946, 2004.

4. Awarded the Nobel Prize for literature in 1923, long after his days as a struggling artist, Shaw refused the prize money, commenting that *the money is a lifebelt thrown to a swimmer who has already reached the shore in safety* (Shaw 1948). Sartre accepted neither the prize nor the money of the 1964 Nobel Prize for literature awarded to him, citing Alfred Nobel's legacy of human suffering as his chief reason.
5. In this poem, the line *I am the doubter and the doubt* is uniquely expressive of the scientific spirit and is exquisitely original. To me, it embodies the combination of religion and science as few other expressions do.
6. He was a controversial figure who, incidentally, married a girl of 14, and was beheaded during the Reign of Terror in France.
7. It is one of the travesties of science that he was widely ridiculed for the gaps in the table, which were seen as a self-evident rebuttal of his own classification, and thus never won the Nobel Prize for so fundamental
a discovery. It is a matter of history that the gaps were later filled, among others, by William Ramsay, Henri Moissan and Marie Curie, all Nobel Prize winners, for those fillings.
8. The following lines from a conversation in the referred book (Jonson, *The Alchemist*) indicate an understanding far ahead of the time.

   Subtle*: No egg but differs from a chicken more*
   Than metals in themselves.
   Surly: *That cannot be.*
   The egg is ordain'd by nature to that end,
   And is a chicken 'in potentia.'
   Subtle: *The same we say of lead and other metals,*
   Which would be gold if they had time.

9. See Teresi 2002; Datta and Singh 1962; Ray 1956; Datta 1932; *Ain-i.Akbari*, Sarton 1955.
10. Shakespeare seems to have given much thought to the concept of nothing or the zero, beautifully brought to life in his play *Much Ado About Nothing* (see References), and quoted by many authors from time to time. Also, Barrow has a chapter of the same title in his *Book of Nothing* (2002).
11. Talking of India's growing population, it is sadly ironical that this creative community is losing its numbers due to its practice of non-proselytization (no conversions) and disapproval of marriage outside the community leading to inbreeding.
12. A ship for England built by a Parsi had the following line carved on it: *This ship was built by a d — d Black Fellow A.D. 1800* (Taraporewala, 2000).
13. The use of this ancient equation in the argument for life leads to the following strange paradox that is yet to be resolved by today's scientists: Assume that the probability of life on any planet including Earth is zero. Even then, this equation suggests that the probability of life in the universe as a whole can be any finite number running into millions! The power of this entire set of equations, traced to Brahmagupta, is clearly incredible.
14. The Poincare conjuecture states that in three dimensions one cannot transform a doughnut shape into a sphere without ripping it, although any shape without a hole can be stretched or shrunk into a sphere.

Chapter 2

1. This caption was inspired by a similar one that appeared in the June 18, 2007 issue of *Time* but with opposite emphasis.
2. It is interesting to recall that the highly secular Ram Mohan Ray was a product of a *madarasa* of the fading Mughal days, known for its rigid adherence to Islamic teachings and culture (see Dalrymple, 2007).
3. Hastings made full use of upper-class Hindus as well as Muslims in formulating rules for the governance of the country, one set for Hindus and another for Muslims. He established a *madarsa-i-aliya* (an exalted

Muslim school) in Bengal and also encouraged education in general. He accepted Hindu practices, with some changes.

4. In a lighter vein, it is interesting to note that some great mathematicians of olden times were anticipatory plagiarists of Ramanujan. According to Robert Merton, quoted by Barrow (1991), anticipatory plagiarism occurs when someone steals your original idea and publishes it a hundred years before you were born.
5. It is said, though I cannot quote any authority in this matter, that Ghosh and Finch did not see eye-to-eye on many issues. For reasons that are obscure, Ghosh did not like the idea of Finch being invited to head the NCL. According to him, the rumor goes, there were prominent Indians available for the job. I do not know if he ever visited NCL, but he made it a point never to set foot in the lab as long as Finch was Director. Finch, for his part, ignored Ghosh.
6. Nicholas Peppas has edited a collection of histories of chemical engineering in various countries and of a few broad areas of the subject in his *Hundred Years of Chemical Engineering* (1989). Mashelkar and Rajan's section on chemical engineering in India gives a fine historical perspective of the growth of this field in the country.
7. According to Deniz Uner, Professor of Chemical Engineering, Middle Eastern Technical University (METU), Ankara, Turkey, and one of my most outstanding Ph.D. advisees at ISU in the USA, Weingaertner was a very prominent technologist in pre-World War II Germany. He later lived in exile in India where he was a Professor of Chemical Engineering at IISC in Bangalore, before moving on to METU where he founded the Department of Chemical Engineering, which today bears his name.
8. Another example of attempts (wittingly or unwittingly) to withhold recognition to Indian scientists is seen in Saha and Bose's translation of Einstein's theory of relativity from German to English, the first such book that appeared within three years of Einstein's epochal publications. This was ignored and it was stated by Meadows during the centenary celebration of Einstein's birth at Princeton that the first translation was by a Japanese author. Fortunately, the Indian American Nobel Laureate Subramanyan Chandrasekhar, who was also present on the occasion, corrected the statement (see *Dreams*, 2002).

Chapter 3

1. It cannot go without comment that, even for a relatively junior position such as assistant director, the chairman of the selection committee was no less a person than a Member (equivalent to a Minister) of the Government of India. It is even more inescapable that this practice was followed for an even more junior position, such as when Maulana Abdul Kalam Azad, Minister for Education, presided over the selection committee that interviewed me for the position of scientific officer at the NCL!
2. The original promotional lines of Burmah-Shell were: "Burmah-Shell in India's life and part of it."
3. This reference, unintentionally derogatory, to the scientific achievements of these *tiny* countries reflects Ray's ignorance of scientists like van't Hoff of Holland, the first winner of the Nobel Prize, and Paul Karrer of Switzerland, also a Nobel Laureate, and a few more, but his intended point of the standard of Indian chemistry (at that time) is well taken.
4. A more recent example (January 1, 2007), which was an important news item in the American media, was the complaint by King Abdullah of Jordan that stinks from Israel were contaminating the atmosphere in Amman, presumably in the palace area. A latter day equivalent of Colville's complaint?
5. Of whom it is said that, but for his frequently and forcefully expressed controversial views on science and society, he would almost certainly have won the Nobel Prize, but this does not seem to have bothered him.
6. Balliol is perhaps the most famous Oxford College, the only one to have its own Bridge Club, and in 2005, had the largest number of applications to any Oxford college.
7. The most descriptive word of today's world is *speed*. For example, investment funds use a simulation program in which survivors out of millions of possibilities speed up the process of successful investment (see *State Street Global Invests in Artificial Intelligence*, 1997). Trillions of speeding processes of this kind (many of a much lesser rate) acting simultaneously speed up the entire process of evolution in what one might call the era of *increasing time compression*.

Chapter 4

1. Some portions of this description rightly belong in Chapter 2 dealing with the British period, but they are included here in the interest of continuity.
2. The Banaras Hindu University was founded by Pandit Madan Mohan Malaviya in 1916 with the cooperation of Dr Annie Besant, the founder of the Theosophical Society of India. The Aligarh Muslim University was among the first institutions of higher learning set up during British occupation. Originally it was called the Anglo-Oriental Mohammadan College, which was founded by a great Muslim social reformer Sir Syed Ahmad Khan (Dalrymple, 2006), along the lines of Oxford and Cambridge (Oxbridge).
3. http://www.iitm.ac.in/mission.
4. As an aside, it is worth noting that Subba Rao had worked with Prof. R. C. Brown at Purdue on some of his pioneering studies on boron chemistry. And when the award of a Nobel Prize for chemistry to Professor Brown was announced, Subba Rao made headlines by talking to the press about his personal involvement in Brown's discoveries and even implying that he should have had a share in the prize. This may or may not be a genuine grievance, but Nobel politics are well known. According to Gratzer (1989), Eleazer Lipskey's novel *The Scientists* is based on the dispute over the award of the Nobel Prize to Selman Waksman for his discovery of the antibiotic, actinomycin. A junior member of the team led by Waksman claimed that the basic idea originated from him and that Waksman had little to do with it. The dispute seems to have culminated in a lawsuit. See also: *Nobel Prize duel*, by Nicholas Wade, 1981; *Nobel dreams: power, deceipt and the ultimate experiment,* by Gary Taubes, 1986.
5. *Butadiene and styrene, in turn, can be made from almost any hydrocarbon. The Germans make it from coal and limestone, because that's what they've got. We, naturally, would make it from oil, because we've got plenty of that. The Russians made it from grain in the beginning but are turning more and more to oil too. Theoretically, you could make it from potatoes, from sugar, even from whiskey if you felt like it…You are a politician, and I am a rubber man, and I say make it from oil.* (Baum, 1943)

Chapter 5

1. Jawaharlal Nehru has often said in his speeches: *We cannot afford to remain static in a dynamic world.* Although a truism, these words from a leader of Nehru's stature were needed in a country not prepared to give up any of its traditional practices or thinking.
2. It is said that Zwicky was pointedly ignored by Robert Oppenheimer of atom bomb fame — who himself was infamously accused of communist leanings. It is not clear whether Oppenheimer did this to tell Zwicky that his unpredictable behavior did not go unnoticed!
3. The NCL's Archives may be referred to for a complete list of books written and edited and chapters contributed by its scientists.
4. Consultancies can be of various types. Instances are not wanting in India of professors calling themselves consultants when all they do is offer routine text-book advice without the need for the employing company to pay a full month's salary. On the other extreme is the kind of consultancy offered by scientists of the class of Feynman, who, on analyzing an accident, suggested that the rubber of the O-ring in a male-female joint might have lost its elasticity in a brief moment of exposure to 0ºC. He demonstrated it by dipping the joint in a glass of ice water. The NCL's consultancies were almost never of the first category; perhaps not of the second either. On a scale of 1 (category 1) to 10 (category 2), I would guess it was somewhere around 6.
5. I use the word mythical because I see nothing sacrosanct about a year that is distinguished only by a nice round number according to one particular calendar!
6. This is an unconfirmed attribution.
7. This was one of those rare occasions when the director invoked a procedure that allowed for the appointment of outstanding scientists on a temporary basis subject to confirmation by due process. This placed a heavy burden on the director for he had to be sure that the candidate was brilliant enough to pass through any selection committee.

8. The CSIR headquarters in Delhi is a purely administrative setup with facilities for technology evaluation and transfer, foreign collaborations and scholarships, recruitment of research fellows, and a few other activities. Planning and allocation of funds for its constituent laboratories is one of its most important functions. It is fortunate that the head of this activity was a scientist of the breadth and vision of A. Rahman, a scholar who specialized in India's scientific history. The NCL of the 1970s and 1980s owed much to him and to his deputy N. R. Rajagopal. He was on the same wavelength as the NCL with regard to planning and modernization. He went on to establish a separate center in CSIR and named it the National Institute for Science, Technology and Development Studies (NISTADS), of which he was the Director for a number of years. More than anyone else, he was responsible for creating a strong awareness in CSIR for such studies. For this accomplishment, Rahman, a gentleman-scholar, certainly deserves the country's unqualified recognition.
9. Wordsmith defies Buggin's Run as: *assignment to a position based on seniority or rotation, instead of merit.* The Peter Principle is a colloquial principle of hierarchiology, stated as: *In a hierarchy every employee tends to rise to his level of incompetence.* The common dictionary definition of blue-eyed boy is: *a man who is liked and admired by someone in authority*.
10. This is the only opportunity I have taken in writing this book to emphasize the fact that, chosen with care and dispassion, the "cult" of BEBs can be an asset to any laboratory. I cannot help recall my late wife's words when I would tell her that I had to go for an important meeting with a colleague: *Which of your favorites is it this time?*
11. I recall a similar situation in which Professor M. M. Sharma (MMS) and I were involved. We were members of a committee for selecting professors at IIT, Mumbai. During discussions after the interviews, the director of IIT made a strong plea for promoting internal candidates, but MMS and I equally strongly disagreed. The director then openly said that by promoting them, we would be mitigating their negative influence. The reasoning did not seem right, but as the director was insistent, with the added plea that he would have a revolt on his hands if they were not promoted, we relented — on condition that the young outside candidates recommended by us would soon be accommodated. As an endnote to this endnote, I was happy to learn later that the director had kept his word.

Chapter 6

1. The thrust of the first 4 lines is somewhat similar to what Finch told KV while handing over the directorship of the NCL to him.
2. When in the early 1960s the directors of the Max Planck Institutes in Germany decided to revise the working hours, he is reported to have expressed his exasperation thus (according to H. A. Krebs, one of his students who also won the Nobel Prize, in his biography of Otto Warburg): *Can you imagine, those people no longer wish to work on Saturdays? When I asked them why they no longer considered it necessary, they said that the employees needed time for shopping. So I told them perhaps they should also give their employees Friday off so that they could do still more shopping.*
3. For instance, Narayanan, who was India's Ambassador to USA for a few years when Indira Gandhi was Prime Minister, told some interesting tales. It appears that President Lynden Johnson greatly respected the Indian Prime Minister and during one of the receptions to her in Washington asked her for a dance. Indira Gandhi was delighted but told the President that her dancing with the President of the United States would not go down well in her country. On another occasion, when Nurul Hassan, who was in charge of the science and technology portfolio, had breakfast in the director's house, LKD's wife insisted on getting a special chair for the 300+ pound Nurul Hassan. When told by LKD that he managed quite well with regular chairs in the NCL, her reply was that that was the director's business, but what happened to the minister at her breakfast table was her business. Nurul Hassan appreciated the comfort of the big chair and told her so.
4. Patenting has always been important, almost since the dawn of civilization. In some ancient civilizations, the preservation of a secret did not need any legal or moral protection. A more direct — and macabre — method did the job more efficiently. Cut off the hands of an artisan, for example, so that he would not repeat his work!

5. In my personal opinion, Bhargava built the first modern state-of-the-art laboratory in India. His short tenure as Vice-Chairman of the knowledge Commission formed by the Prime Minister provided him with the best opportunity to collide with dream, as I have ventured to do in Chapter 18 for the NCL.
6. I would be remiss if I did not mention one change that was counterproductive. Performance evaluations and many appointments were centralized, thus reversing the process started by Hussain Zaheer, one of the broadest minded Directors-General of the CSIR, and providing more muscle to Delhi's bureaucracy. There were many points in favor of this reversal but, in sum, it was not for the greater good of science in India.
7. As summarized by Gratzer (1989), a striking example is *the relationship between (*the*) research grandee (*Carlo Rubbia*) and the armies (at least in particle physics) of his vassals*, narrated by Gary Taubes in his *Nobel Dreams*. Rubbia forbade his students and associates from speaking about their research with anyone without his permission.
8. In naming these scientists, who will pass muster by the highest standards, I have not (for obvious reasons) considered the present scientific pool of the laboratory (with the exception of Kulkarni, whose contributions I can personally judge).

Chapter 7

1. Not *SCIENCE* — to let Pasteur rest in peace, see Chapter 9.
2. Well might Darwin have said this, for his own cousin Francis Galton was a polymath *extraordinaire*, who did original work of the highest order in such far-flung areas as statistics (he invented regression analysis), meteorology, genetics, writing, exploration, criminology, library science.

Chapter 8

1. From Maxwell's ode "To the chief musician upon nabla 1882." This captivating rendition of science in verse by a cloud-capped genius is part of an ode to his contemporary John Tyndall and to the Assyrian harp, the nabla.
2. Once when there was an explosion in the Physics Department of the University of Berne, it was pointed out, rather ominously, that just at that time Pauli had alighted at the railway platform in Berne for a change of trains!
3. A perfume must be distinguished from a perfumery chemical. As pointed out in the patent cited above, perfume = perfumery chemical + additives.
4. Three women, Vandana Shiva (renowned Indian environmentalist), Magda Aelvoet (then Member of the European Parliament and President of the Greens in the Parliament), and Linda Bullard (of the International Federation of Organic Agriculture Movement) filed a case in the mid-1990s claiming that the fungicidal properties of the neem tree were public knowledge in India for centuries and that the patent obtained by the US government and Thermo Trilogy Corporation was illegal. In a landmark victory in the world's first case against such bio-piracy, the European Patent Office upheld on March 8, 2005, the decision to revoke the neem patent (see neem website).
5. *Nobel Dreams* by Taubes (1986) and *Nobel Prize Duel* by Wades (1981) record illuminating tales of how some of the greatest minds in science behaved not so greatly in their quest for the world's highest honor. Instances are not lacking of such conduct even in the chase for lesser honors.
6. When William Perkins discovered a new dye in 1856, the French called it mauve, the name by which it is known to this day. It became so popular that in today's world it would be called a T-shirt sensation. It is learnt (Adrosko, 1971) that even the London bobbies directing loiterers seem to have told them to *get a mauve on* (to get a move on).
7. This was a reaction fraught with safety problems, and there was no mandatory protocol for handling such reactions in the NCL of the 1960s. All that happened was I was told to exercise extreme caution and ensure that no scientist/student was injured. We all managed to get away with no more than minor burns and assorted injuries! Such a situation, I am assured, is unthinkable in the NCL now.

8. Tissue culture in India made its debut at the NCL, along with one other laboratory. In a land close to India, which I shall not name, it is stated to have made a kingly debut — not metaphorically but really and truly. The story of that royal beginning was told by Julian Huxley in the words of his friend Hascombe and, very greatly compressed, is as follows. Taking Huxley to a 'laboratory' (such as it was!), Hascombe explained: This is known to the people as the Factory of Kingship or Majesty. If you prefer a more prosaic name, call this the Institute of Religious Tissue Culture. (The king's life is of paramount importance to the people, and it should be preserved and propagated by tissue culture.) So, under threats of death if anything untoward occurred, I was allowed to remove small portions of his Majesty's subcutaneous connective tissue under a local anaesthetic in the presence of the assembled nobility. I put fragments of this into culture medium, and showed it to them under the microscope...After 3 days, to my joy, they had all taken root and shown abundant growth. I could see that the Council was impressed. [The follow-up experiments having not taken well], I pointed out to Bugala that they could now disregard some of the older implications of the doctrines of Kingship. The most important idea I was able to introduce was "mass propagation." Our aim was to multiply the King's tissues indefinitely! (see Gratzer, 1989)
9. Instances of rivalry, even acute rivalry, in science are not hard to find, but entomology runs away with the prize in driving one of the rivals to insanity because of an ignominious feud! The two entomologists concerned were the celebrated W. T. Harpley of *Periplaneta Hapliia* fame and Professor Pawkins known for his revision of the *Microelepidoptera* in which he altogether extinguished a new species created by Hapley. H. G. Wells, in his *Moth* (1895) recalls the final days of the demented Hapley worried by a moth that did not exist and that, he insisted in his saner moments, was the ghost of Pawkins! An instance that came close to this in the NCL was in the rayon grade pulp project where one of the assistants felt so terrorized by the project leader that he had to undergo psychiatric treatment for a while. I had him transferred to another group, but soon he left NCL.
10. With apologies to Berzelius**:** The word *catalyze* is perhaps the most indiscriminately used scientific word in almost every unscientific activity, like in describing the quickened rise or fall of a politician, the hastening of a political, social or any other occurrence, the assisted flourishing or dissolution of a political philosophy, or any such event that is accelerated or decelerated by intentional intervention. To keep the good old Swede from turning in his grave, I use the word here in its pristine form, as originally defined by him.
11. Because of the difficulty in fully grasping the meaning of thermodynamics, and because of its fundamental role in defining the occurence and course of natural phenomena, several pithy sayings about it have sprung up. The present section commences with a quotation from a famous author with no pretensions to high science. Here is another story attributed to the incomparable Walther Nernst (1920 Nobel Prize winner in physics, who was buried three times and drew the amused ire of his pall bearers: *You can't bury Nernst too often*!). That thermodynamics was never far away from his ever agile mind is seen from the remark he made when he went into his cowshed one winter morning and found it warm without artificial heating (Mendelssohn, 1973). When informed that it was probably due to the metabolic heat generated by the animals, Nernst said that he would sell the cows and invest the money in carp since he did not intend to spend his money on meat production attended with so much waste heat when the same thing could be done isothermally!
12. While informally discussing chemical engineering amongst a group of scientists, I remarked (originally as I believed) that a chemical engineer is someone who talks chemistry in the presence of engineers and engineering in the presence of chemists, thus staying clear of the dangerous possibility of any in-depth discussion. Half a century later, when I began on this book, I was browsing the internet and various books to look for a suitable quote for the section on chemical engineering. What I found literally took my breath away: *A chemical engineer is someone who talks chemistry…..*!
13. Substitution of the words *mathematical modeling* for *conjecture* is a truer representation of science today than in Mark Twain's time.
14. R. Kumar of the Indian Institute of Science, Bangalore, had made a spirited beginning in this area in India in the 1960s. This was followed some years later by a few others, notably the versatile J. B. Joshi of the UICT, Mumbai. Mark Twain's saying is particularly relevant to some of the modeling studies

during this period, since the data on which they were based was minimal, and the research was largely confined to refinements in statistical methods for selecting the best model. Kumar's and Joshi's studies also involved much experimentation.

15. It is to the credit of Max Planck that his brilliance and commitment to science never wavered in spite of a string of tragedies that shadowed him throughout his life, culminating in the execution of his son by Adolf Hitler. He continued to enrich human thought to the end of his days.
16. Although this quotation is more specific to generation and propagation of waves, I use it here because it also equally captures the essence of instability.
17. This line was quoted by Rutherford (Gus) Aris in his article in honor of Neil Amundson on his 60th birthday, but Gus made it clear that he was referring not to the aging subject of the honor but of the article, the reaction pot!
18. *The Assayer* is regarded as a masterpiece of style not just by scientists but, even more, by artists, poets and writers (see Mariano Artigas, *New Light on the Galileo Affair* published in *Metanexus*, April 30, 2002).
19. Ranade and Kulkarni were students of Professor J. B. Joshi, Director of the University Institute of Chemical Technology, Mumbai, who has been largely responsible for introducing research in CFD in India.

Chapter 10

1. Goethe, 1963.
2. This is a kind of misplaced optimism that survives to this day all over the world, even embracing events of the greatest consequence. For example, how does one define success, failure, or if a task is completed? A recent poll question by a TV network in connection with the Iraq war: How do you define success? vindicates NCL's ignorance of half a century ago on a much lesser issue and, incidentally, trivializes a global event (by demoting what should be an inarguable fact to an individual opinion).
3. For the information of non-technical readers, a non-return valve is one which allows flow in only one direction and seals off any backward or return flow.
4. In the course of writing this book, I came across an article with the intriguing title "Reusing a Process Without Reinventing the Wheel," written by a management and technology consulting company, BearingPoint. Although written in an investment and business context, and its application to technology development is dubious, it makes an interesting reading.
5. Incidentally, this is not something that is peculiar to India. The managing director of Francolor in Paris told me once that, after all the sophisticated tests for color matching, they would finally turn to the human eye of a long-time expert for final clearance!
6. This was not the first instance of wanting to establish a major facility in a jail building. The first Indian Institute of Technology was started in a jail building in Kharagpur (see Chapter 4). And now from jails to palaces! As though to prove its commitment to egalitarian principles, the CSIR established its Central Food Technological Research Institute at the magnificent palace of the Maharaja of Mysore in Mysore, and the Central Drug Research Institute at Chatarmanzil, a famous palace in Luknow.
7. Looking back at this costly failure, I am convinced that *success* in winning the contract would have been several-fold costlier to the NCL — in more ways than one. It also emphasizes the fact that over-analysis can lead to ambivalence. As I remark later in Chapter 18, lukewarmness at the leadership level is bad, and the NCL was no exception to exhibitions of this trait, however infrequently or driven by circumstances beyond control.
8. The literal translation would be "forest dwellers" but actually it refers to inhabitants of the region from the distant past, probably from the pre-Aryan days. They are usually illiterate and live far below the poverty line.
9. This cell was created to assist the establishment of simple small-scale processes, with none of the modern concepts of small-scale engineering, as described, for instance, in the book: *Chemical Process Technology* by Jacob A. Moulijn, Michiel Makkee, and Annelies van Diepen. In other words, the processes were not to be based on the use of micro-reactors with sophisticated controls, multiple-purpose reactors with

their own sophisticated strategies of optimal use, etc., but were to be developed for easy use by average chemists and operators. The use of micro-reactors and other modern tools was undertaken by the NCL in its later years (see Chapter 8).

10. Part of the work described in the previous sections was also sponsored by the industry, but had practically no part in the work done at the NCL; and since much of it was funded by the NCL, it was included there and not in the present section. In any case, since the NCL was fully involved in all the projects, sponsored or unsponsored, with a fair portion of the expenditure borne by it (with the exception of major equipment), the division till 1990 was somewhat arbitrary.
11. Trivedi's enthusiasm for practically-oriented science teaching and research found its best expression in his enthusiastic but futile pursuit of a dream: to establish at Ahmedabad in the state of Gujarat a national institute at the graduate level modeled along highly original lines involving top scientists and engineers of Indian origin from the USA and other countries, as well as visiting scientists/professors from many countries. I had agreed to coordinate this effort, as consultant from the USA, on an international basis and had even prepared a report for him and his co-sponsor K. G. Shroff, Managing Director of Excel Industries. Things were moving smoothly when, suddenly, the Gujarat government fell, and the new government permanently shelved all such initiatives of its predecessor. Seeing no hope of revival, a heartbroken Trivedi gave up.
12. Said in the context of the automobile industry, this is equally valid for industrial/power alcohol production.

Chapter 11

1. Hussain Zaheer, who was Director-General of the CSIR in the early 1960s, had set three major goals for the laboratories (in keeping with the political persuation of the time): import substitution (regardless of the novelty of the substituting process), export promotion, and use of locally available raw materials. These goals were vigorously pursued by Tilak at the NCL till the late 1970s.
2. It is pertinent to note here that this seems to have been a common practice in India. Companies like Excel Industries are reported to have made excellent use of TVA's (Tennessee Valley Authority) decision to give away their designs for several selected plants to anyone who wished to use them (I am not sure if a nominal fee was charged or not).

Chapter 13

1. Those who tend to monopolize the stage in a meeting with a non-stop flow of words and occasional table-thumping would do well to remember Adlai Stevenson's admonition:

   > *The sound of tireless voices is the price we pay for the right to hear the music of our own opinions... Every man has a right to be heard, but no man has the right to strangle* [debate] *with a single set of vocal cords.*
   >
   > *Stevenson, 1952*

2. Mencken, with characteristic sarcasm, used the term "taste of the American public" instead of "role of administration" added by me.
3. My own experience in the USA for nearly 20 years has clearly shown that it is much more procedure bound with unalterable steps preceding any major decision. For example, the scrutiny of applications for an advertised position is governed by a time-consuming procedure that requires reasons to be clearly recorded for rejecting any application. Nothing goes unrecorded! There is no such requirement in India, where there is some room for personal judgment.
4. It would serve the NCL well if a section is created with top scientists with formal training in popular science writing. Some NCL scientists with a flair for writing may also be selected for formal training.
5. A common example known to, but not noticed by, air travelers is the following: "In the event of the plane having to land on water" (announcement by an English air hostess) as against "In case of water landing" (same announcement by an American air hostess).

6. I came across this saying in one of my readings and I believe it was anonymous. If there was an identified author, I apologize to him for my not acknowledging him.

Chapter 14

1. On a personal level, I find something wonderfully musty about a room full of books, particularly old books and original manuscripts. I could never accept a chip as a substitute to this beguiling collection of paper and parchment, especially the restored ones — except in situations demanding speed. To quote Henrikas Yushkiavitshus of UNESCO (2002):

    *We were brought up on the written word; our children are and will be brought up on images. Will they lose touch with the book? Will they lose **touch of the book** — this very special feeling that nothing can replace? Nobody can tell exactly what the library of the future will look like. Will it preserve its traditional bookshelves and the typical smell of old books or will it look like the inside of a huge electronic brain. Whatever the picture, the central element of that picture will continue to be the Librarian — it will be you. You are the navigators that take the library's ship through the ever-expanding ocean of information.*

2. The measurement of the speed of light by Michelson and Morley in the 1880s, the gravitational constant based on a conjecture by Newton in his *Principia* (1687), and an incredible number of measurements pertaining to the very large (in astrophysics) and the very small (in sub-atomic research). Even legal battles are not immune from decisions delivered based on measurement, such as the fixing of the boundary between the estates of two warring Americans, William Penn, the owner of the colony of Pennsylvania, and Lord Baltimore, the owner of the colony of Maryland (Bryson, 2003). The measurements of Mason and Dixon, which later gave rise to what has since been known as the Mason-Dixon line, formed the legal dividing line between the estates of Baltimore to the south of the line (known as the slave states) and of Penn to the north (known as the free states). The division of India into linguistic states was beset with many legal and political battles before it was fully resolved, based on some precise boundary measurements.
3. www.dukemagazine.duke.edu/issues/091007/depgar.html

Chapter 15

1. My experience had taught me that haste and urgency could be added to such a job (considered non-essential by the Indian establishment and "pork" by the American) by attaching it as a footnote to an important activity. This is precisely what was done, and the work was finished in record time (with much prodding, of course).
2. My late friend and colleague Madhusudan Goswami (a highly regarded Ph.D. in chemical engineering from the University of Glasgow, who as a Senior Scientific Assistant, was fully justified in not taking kindly to me when I first joined the lab as a Senior Scientific Officer, but with characteristic generosity forgave what he thought at the time was my unwarranted higher position, and became a very close friend in subsequent years) had this to say about the part-time doctors. One of them, perhaps somewhat overawed by the "doctors" of the NCL, never prescribed a medicine without the patient's endorsement. It is also reported that he invariably asked the patients to suggest the medication themselves!

Chapter 16

1. What would have happened if so many things had not happened when they did? How much longer would it have taken for somebody to discover Nylon if DuPont had not discovered it when it did? How much longer for a platformer (for refining petroleum) if UOP hadn't come up with it when it did. On a loftier scale, how much longer for the atomic theory to be proposed if Ernest Lord Rutherford had never existed? There can be no answers. C. P. Snow's speculation (1967) regarding the last item: *Perhaps ten years. More likely only five.* All this is in line with the theory of evolution of life, of society, of cities, indeed of the

universe itself. Entities adapt, disappear, or minimally survive, depending on a myriad circumstances (see Fabian, 1998). Without the changes mentioned, the NCL might have minimally survived — perhaps not as the force it evolved to be.

2. Authentic discussions of similar performances seem to have reached the pages of *Nature*. Martin Gardner's "Science: Good, Bad and Bogus" (1957) throws interesting light on this issue. Taylor, a mathematics professor, appeared on a BBC television show with the illusionist Uri Geller and watched him with wonder as he broke a fork by stroking it and duplicated a drawing in a sealed envelope. Such acts soon came to be known as the Geller Effect or (for reasons I cannot quite fathom) the shyness effect! Taylor even produced a book titled Superminds (1975) in which he extolled Geller's abilities, showed photographs of grinning children holding cutlery they had supposedly bent and of flying spoons and tables, and attributed them all to electromagnetism. But several years later he retracted, rather mildly, in an article in *Nature*: "Can Electromagnetism Account for Extrasensory Phenomena" (1978).
3. They were the days of the second World War and Lord Todd (a Nobel Laureate), also a reasonably heavy smoker, had traveled by train with hardly a cigarette to smoke all the way, not because the train was smoke-free, a latter day phenomenon, but for the simple reason that cigarettes were not available on the train. Immediately on getting off the train, he was taken to the officers' mess for lunch. The rest of the story is best told (almost) in Lord Todd's own words:

   Todd: *Can I have some cigarettes?*
   Barman*: What is your rank?*
   Todd: *I am afraid I haven't got one.*
   Barman*: Now that puts me in a spot, for orders about cigarettes in this camp are clear — 20 for officers and 10 for other ranks. Tell me what exactly are you?*
   Todd (somewhat self-importantly): *I am the Professor of Chemistry at Manchester University*.
   Barman (after some contemplation): *I will give you 5!*

   Todd, 1984

   That day forward, Lord Todd records, he had no illusions about the importance of professors. Finch, too, need not have entertained any illusions about a professor smoking a Charminar!
4. This is a story that came to my knowledge through the NCL/CSIR grapevine, and I cannot be certain about its authenticity.

Chapter 18

1. "What's past is prologue" is a very famous line used frequently, yet eternally fresh, and is carved on the National Archives Building, Washington, D.C., USA.
2. Johnson sarcastically objects to the physician's attribution of cause to a human physical condition when it is often no more than a subsequent step in the natural sequence of events.
3. http://www.abc.net.au/rn/science/ss/stories/s199676.htm
4. See Samuel Johnson's famous definition: *Is not a patron, my lord, one who looks with unconcern on a man struggling for life in the water, and, when he has reached ground, encumbers him with help*? (Letter, February 7, 1755, to his patron Lord Chesterfield in John Boswell, *Life of Samuel Johnson*, 1791, 1921)
5. I am not so sure that the hyphen should be strengthened. It might be argued equally forcefully that the hyphen should be weakened to the point of extinction, so that a single new discipline emerges replacing the two brought together by grammar!
6. A refreshing exception is the Center for Cellular and Molecular Biology (CCMB), another laboratory of the CSIR, the brainchild of P. M. Bhargava, an IICT scientist who became CCMB's first Director. This was built as a state-of-the-art laboratory in all aspects of its functioning. The CSIR objected to many of his ideas but Bhargava stood his ground and CCMB became a modern reality. An even more elegant example is the Jawaharlal Nehru Center of Advanced Scientific Research created by C. N. R. Rao at Bangalore. The University Institute of Chemical Technology (UICT) at Mumbai is undergoing a similar transformation under J. B. Joshi/J. D. Yadav.

7. There is only one exception to this recommendation: M. M. Sharma, who has consistently striven to elevate any issue with which he was concerned.
8. A historically important example is that of the great Belgian biologist, Jules Bordet (see Paul de Kruif's Memoirs, *The Sweeping Wind,* 1962). Bordet had discovered the spirochete of syphilis before Schaudin, but dared not publish this tremendous discovery without consulting his guru, the great Metchnikoff of the Pasteur Institute. Metchnikoff was getting old and could not see well in the microscope, but this did not deter him from advising Bordet against publication. So, as Bordet later remarked: *I lost that one.*
9. Plagiarism is difficult to define. Here is Mencken's characteristically cutting view that speaks for itself: *Stealing from one is plagiarism. Stealing from many is research.*
10. In their book *Betrayers of the truth*, Broad and Wade (1982) give an example of the second extreme that should serve as a constant reminder of this, the most outrageous expression of intellectual dishonesty. They cite the example of a certain Albasti, known only to himself and his small circle of friends, who managed by various means to get hold of manuscripts by other authors before they were published and sent them out in his own name (sometimes adding fictitious co-authors) to much less known Japanese journals where they were quickly published, thus giving him precedence. On the other hand, accusations of plagiarism cannot always be taken seriously. Even Einstein did not escape such an accusation.
11. P. B. Medawar, a colleague of J. B. S. Haldane, has the following story to tell about the eccentric polymath: Haldane worked in a room which was never tidied or cleaned. The fossils upon which he was one day proposing to undertake studies were clearly undergoing a second internment, the sediments this time consisting of atmospheric dust and soot, together with manuscripts, committee reports, and official communications from the college...It was the laugh of the department when electricians whose duty it was to rewire the office demanded danger money to work on it. (Medawar,1967)
12. The numbers in this paragraph have been taken from a BBC talk by a Cornell University professor (Basu, 2006). His statement that not a single university from India finds a place among the top 300 in the world is not borne out by facts.
13. A word of caution here, for this can lead to replenishment in one part at the expense of depletion in another. Balance must be quickly restored. The chemical engineer in me cannot help drawing a parallel with a chemical reactor in which hundreds of tubes packed with catalyst are paced in a shell and the reactant passed through them. A slight perturbation at the entrance can cause a higher flow in one tube in relation to that in a neighboring tube, leading catalyst depletion in that tube and its accumulation in the neighbor. This process continues till one tube is empty and another too full to hold the carryover catalyst. The resulting instability can be disastrous, unless corrected in time.
14. I refer here to the lecture by George Andrews, Distinguished Professor of Mathematics at Penn State University, and President of the American Mathematical Society, and to the subsequent information kindly provided by Professor Tim Huber. Huber referred me to an excellent article in New York Times on Ramanujan by Gleick (1987), titled "An Isolated Genius Gets His Due," which makes fascinating reading. I quote his words on the importance of Ramanujan's "practicallty useless" work: Now his work is flowing into mathematics and science more deeply than could have been imagined a generation ago. Computers, with special programs to manipulate algebraic quantities, have made it possible for more ordinary mathematicians to pick up the trail of his thought. And modern physics, from the superstring theory of cosmology to the statistical mechanics of complicated molecular systems, finds itself turning more and more often to the pure findings of number theory and complex analysis — the worlds of Ramanujan. (Gleick, 1987)
15. Charles Lamb was associated with the East India Company, and his reverie is perhaps the only single-paragraph writing in the English literature.
16. These lines were inspired by the *Rubaiyat* of Omar Khayyam: *The moving finger writes, and having writ moves on* (first English translation by Edward Fitzgerald, 1809 — 1883, over a period of decades).
17. One can quote many instances from the past to prove this point, but the following is particularly illustrative. The great Reynolds of viscous flow/Reynolds number fame was teaching a class attended by Nobel Prize winning J. J. Thomson of electron fame. He would often forget about the class and had to be reminded. He would then briskly walk in, open a page from the famous Rankine's book, look at

the equation there and declare that it was wrong. He would then proceed to the black board, write some equations there, stare at them, rub them out, write some more equations, rub them out too, write a fresh set of equations, and then declare most innocently that Rankine was right after all! This interesting exercise, as he remarks in his *Recollections and Reflections (1936), did not increase our knowledge of facts, but showed the workings of a very acute mind grappling with a new problem* (Thomson, 1936). Ability to articulate is always an asset but certainly not essential in research oriented teaching, where inspiration is central.

18. Dirac often spoke in monosyllables, more often in single words like yes or no. Infeld recalls the story of a famous French friend of Dirac's talking to him painfully for days in his laborious English. On one occasion, finding it particularly difficult to express some complex thoughts in English, he asked Dirac: *Do you know French*? Pat came the reply: *Yes, I do. My mother is French*. When asked why he had allowed the Frenchman to struggle with his English for days by not telling him that French was his mother tongue, his innocent response was: *You didn't ask me*!
19. http://rpo.litrary.utoronto.ca/poet/143.html.
20. Facts can also be ugly, according to Thomas Huxley, who famously said: *The great tragedy of science: the slaying of a beautiful hypothesis by an ugly fact*. Stephen Jay Gould (1985) emphasizes this fact in an entirely different way: *We often think, naïvely, that missing data are the primary impediments to intellectual progress - just find the right facts and all problems will dissipate. But barriers are often deeper and more abstract in thought. We must have access to the right metaphor, not only to the requisite information. Revolutionary thinkers are not, primarily, gatherers of facts, but weavers of new intellectual structures* (Gould, 1985).
21. I am for facts. They are important. On the other hand, the opinions of men like Emerson and others that I have quoted in this book should encourage us to look beyond facts to what causes them, since most of them are no more than experimental observations on specific systems that get repeatedly refined, sometimes even proved wrong. Very few of them are general constants (facts or truths) of chemical, physical or biological phenomena.
22. This statement is based on a lecture I once heard by C. V. Raman, in which he said (and here I quote from memory): *research need not be useful in order to be valuable.*
23. Whoever thought that understanding evolution, the atom, the star, the chemical band, the splitting of light, analyzing the God Particle, and a myriad other useless discoveries will lead to a better life for humankind.

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LIST OF ABBREVIATIONS

AAAS	American Association for Advancement of Science
ABCDIO	Access to Biological Collections Data of Indian Origin
ABS	Acrylonitrile Butadiene Styrene
ACC	Associated Cement Company
ACPL	Adarsh Chemicals Private Ltd.
ACS	American Chemical Society
ADL	Arthur D. Little Inc.
AEC	Atomic Energy Commission
AES	Acrylonitrile Ethyl Styrene
ALIS	Alberta Learning Information System
AMPS	2-Acrylamido 2-Methylpropane Sulfonic Acid
AO	Administrative Officer
APA	Aminopenicillanic Acid
APL	Asian Peroxides Ltd.
ARDE	Armament Research and Development Establishment
ASPEN	A Systematic Process Engineering Design
ATI	Advanced Training Institute
BCE	Before Common Era
BAM	Brewster Angle Microscope
BDD	Business Development Division
BEG	Bombay Engineering Group
BEP	Break Even Point
BIOS	British Intelligence Objectives Sub-committee
BOD	Biological Oxygen Demand
BPM	Bharat Pulverizing Mills
BVM	Bharat Vijay Mills
CE	Common Era
CASTFORD	Center for Application of Science and Technology for Rural Development
CBNB	Chemical Business News Base
CD	Compact Disc
C-DAC	Centre for Development of Advanced Computing
CD-ROM	Compact Disc Read Only Memory
CDS / ISIS	Computerized Data Services/Integrated Set of Information Systems
CEBC	Center for Environmentally Benign Catalysis
CEPD	Chemical Engineering and Process Development

CERT-IN	Computer Emergency Response Team (India)
CFB	Central Forensic Bureau
CFCs	Chlorofluorocarbons
CFD	Computational Fluid Dynamics
CHEMCAD	Chemical & Computer Aided Design
CIOS	Combined Intelligence Objectives Sub-Committee
CMD	Chairman and Managing Director
C-MET	Centre for Materials for Electronics Technology
COA	Controller of Administration
COF	Controller of Finance
CP-MAS	Cross Polarized-Magic Angle Spinning
CSIR	Council of Scientific and Industrial Research
CSTR	Continuous (Flow) Stirred Tank Reactor
DACL	Diamines & Chemicals Ltd.
DBT	Department of Biotechnology
DCEP	Dalal Consultants and Engineers Private Ltd.
DDT	Dichloro-Diphenyl-Trichloroethane
DETA	Diethylnetriamine
DIPB	Diisopropylbenzene
DIRC	Digital Information Resource Center
DIT	Database of Indian Taxonomists
DMA	Dimethylaniline
DMDCS	Dimethyldichlorosilanes
DNA	Deoxyribonucleic Acid
DOE	Department of Education
DOEACC	DOE Accredited Computer Course
DSM	Dhampur Sugar Mills Ltd.
DST	Department of Science and Technology
DTS	Division of Technical Services
EB	Ethylbenzene
EC	European Community
ECOFRIG	Ecological Refrigeration
EDA	Ethylenediamine
EIL	Engineers India Ltd.
ENCICARB	The name of Catalyst developed by the NCL (reflecting origin as the NCL)
EO	Ethylene Oxide
EPC	Export Promotion Council
ERDL	Explosives Research and Development Laboratory
ERNET	Education & Research in Computer Networking
ESCA	Electron Spectroscopy for Chemical Analysis
ETS	Engelhard Titano Silicate

FACT	Fertilizers and Chemicals of Travancore
FAO / IAEA	Food and Agricultural Organization / International Atomic Energy Agency
FERA	Foreign Exchange Regulation Act
FF	Fukui Functions
FIAT	Field Information Agency Technical
FT-IR, FTIR	Fourier Transformer Infrared (Spectroscopy)
GACL	Gujarat Aromatics and Chemicals Ltd.
GATT	General Agreement on Tariff and Trade
GC-MS	Gas Chromatography-Mass Spectroscopy
GE	General Electric
GOAF	Government Opium and Alkaloid Factory
GSI	Geological Survey of India
GTZ	Deutsche Gesselschaft fur Technische Zusammeenarbeit, GmbH
HAL	Hindustan Antibiotics Ltd.
HALS	Hindered Amine Light Stabilizers
HCCP	Hexachlorocyclopentadiene
HCE	Hexachloroethane
HDAC-SP	Histone Deacetylases-SP
HDCL	Hindustan Development Corporation Ltd.
HETE	Hydroxy Eicosa Tetraenoic Acid
HFCs	Hydrofluorocarbons
HIDECOR	Human and Institutional Development in Ecological Refrigeration
HIL	Hindustan Insecticides Ltd.
HOC	Hindustan Organic Chemicals Ltd.
HPL	Haldia Petrochemicals Ltd. / Hindustan Polymers Ltd.
HPLC	High Pressure Liquid Chromatography
HR-MAS	High resolution-Magic Angle Spinning
HT	High Temperature
HTS	High Throughput Screening
IACS	Indian Association for the Cultivation of Science
IARC	International Agency for Research on Cancer
ICAR	Indian Council of Agricultural Research
ICI	Imperial Chemical Industries
ICMA	Indian Chemical Manufacturers' Association
ICREC	International Chemical Reaction Engineering Conference
ICS	Indian Civil Service
IDBI	Industrial Development Bank of India
IDPL	Indian Drugs and Pharmaceuticals Ltd.
IDRA	Indian Drugs Research Association

IEP	Import Export Policy
IGR	Insect Growth Regulator
IIM	Indian Institute of Management
IIT	Indian Institute of Technology
IIM	Indian Institute of Metereology
ILTP	Integrated Long Term Program
INCON	International Conference on Instrumentation and Control
INSA	Indian National Science Academy
INSDOC	Indian National Scientific Documentation Centre
IP	Intellectual Property
IPCL	Indian Petrochemicals Corporation Ltd.
IR	Infra Red
ISRO	Indian Space Research Organization
ITI	Industrial Training Institute
IVCL	Indo Vanillon Chemicals Ltd.
JCR	Journal Citation Report
LAN	Local Area Network
LB	Langmiur Blodgett
LC-MS	Liquid Chromatography Mass Spectroscopy
LGPC	Linear Generalized Predictive Control
LIBSYS	Libsys Corporation
MAS	Magic Angle Spinning
MCB	Monochlorobenzene
MECON	Mechanical Engineering Consultants
MEK	Methyl Ethyl Ketone
MERADO	Mechanical Engineering Research and Development Organization
MIDC	Maharashtra Industrial Development Corporation
MIT	Massachusetts Institute of Technology
MITCON	Maharashtra Technical Consultancy Organization Ltd.
MMA	Monomethylaniline
MNC	Multi National Companies
MoEF	Ministry of Environment and Forests
MRCC	Multi-Reference Coupled-Cluster Theory
MSFC	Maharashtra State Finance Corporation
MSI	Marine Survey of India
NABARD	National Bank for Agricultural Research and Development
NACID	National Access Center for International Database
NADP	Nicotinamide Adenine Dinucleotide Phosphate
NARI	National AIDS Research Institute
NATCOM	National Communication Project
NCCS	National Centre For Cell Science
NCIM	National Collection of Industrial Microorganism

NCST	National Committee on Science and Technology
NDA	National Defense Academy
NET	National Eligibility Test
NFKB	Nuclear Factor Kappa B
NIC	National Informatics Centre
NICHEM	National Information Center for Chemistry and Chemical Technology
NICSI	National Informatics Centre Services Inc.
NIDC	National Industrial Development Corporation
NISSAT	National Information System for Science & Technology
NIXI	National Internet Exchange of India
NMITLI	New Millennium Technology Leadership Initiative
NMR	Nuclear Magnetic Resonance
NOCIL	National Organic Chemical Industries Ltd.
NRDC	National Research and Development Corporation
NTP	National Toxicology Program
OCCB	Organic Chemistry Chemical Biology
ODA	Overseas Development Administration
OGL	Open General License
OSHA	Occupational Safety and Health Administration
PCR	Polymerase Chain Reaction
PFCs	Perfluorocarbons
PM	Prime Minister
PMT	Pune Municipal Transport
PNA	Peptide Nucleic Acids
POM	Partial Oxidation of Methane
PPD	Project Planning and Development
PSU	Public Sector Undertaking
PTA	Parents Teachers Meeting
PTC	Plant Tissue Culture
PVC	Poly Vinyl Chloride
R & D	Research and Development
RF	Research Foundation
RLDC	R. L. Dalal and Co.
RNA	Ribo Nucleic Acids
RPBD	Research Planning and Business Development
SA	Standard Alkali
SaGrIS	Sacred Groves Information System
SAIL	Steel Authority of India Ltd.
SAMEER	Society for Applied Microwave Electronics Eng. Research
SAMPADA	A Multi-Taxon Biological Collections Data Management System
SAN	Styrene Acrylonitrile

SAPO	Silico Alumino Phosphate
SBR	Styrene Butadiene Rubber
SCI	Sudarshan Chemicals Industry
SDC	Swiss Development Corp.
SDL	Sahyadri Dyestuffs Ltd.
SELEX	Systematic Evolution of Ligands by Exponential Enrichment
SET	State Eligibility Test
SIL	Special Instruments Laboratory
SMCL	Standard Mills Company Ltd.
SOCL	Somaiya Organo Chemicals Ltd.
SPA	Solid Phosphoric Acid
SPB	Sports Promotion Board
SPREAD	Sponsored Research and Development
SPV	Special Purpose Vehicles
SR Club	Staff Recreation Club
SSBM	Sir Shanti Swarup Bhatnagar Memorial
SSI	Small Scale Industries
STM	STM is an international association of Scientific, Technical, Medical and Scholarly Publishers
STP	US-based Soceity of Toxicologic Pathology
STPI	Software Technology Park of India
SVM	State Vector Machine
SWA	Scientific Workers' Association
TAB	Technology Advisory Board
TDWG	A Software by GBIF and CODATA Taxonomic Database Working Group
THPE	Tris Hydroxy Phenyl Ethane
TIFR	Tata Institute of Fundamental Research
TOCC	Thai Organic Chemicals Co.
TPA	Tons Per Annum
TPS	Technology Policy Statement
TRIPs	Trade Related Intellectual Property
UCL	United Catalyst Ltd.
UDCT	University Department of Chemical Technology (Mumbai)
UGC	University Grants Commission
UICT	University Institute of Chemical Technology (Mumbai)
UNANST	Units on Nanoscience and Technology
UNDP	United Nations Development Program
UNESCO	United Nations Educational Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
UOP	Universal Oil Products

UV	Ultraviolet
VAPIS	Value Added Patent Information System
VASVIK	Vividhlaxi Audyogik Samshodhan Vikas Kendra (Mumbai)
WFCC	World Federation of Microorganisms
WHO	World Health Organization
WIPO	World Intellectual Property Organization
WMDC	Western Maharashtra Development Corporation Ltd.
ZSM	Zeolite Synthesized by Mobil

I began with a lament* and end with another ...

Your story is fully told,
Stay now the course you dearly hold,
Rejoicing in adventure's lofty embrace,
In ways daring, of hesitancy not a trace.

In overlapping cultures you saw light,
Reared in the bosom of one economy,
You eased into the other in splendid dichotomy,
Restless and intense, you now stand tall and bright.

The trodden path is not yours to redeem,
Create a thinking where thinking itself is supreme,
Facts live and die by the day,
Look for what is behind for that alone will stay.

Refine, enhance, innovate, as you must,
Redefine industry's role to keep your trust,
Spread your ware in and out of your land,
And boldly, by wit and acumen, stamp your brand.

But, above all, go beyond increment,
For that is your challenge, your unspoken pledge,
Dismantle an extant theory, not nibble at its edge,
Devise a new measure, a stunning new experiment.

"On the shoulders of giants" India did once soar,
Oh, what a lament, not a giant for four score years or more,
Why, why can't a giant be bred?
Or, has lofty ambition forever fled?

No, — in prose and in verse — I do say,
The gathering strength of the past will surely have its day,
When a future, dancing at the avant-garde of the present,
Will rise and bid adieu to the lingering lament?

*See page vi, a Babylonian lament

INDEX