SCIENCE AND TECHNOLOGY IN INDIA

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Edited by
B.R. NANDA

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B.R.N.

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INTRODUCTION

India has witnessed a phenomenal development of science and technology since the attainment of independence, but the record before 1947 was not entirely barren. Some of the greatest Indian scientists of this century—C.V. Raman, S.N. Bose, M.N. Saha, and Birbal Sahni—did their best work in the pre-independence era. In 1947, eight out of the nineteen universities in the country offered post-graduate courses in science, and there were thirty-eight engineering colleges with nearly three thousand students on their rolls. Outstanding research institutions, such as the Indian Institute of Science, Bangalore, the Tata Institute of Fundamental Research and the Indian Institute of Agricultural Research had already been established. The former had started a course in electrical engineering as early as 1915; two years later the Benares Hindu University had introduced a course in metallurgy. The Indian Research Foundation—the precursor of the Indian Medical Association—had been in existence since 1911, and the Indian Council of Mines at Dhanbad since 1926.

Considering the size of the country and the magnitude of the problems it faced, the scientific and technological infra-structure which India inherited from the British regime was, nevertheless, pitifully small. Of the potentialities of economic development through the application of science, there was very little awareness in the higher echelons of the Raj. The few research institutions which existed suffered from unimaginative bureaucratic parsimony and red-tape. As Dr. Ramalingaswami tells us, the Haffkine Institute started its career in Grant Medical College, Bombay in 1893 with "one clerk and three peons". Fifty years later, even an organization like the Indian Council of Agricultural Research lacked both the authority and the resources to make a tangible contribution to agricultural development. Whenever there was a clamour for economy in civil expenditure—such as during the economic depression (1929-32) and the second world war (1939-45)—research institutions were among the first victims of the axe wielded by the Finance Ministry. It was not merely that most British officials were deliberately unsympathetic to Indian progress; many of them had grown up at a time when in their own country the idea of large-scale state aid for scientific research had not won wide acceptance. To these officials, harassed by intractable administrative and political problems, science and technology must have seemed academic issues. That India should continue to produce raw materials and import manufactured goods must have seemed a natural part of the Imperial scheme of things. No wonder that in the decades preceding the second world war, agriculture stagnated, and industry made slow progress.

It was fortunate that the government of independent India was headed by a man, who considered science and technology as essential levers for lifting the country out of poverty and backwardness. Jawaharlal's interest in science had been stimulated in his childhood by his Irish-born tutor who rigged up a little laboratory in Anand Bhawan. Nehru studied botany, zoology and geology at Cambridge, but took to law and politics: he had thus little time to devote to science. Curiously, politics brought him back to science. As Nehru told an assembly of Indian scientists: "Politics led me to economics and this led me inevitably to science and scientific approach to all our problems and to life itself. It is science alone that would solve the problems of hunger and poverty." During the years 1939-41, as chairman of the National Planning Committee of the Indian National Congress, Nehru gained a deep insight into the basic problems of the Indian economy. "There are three fundamental requirements for India," he wrote in 1940, "and these are a heavy engineering and machine building industry, scientific research institutions and electric power. These must be the foundations of all planning."

Nehru had the prescience to realise thirty years ago that the day of the individual scientist working in isolation was passing, and that India could not do without an adequate infra-structure for science. Two able scientists, Homi Bhabha and S.S. Bhatnagar, who were also men of great energy, drive and organizing ability, helped Nehru in building this infra-structure. Bhatnagar planned a chain of national research laboratories and Bhabha laid the foundations of

India's nuclear research programme. Nehru indicated the new status of scientific research in India by agreeing to be the President of the Council of Scientific and Industrial Research, and by keeping the Department of Atomic Energy under the direct control of the Prime Minister. Several new research institutions—for example the Central Statistical Organization, the National Sample Survey, the Indian Standards Institution and the Indian Science Academy—owe their origins or development to the inspiration or support they received from Nehru. Long before he came into office, Indian scientists had seen in him an ally and a patron of science. He had been elected to preside over the Indian Science Congress session in 1942 but being in jail could not do so. As Prime Minister, he made it a point to be present at the annual meetings of the Indian Science Congress. Such gestures were not without their significance. As Nehru put it, "I have felt the need for encouraging the scientific work and research and I have concerned myself with important organizations; that does not mean that I know very much about science... but I felt and it was agreed that it would be helpful if I were sometimes to play the part of a showboy.....My interest largely consists in trying to make the Indian people and even the Government of India conscious of scientific work and the necessity for it." In 1958 Nehru piloted through the Parliament a "Science Policy Resolution," pledging the country to foster, promote and sustain cultivation of science and scientific research "by all appropriate means." This resolution was not merely a dramatic gesture, but an expression of Nehru's faith in science as an instrument for ushering India into the modern age. He saw research in science and technology not as an end in itself, but as an essential part of a socio-economic framework. He assigned to science a crucial role in planning, and went so far as to describe planning as "science in action." It was Nehru's government—as G.H. Keswani, says in the first article in this volume—which lifted Indian science from its small beginnings to a national effort.

Nehru's interest in science found one of its earliest expressions in atomic research. It is significant that, despite the distractions which the government of independent India had to face in the aftermath of the partition of the sub-continent, the Atomic Energy Commission was set up as early as August 1948. Nuclear power was then in the words of Homi Bhabha, "still in its infancy and its economics unknown; it needed the farseeing vision and imagination of a great man to embark an industrially backward country on a programme of atomic research development." To the success of this programme Bhabha's own contribution was tremendous. His personal access to the Prime Minister and his contacts with scientists in other countries were an asset to him, but he had also a genius for organization. He knew how to inspire those who worked with him in a spirit of cooperation and team-work. He took the precaution of maintaining a strong base in pure science in the new set-up. He established a nuclear fuel complex at Hyderabad and also made arrangements for electronic instrumentation. He set up a training school, which was useful not only for the instruction of the new entrants, but as a link between generations of scientists. The young scientists became, as Dr. Ramanna tells us in his survey of the development of nuclear energy in India, "question masters to their senior colleagues and therefore provided an intellectual background which is the only way an aging scientist can remain youthful in the field." When Bhabha became the Secretary of the newly created Department of Atomic Energy in 1958 he made it a condition that he would not be cut off from direct participation in scientific work. Indeed, the secretariat of the new department was shifted to Bombay, close to the scene of operations. Thanks to Nehru's unstinted support, Bhabha was assured of ample authority and resources for his projects. Bhabha was grateful for this support, but reckoned that the heavy investment which the nation was making in atomic research would be more than justified if cheap electric power could give a fillip to economic development. This was also the ambition of Jawaharlal Nehru, who always saw science and technology essentially as tools for human welfare.

Though the Indian Agricultural Research Institute and the Indian Council of Agricultural Research were venerable institutions, having been established in 1905 and 1929 respectively, agriculture and agricultural research—as Dr. B.P. Pal reminds us in his article on Indian agriculture—occupied a lowly status in that regime. The agricultural scientist commanded scant respect and ranked rather low in the official hierarchy. In the district the deputy director of agriculture was considered a subordinate official. In some provinces there was just one "agricultural demonstrator" for the whole district who could at a pinch be diverted to such routine chores, as the issue of kerosene rations.

Contrary to a widespread impression, Nehru did not ignore the agricultural sector. He gave a high priority to multipurpose hydro-electric and irrigation projects. True, he did not himself preside over the institutions connected with agricultural research, as he did over those of atomic and industrial research. Nevertheless, most of the programmes which culminated in, what has come to be known, as the "green revolution" were initiated when Nehru was in office. These programmes included the revitalisation of the Indian Council of Agricultural Research and the Indian Agricultural Research Institute, the formulation of the "All-India Coordinated Projects" and the emergence of the agricultural universities as centres of both teaching and extension work. Dr. Pal has narrated the "inside" story of the "green revolution," how with modern technology and international cooperation, Indian scientists succeeded in developing new strains of plants, and then through well-thought-out schemes of inter-disciplinary cooperation, high yields were ensured from the new strains. One of the most surprising and heartening aspects of the "green revolution" was the response from the farmers who were believed to be old-fashioned and conservative, but took up the new technology readily and used it with great enthusiasm and skill.

The "green revolution" was thus brought about not with a magic wand, but through hard and ceaseless toil by scientists in the laboratory followed by careful planning and field work. If the yields of crops other than wheat are to be raised significantly, similar ingenuity, perseverance and multi-disciplinary cooperation will be required in future years. The axiom "whosoever sits on his laurels, wears them in the wrong place," is one which those concerned with the future of our agriculture can forget only at their own peril.

Nehru realised the importance of extending facilities for studies in the sciences and technical training. Soon after assuming office, he appointed a Scientific Manpower Committe, and had the satisfaction of seeing five institutes of technology come up at Kharagpur, Bombay, Madras, Kanpur and Delhi, besides a number of regional engineering colleges. This enabled the country to build up a reservoir of highly qualified engineers. A parallel expansion took place in the training of technicians in polytechnics. A number of institutions for specialised training such as the National Institute of Foundry and Forge Technology, School of Planning and Architecture, the Institutes of Management and the All-India Institute of Medical Sciences were set up. Professor M.S. Thacker, who was himself associated with some of these developments in technical education, has given us a resume of them in his article on technical education.

A similar expansion took place in science education. The number of universities multiplied manifold and science graduates and post-graduates poured out of the portals of the universities in their thousands every year. Though excellent work was done in some universities—especially in the centres of advanced study in science such as those at Delhi, Calcutta, Chandigarh—few critical observers would differ with Professor Mahanty's melancholy conclusion in his paper on "Science in the Universities," that the quality of doctoral research "is alarmingly low." One of the reasons for this decline may have been owing to the creation of some of new universities as "political status symbols" of state-level politicians. There is, however, no doubt that there was also a brain-drain from the relatively less endowed and equipped universities to central research institutions, such as the Department of Atomic Energy, the Defence Science Wing and national research laboratories. In retrospect, it seems, that the scales were heavily weighted in favour of "Big Science" financed by the government. Only a clearer appreciation of the differing needs of research in pure and applied science could help to readjust the balance.

"The true scientist," Jawaharlal Nehru wrote in the *Unity of India* "is the sage unattached to life and fruits of action, ever seeking truth, wherever this quest might lead him to." This may sound a bit too idealistic, but it is noteworthy that Professor Sudarshan, while describing "the human condition that fosters and rejoices in the pursuit of science" lists vision, ability, integrity, energy, enthusiasm, flexibility, humanism, creativity and humility, among the qualities of a man of science. Pure basic research is an endless quest; to function effectively, the scientist needs an atmosphere conducive to intellectual freedom, self-criticism and uninhibited communication with fellow-scientists. Obviously, such an atmosphere can be produced more easily in an academic institution than in a centralised research body where the organization is necessarily hierarchical.

The problems of applied science—technology—have to be seen in a different context. The technologist uses already confirmed knowledge about the natural world for practical purposes. As Dr. Varadarajan explains in his article, "Science and Industry," industrial research is an economic activity although of a very special nature involving science as a major in-put, and demanding a wide range of skills from scientists, engineers, economists, financiers, production experts and marketing men. Applied science, like all economic activity, should be subject to cost-benefit analysis, and aim at the highest prossible return for a given investment of human and material resources. Dr. B.D. Nag Chaudhuri, in his article on "Science and Defence", points out how science can help to rationalize defence expenditure; within the same techno-economic constraints it may be possible to acquire greater military strength at the same cost. In other spheres of national planning too the same approach would yield optimum results. The choice of technology for development of mineral resources—of which V.S. Krishnaswamy gives a thoroughgoing survey in his paper—is especially subject to cost-benefit analysis. In his survey of bio-medical research, V.S. Ramalingaswami shows how the staunch pursuit of concrete objectives, especially in preventive and community medicine, may pay rich dividends. Our greatest resource, he says, "is human resource, the large number of men and women with manifest and potential talents." The central problem of "science management" is how to identify men and women of outstanding merit and to place them in an environment in which they can give their best.

The challenges facing us today call for a high degree of sophistication and sagacity in the application of science. The choice of technology is not so simple a matter as it may at first appear. Unfortunately, owing to the colonial interlude, India missed the industrial revolutions of the 18th and 19th centuries, and must now make up for lost time. However, as Dr. Jagjit Singh tells us, it is not easy "to leap-frog the technological gap unaided and alone." He draws a distinction between "low" and "high" technology, and reminds us that most of our research laboratories are equipped at present for "low technology" involving "small improvements in widely used products." High technology cannot be acquired quickly and must need be imported; even Lenin did not spurn the aid of American capitalists in building great hydro-electric dams in the Soviet Union. A developing country cannot, however, afford to fritter away its limited resources indiscriminately; the import of technology must be confined only to a few essential fields. The wholesale reproduction of western technology may be not only wasteful but harmful. Apart from the ecological hazard inherent in uncontrolled industrialization, there is the implicit assumption in western technology that the need for human labour should be reduced if not altogether eliminated. For India, with its vast reservoir of unemployed and under-employed millions, such an assumption is wholly irrelevant. Moreover, we cannot in the foreseeable future, accumulate enough capital to adopt capital-intensive technology on a large scale· It has been calculated that while in a labour-intensive industry it takes six months' salary to provide work for one man, in a capital-intensive industry the investment would be the equivalent of 350 months' salary. Clearly, economic growth wholly on the western model would be a snail-pace affair.

G.H. KESWANI

JAWAHARLAL NEHRU AND SCIENCE

Before Jawaharlal Nehru went to Harrow at the age of 16, he was educated privately at Allahabad. Sufficient record is not available to estimate the level of scholarship attained by Nehru before he left India, but a sketch can be thinly drawn. We know about the books he read. But more significantly for our present purpose, we know that his English tutor Brooks, an ardent theosophist appointed on the recommendation of Annie Besant, fitted a small laboratory in Nehru's house at Allahabad, for experiments in physics and chemistry. Nehru tells us in his autobiography that he spent long and interesting hours in these experiments. It seems, however, that he did not get sufficient instruction in mathematics. As is well known, mathematics has to be learnt when one is young: later it is difficult to grapple with it. The result was that at Cambridge, Nehru had to abandon physics midway, because he did not know enough mathematics. He said so candidly in his letters to his father.[1] Years later, when Jagjit Singh took his book, *Great Ideas in Mathematics*, to Nehru, he enquired whether that book for the popularization of mathematics contained any forbidding formulae. In the meantime, he chanced to see a Lebesgue integral on page 140 of the book. Nehru, whose sharp visual sense was matched by his humour, exclaimed: "It is enough of a scorpion to scare away the most stout-hearted non-mathematical layman." Still Nehru admired mathematics. He had the basic ingredient of this discipline—that is, logic—very much in his thought and methods. The only scholar at Trinity whom he mentioned admiringly in a letter to his father, was C.G. Darwin, a grandson of the famous Darwin, saying almost enviously, "most people think he will be a Sr. W. (Senior Wrangler)."[2]

[1]S. Gopal (ed.), *Selected Works of Jawaharlal Nehru* (Delhi, 1972), Vol. I, p. 61.

[2]*Ibid.*, p. 52.

Although, Jawaharlal did some elementary algebra, geometry and mechanics, as additional subjects at Harrow, he had only two years at this school, during which he could not have gone much beyond where Brooks had left him.

At Harrow, Jawaharlal's housemaster summed up his performance as "very creditable stand"[3] and he was specially praised for some papers in history in which he was later to take so much interest and even greater part. At Trinity College, he ultimately took the Natural Science Tripos in geology, chemistry and botany, in second class with honours, somewhat to the disappointment of his father, who confidently expected him to get a first. In fact Motilal had hoped earlier that his son would be a Senior Wrangler.[4] In his own words, Jawaharlal completed his academic career at the Inner Temple, before he was called to the bar, "with neither glory nor ignominy." He toyed with the idea of another degree at Oxford or a course at the London School of Economics, but ultimately decided to return home in 1912.

We may ask a somewhat fanciful question. If Jawaharlal had continued with his career in science, it is probable that he would have become a notable experimental scientist.[5] Indeed, he was an experimentalist. To experiment is to plan and take a course of purposive action, while keeping an open mind as to the results. Nehru's political philosophy could best be described by one word "experimental" as we shall further argue in the sequel.

II

The ethos of science is governed by a spirit of free-ranging inquiry which in turn is begotten by curiosity. Asked about his special talents, Einstein remarked: "I have no special gift—I am only passionately curious";[6] and Jawaharlal was always stirred by curiosity. He was with his father in Germany to see Count Zeppelin's dirigible airship in 1909.[7] He was one of the first Indians to fly in 1912. He admired the pioneer aviators of America and Europe. As Prime Minister, he went to the Delhi airport personally to receive Yuri

[3]Emil Lengyel, *Jawaharlal Nehru: The Brahaman from Kashmir* (New York, 1968), p. 38.

[4]V.N. Chhibber, *Jawaharlal Nehru: A Man of Letters* (Delhi, 1970), p. 11.

[5]G.H. Keswani, "Nehru and Science in India", *The Illustrated Weekly of India*, January 24, 1965.

[6]Banesh Hoffman, *Albert Einstein* (New York, 1972), p. 7.

[7]Walter Crocker, *Nehru: A Contemporary's Estimate* (London, 1966), p. 138.

Gagarin, the first earth cosmonaut in space. He liked big machines and fast travel. Krishna, his sister, relates an episode showing how keen his curiosity was.[8] In 1948, when he was the Prime Minister of India, someone gave him an electric razor. He was so fascinated by it that at a dinner party in his house, he sent for the razor and demonstrated it to his guests by shaving himself at the table. Nehru was then fifty-nine years old. Nehru preserved this child-like innocence and curiosity almost till the end. I suggest these are the qualities characteristic of a scientist (even if he does not practise science), and of an experimentalist.

Talking of young Nehru's innocence, one might recount his attitude towards matters of sex, marriage and personal looks. A recent writer on Nehru tells us that while in England as a student he was untouched by the temptations of youth.[9] Doubtless he had sophisticated conversations on morality, referring casually to Havelock Ellis, but essentially he remained untouched, if not quite an ascetic, during this period.[10] His letters of that period, written to his father, abundantly show this. There does not seem to be any guile in these letters.

When he was in his twenty-first year, Jawaharlal wrote to his father: "Joys of matrimony appear to me wholly imaginary, and do not at all appeal to me."[11] And he wrote to this effect more than once. During those seven years in England, he played tennis, swam, rode horses, visited Europe a number of times, worked moderately for his academic career, and kept in touch with political developments in India, but did nothing intensely. It was as if young Nehru was seeing things from a distance.

Handsome Jawaharlal started losing hair at the age of twenty-two but he reported their gradual disappearance to his father with complete equanimity, setting aside with scientific reasoning the applications of lotions and "what-have-you", suggested by his loving father.[12]

He reflected later that he was essentially an abnormal person with a sense of mystery and unplumbed depths, which he could not himself fathom. Those who have gone through this process of fathoming

[8]Krishna Hutheesing, *We Nehrus* (Bombay, 1967), p. 58.
[9]Emil Lengyel, *op. cit.*, p. 44.
[10]M. Chalapathi Rau, *Jawaharlal Nehru* (Delhi, 1973), p. 8.
[11]*Selected Works of Jawaharlal Nehru, op. cit.*, Vol. I, p. 68.
[12]*Ibid.*, p. 92.

and self-probing, would know that while it reveals, it creates even deeper mysteries. Yet the process is not without its reward of detachment and peace. Nehru seems to have won many of these rewards from nature and bathed blissfully in a sea of detachment.[13] There is no doubt that from the beginning, a kind of universal spirit moved him. *Sarvatmabhava* was his nature and presiding mood. Scientific inquiry too is moved by this spirit, this *bhava*, because science is universal and common to all creeds and countries. It prevails equally on the earth, the solar system and the yonder astronomical universe.

Why did Nehru then work the wobbling wheel of politics? He himself once quoted George III of England: "Politics is a trade for a rascal, not a gentleman."[14] However there is no doubt that he himself made the choice of a political career owing to the enormous opportunities for service it offered, far exceeding those open to a doctor, an engineer or a scientist.

Nehru does not seem to have got much out of Brooks in Allahabad, Edgar Stogdon, his tutor at Harrow, the dons of Trinity College and the legal wizards at the Inner Temple. Like Einstein, Nehru was his own tutor. As is well known, Einstein was a "drop-out" in school and had failed in the entrance examination to the Swiss Federal Polytechnic School; he found the usual systems of education stifling.[15]

Nehru seems to have taught himself and introspected deeply, mostly during the many years in jail. During these years he read widely, wrote down important passages and commentaries, and disciplined and sharpened his intellect. He upbraided himself in his diaries if he had lazed on any day in the jail. When outside, he had hardly any time to study. Since the lists of all books which he received in prison are available, we have almost a complete record of what he read in jail. Also Nehru mentioned most of the books he read, in his jail diaries, often giving the date of completion of the book. His well-known works like the *Glimpses of World History*, his *Autobiography*, and *The Discovery of India*, were beneficial outfall from these various unjust imprisonments. As to science, it is known that he read James Jeans, Eddington, Einstein, Russell and Pavlov. These were not dilettante readings. His grasp of fundamental ideas seems to have been rather secure. Crocker has recorded an episode to bear this out. He took an eminent biologist, a Nobel Laureate,

[13]Jawaharlal Nehru, *The Discovery of India* (Calcutta, 1946), p. 47.

[14]*Selected Works of Jawaharlal Nehru* (Delhi, 1972), Vol. III, p. 390.

[15]Jeremy Bernstein, *Einstein* (London, 1973), p. 26.

to Nehru, then Prime Minister. The biologist made a careless statement about some work. "Nehru pounced upon it, politely, and demolished it."[16] But, of course, history was his *metier*.

His jail-notes of 1922 are entitled, "Notes and Quotations, Volume I, Indian History and Miscellaneous,"[17] and these studies continued, more or less until he became the Prime Minister of India.

III

I do not know who first used the phrase, "scientific temper," in the emphatic manner in which Nehru did. But I learnt it from Nehru's writings and speeches. Even his early works pulsate with the spirit of science—that intellectual adventure informed by a critical method, the goal of which is knowledge, *which is the truth.* This truth of science, as distinct from the truth of ethics, for example, is *not* immutable. It is subject to revision and renewal. It is in the nature of science to be falsifiable. This doctrine would not have been accepted by many scientists in the last century to whom science was immutable and abiding truth. The present generation, mainly under the influence of Karl Popper, regards falsifiability of science as the central pillar of the methods of science. The important thing about science is that only disproof is conclusive: proofs are tenable only tentatively. The greatest of theories in science can be toppled by just one unfavourable but indisputable test. Science must, therefore, continuously experiment to support, extend and refine its structure if experiment or observation shows it to be wrong, it has to be ever ready to change to accommodate itself to the new evidence. It is remarkable that Nehru should have formed these views and he expressed them with great lucidity and emphasis.[18] "And so truth has ever to be sought and renewed, so that as understood by man, it might keep in line with the growth of his thought....This is the scientific approach, the adventurous and yet critical temper of science, the search for truth and new knowledge, refusal to accept anything without a test."

This continuing characteristic of science, its programme of transformation and change, is its main charm, because, in the words of the mystic English poet, William Blake: "Eternity is in love with the

[16]Walter Crocker, *op. cit.*, p. 137.

[17]*Selected Works of Jawaharlal Nehru* (Delhi, 1972), Vol. I, p. 309, pp. 299-306; also, see Vol. IV, (Delhi, 1973) pp. 319-88.

[18]John Gunther, *Procession* (London, 1965), pp. 189-92.

productions of time." It is this "endlessness" of science, to borrow a word from James Joyce, its continuous creative faculty, almost equalling God's, which is the inspiration and thrill of science.

Science, yes, but science is not enough. It is necessary but not sufficient. Those who practise and direct it, have to be quickened to seek legitimate goals of science. The important point that Nehru made was that, although these goals lie outside of science proper, they are reachable through the scientific method, a theme dear to Russell also. Here Nehru must be quoted at length:

> Though I have long been a slave driven in the chariot of Indian politics...my mind has often wandered to the days when as a student I haunted the laboratories of that home of science, Cambridge....In later years, through devious processes, I arrived again at science, when I realised that science was of the very texture of life....Politics led me to economics, and this led me inevitably to science and the scientific approach to all our problems and to life itself. It is science alone that could solve these problems of hunger and poverty.[19]

There is no doubt that the future will see more and more applications of science and the scientific method to all human problems, particularly economical and social problems, into which science has just begun to enter. If you look at many modern works of economics, you would find that they are science. Some indeed, like Samuelson's are almost pure science. The idea that science is the Prometheus of humanity, recurs in Nehru's thought. Addressing the Ceylon Association for the Advancement of Science, in Colombo, some months before his death, Nehru asserted: "I do believe quite stoutly that the whole method of science, the approach of science is essential for the survival of humanity."[20] That day is to come when in the words of the poet, Shelley, whom Nehru read in prison,

> All things are void of terror: man has lost
> His desolating privilege; and stands
> An equal among equals: happiness
> And science dawn though late upon the earth.

Nehru maintained that even religion has to be transformed by

[19]Jawaharlal Nehru, *The Unity of India* (London, 1941), p. 176.

[20]Jawaharlal Nehru, *Science in the Development of a Nation* (Colombo, 1962) p. 16. An address to the Ceylon Association for the Advancement of Science, October 15, 1962.

science. The minimum requirement is that religion must conform to science. As he put it, "*Dharma* is good so long as it does not get into conflict with the rational or scientific attitude." Indeed, his preference seems to have gone even further. He desired direct application of the scientific method to the religious experience itself. There are good reasons, therefore, for his high opinion of Buddhism which he regarded as a scientific religion.[21] He averred that Buddha's method was one of psychological analysis and that Buddha had insight in the latest methods of science.[22] He paid a high and patriotic tribute to Buddha in these words, "And the nation and the race which can produce such a magnificent type must have deep reserves of wisdom and inner strength." He was not the only person of sensitive judgement to do so. Arnold Toynbee echoed this in his contribution to a Nehru memorial volume. Toynbee regards Buddhism as the first movement in history, to think and feel in terms of the human race as a whole.[23] I should not let go this opportunity to reproduce what is perhaps the highest homage to Buddha, paid by the poet, Rilke :

Buddha in der Glorie
Doch in dir ist schon begonnen
was die sonnen übersteht.[24]

Since the sun will burn for more than five billion years, and the age of the universe according to reliable cosmologists is only somewhat longer, we are assured by Rilke that Buddha is immortal, for all practical purposes, I like to think that Nehru, and Gandhi even more, carried their fire from the same source as Buddha.

IV

It can scarcely be denied that the state of science in India even before 1947 was quite robust. Bose, Raman, Krishnan, Saha, Mahalanobis, Kothari, Birbal Sahni, Chandrasekhar and even Bhabha were the products of the pre-independence generation. Scientific research then was the effort of a few inspired individuals. For experimental work expensive equipment was not required and the

[21]Jawaharlal Nehru, *The Discovery of India*, p. 15.
[22]*Ibid*, pp. 486-88.
[23]*The Emerging World* (Bombay, 1964), p. 238.
[24]Rainer Rilke, *Selected Poems*, with English translation (California, 1962).

contemplative Indian genius was bound to strike out, here and there, in new directions, no matter how little the government patronage might be. This was not an exclusive Brahmanical talent. It was Nehru's government which lifted Indian science from its small beginnings to a national effort. The Indian government spent Rs. 550 million on research in 1964, the year of Nehru's death. In 1947, it was merely Rs. 24 million.

It is not so well known that even before 1947, Nehru was very dear to the Indian scientists. Indeed, he was the president—elect for the session of the Indian Science Congress which was to be held early in 1943. Unfortunately, he could not preside over it, since he was in jail for his part in the Quit India movement. Wadia, the outgoing president, feelingly referred to Nehru's leavening effect on the organization and working of the National Planning Committee, which from 1938 onwards had examined the problems of application of science to industry. At the Indian Science Congress session in 1944, the president, S.N. Bose, again poignantly referred to the absence of Jawaharlal Nehru. It is remarkable that Nehru, a "non-practising scientist" should have been elected as the president, not once, but once more in 1946, for the session held in January 1947. From then onwards, Nehru was a part of the Indian Science Congress, and never missed any of its yearly sessions upto his death in 1964.

Why did Nehru as Prime Minister, unfailingly go to each science congress? It appears to me that there were two reasons. The first, a psychological one, was that he felt exhilarated in the company of scientists and recovered some of the glory he had himself aspired to but had not attained in the academic field. The other and, I should say in fairness to Nehru, the more important reason was that he wanted to raise the prestige of the science congress itself, and thus subtly carry the message of science to everyone who read the daily newspapers. He said so himself at the 1958 Congress: "Now I come here because honestly I feel that by my coming I may not perhaps do much good to you. But I think I can do good to others, that is to say, to make many people of India, who may not be interested in science, think of it, and that is, I think, a worthwhile task." It appears that he never prepared his speeches for the science congresses. These speeches rolled on naturally and revealed the many-coloured patterns of the kaleidoscope that was Nehru. Generally there was no stock-taking of the past or a comment on what he had said earlier. These speeches were more or less philosophical soliloquies, about what the scientist should do or be, but not so much, about what was to be achieved. They invariably hit the truth but then the hammer rested.

In 1949 he said that scientists must develop organic knowledge of human history and human advance, but those in charge of science teaching learnt nothing from it. In the following year, he asserted that the present problems of India required, not classical philosophers or the approach of a lawyer, but a partly scientific and a partly engineering approach. The western societies, as Betrand de Jouvenal remarks, "were first ruled by clerics, then by jurists; now the scientists were replacing the jurists." However, in India, the jurists still ruled supreme. It was an ideal state for the administrator, the policeman and the judge, because law and order was still considered the most important activity of the government. Science and technology required highly ordered societies for fruition. Nehru returned to the cognate theme of the role of young talent in science and government many times. At the Science Congress addressed by him in 1963, he said: "The best scientific work is done by a person in his twenties and thirties, and I feel that, perhaps it is somewhat better to give opportunites of leadership to younger people than to follow the Government's example of giving too much credit to age and seniority." Nehru's advice does not seem to have been followed. In 1963, Kurt Mendelssohn from England visited India and China to assess the development of science in the two countries. Nehru was anxious to learn from him what he thought about India's progress in science and technology. I do not know what Mendelssohn told him but among other things, Mendelssohn wrote in the *Listener* that it was not the know-how of science that the Indians needed so much as the know-how of talking to their government.[25]

It is as easy as it is unjust, to say that Nehru should have implemented all his ideas about the management of science and government. The truth, to which we shall return with remorse at the end of this essay, is that we expected Nehru to do almost everything *himself*. After all, he carried a burden, heavier than that of any other Prime Minister, the indefatigable Churchill not excepted.

[25]Kurt Mendelssohn, "Science in India," *The Listener* (London), September 24, 1964.

V

While Britain ruled India and jailed Indian nationalists, there were Englishmen who remained remarkably free from rancour. This was the more true of British scientists. They proposed and elected a number of Indians as prestigious Fellows of the Royal Society of London. By far the most sympathetic and appreciative among the British scientists were Lord Rutherford, Sir James Jeans and Sir Arthur Eddington. Rutherford accepted the presidentship of the annual session of the Indian Science Congress in 1937, but he died before the session was held, and Sir James Jeans presided in his place. Nehru was also invited and spoke at this session.[26] The British Government in India, however, showed no great interest in the promotion of science, research and technology in the country. Indigenous development was encouraged only to the extent it was necessary, but could not be provided by Britain. The number of engineering colleges, for example, was only eight, and they were designed merely to provide supporting cadres for the British engineers whose main objective was the maintenance of an efficient mechanism for governance, rather than extensive public welfare. Even the many irrigation schemes which were executed were primarily measures for maintaining food supply at a level necessary to ensure subsistence and law and order. Thus India lost valuable time in the race for industrialization. As Nehru put it, India had to jump over these lost centuries. That in essence was the problem at the time of independence. A small beginning was no doubt made by the British in 1942, when the Council of Scientific and Industrial Research (CSIR) was established. But the purpose again was to bolster the war effort.

The Indian Agricultural Research Institute and other similar institutions established earlier hardly scratched the surface in a vast country. However, when Nehru joined the Interim Government in 1946, S.S. Bhatnagar was already in charge of CSIR. It was a case of a good horse waiting for a good spur. Bhatnagar with Nehru's encouragement and support projected a chain of national laboratories. On January 4, 1947, Nehru laid the foundation stone of the National Physical Laboratory. His theme at the ceremony was the importance of starting atomic research in the country. And God sped the plough.

As we enter the National Physical Laboratory at Delhi, we see an inscription from Louis Pasteur: "Take interest, I implore

[26]Jawaharlal Nehru, *The Unity of India*, p. 175.

you in the sacred dwellings which one designates by the expressive term, laboratories. Demand that they be multiplied and advanced. These are the temples of the future—temples of well-being and happiness. There it is that humanity grows greater, stronger, better." Nehru set out to build as many of these temples as were required for the worship of science. He himself remained the president of the CSIR until his death in 1964. By then thirty national laboratories or kindred institutions had come into existence. The CSIR spent Rs. 82 million in the year 1963-4, the financial year, preceding Nehru's death. Research in fuel, food, physics, electronics, aeronautics, cosmic rays, chemistry and many other branches of science could now be carried out in India.

The temples were ready but where were the worshippers? I shall return to this question later.

Planning has been regarded by some as a magnificent obsession of Nehru. This is true and this is as it should have been. To see the force of a proposition, it is usually useful to examine its opposite. The alternative to planning was *laissez-faire*, almost a refusal by the government to participate in the building up of a new India. It is doubtful if any other person in India had Nehru's experience in planning. In 1938 Subhas Bose, who was then Congress President, constituted the National Planning Committee with Nehru as its Chairman. As was his wont, Nehru took this job extremely seriously. In the twenty-one months, before he was sent to jail in September 1940, he presided over seventy-one formal meetings of the committee. He resumed his work in 1945 after he was released from jail and no sooner had the Interim Government been formed in 1946, than Nehru set up a Planning Advisory Board (and also the Scientific Manpower Committee). This became the Planning Commission in 1950. The five year plans commenced on April 1, 1951 and Nehru, as Prime Minister, became the Chairman of the Commission. Throughout his chairmanship he visited the offices of the Planning Commission about twenty times a year on the average. He presided over the last meeting of the Planning Commission, a fortnight before his death. At this meeting he said he would be glad to give as much time as was equal to the Planning Commission since he was deeply interested in planning.[27]

[27]Tarlok Singh, "Jawaharlal Nehru and the Five Year Plans" in B. K. Ahluwalia (ed.), *Facets of Nehru* (Delhi, 1967), p. 51.

Nehru had been steeped in the problems of planning even earlier. In England he was some kind of a Fabian. He thoughtfully read the Webbs in jail during one of his early "trips", as he called them. In February 1927, he attended the Congress of Oppressed Nationalities at Brussels, as well as the League Against Imperialism, the executive committee of which included Nehru, Einstein and Madam Sun Yat-sen. From there he went to Moscow in November 1927 as an invitee of the "Society for Cultural Relations with Foreign Countries" to see the tenth anniversary celebrations of the Russian Revolution. It was there that he saw what he described later as "the mightiest experiment in history." On return to India he wrote a series of articles in *The Hindu* and *Young India*. These articles were largely descriptive. They had little of radical jargon.[28] Nehru was interested in the results of the experiment, not in the abracadabra of its philosophy. The results were very impressive and continued to be more and more so. Nehru, the Prime Minister, looked for the techniques. Soviet Russia had commenced its five year plans (*Piatiletk*) in 1927. These were the prototypes for husbanding the resources of a free country and for building it. With his background of science, he had rightly concluded: "Planning is science in action."[29] We see the unmistakable experimentalist peering out.

All this is right and amiably in place. Planning is necessary and almost a "mathematical formula", as Nehru maintained in an interview.[30] The question is: which formula? Now, the All-India Congress Committee had set the political goal of planning for the national government immediately after independence. It said unmistakably that the formula was to find "an alternative to the acquisitive economy of private capitalism and the regimentation of a totalitarian state." Mahalanobis called it the principle of the middle-way.[31] But this was not precise enough. There can obviously be many middle ways. More than this, there was the question of participation of the people in the execution of the plans. Philosophically the question crystallizes into the simple words: "Can you create prosperity without

[28]See *Selected Works of Jawaharlal Nehru*, Vol. II, pp. 379-451.

[29]Presidential Address at the Institute of Public Administration, New Delhi, April 6, 1957.

[30]R.K. Karanjia, *The Mind of Mr. Nehru* (London, 1960), p. 49.

[31]P.C. Mahalanobis in R. Zakaria, (ed.) *A Study of Nehru*, (Bombay, 1959), p. 314.

capitalism or totalitarianism? This question gets roughly translated into: Can you create wealth without incentive or by compulsion to work? The answer *can* be yes, but only in a society where men are actuated by a deep and voluntary discipline. Unfortunately, we do not seem to have attained such a discipline. The stark and unmitigated fact about our people is that industrial and urban populations do not work hard enough. Nehru thought climate had something to do with capacity for hardwork,[32] but the fact is that up to the fifteenth century, the East (Eastern countries such as China and India) was ahead of the West, in spite of the differences in climate.

In my opinion the first three five year plans were as good as they could have been. A lot can of course be seen with an economist's sharp hindsight, but it is important to remember that these plans were generally accepted by some of the most eminent economists of the time. The third plan, which was to cover the period till March 31, 1966, epitomized the results of the Nehru period in planning.

The following figures should give an overall view of planning during these years:[33]

Year	*Expenditure of Union & States (Rs. Billion)*	*Index of wholesale prices*	*GNP (Rs. Billion)*	*GNP at 1961-62 prices (Rs. Billion)*	*Population (Billion)*	*Per Capita income at constant prices*
1961-62	20.5	100	149(100)	149(100)	4.39(100)	340
1962-63	26.1	102	158	155		
1963-64	31.1	108	181	167		
1964-65	35.4	122	212	174		
1965-66	40.6	132	218(146%)	165(111%)	4.90(112%)	340
					(interpolated 5.5 in 1971)	

These figures tell a tragic sisyphean tale. The governmental expenditure doubled but GNP (at constant price) increased by 11 per cent only, while the population also increased by about 11 per cent. The

[32]Karanjia, *op. cit.*, p. 50.
[33]*Statistical Outline of India*, Tata Services Ltd. (Bombay, 1961-66).

government doubled its expenditure, but produced enough only to compensate for the increase in prices and population.

In the year 1928, Nehru wrote a pamphlet in Hindi entitled: *The Poverty of India and its Cure*. He quoted in it the figures of per capita income in India.[34] Dadabhai Naoroji who worked it out first, put it at Rs. 20 per year.[35] Lord Curzon got a figure of Rs. 30 per year. These amounts at the then prevailing prices had probably the same purchasing power as the current figures.

Gunnar Myrdal has blamed the poverty of Asia on "softness", a lack of will to do what even the Asians themselves believe is necessary. According to him an aspect of this "softness" is corruption.[36] I believe that during the period in question the government was as clean as any other democratic government, but there is no doubt that there was managerial incompetence as well as indiscipline among workers. It was a lack of synergy, to use a fashionable word: there was no union between the goals of the individual and the community. The people were called upon to work and lift themselves to the promised rewards of the plans, but by and large, they failed to respond adequately. To what extent the leaders themselves can be blamed for not having aroused the people to discipline and work, is difficult to assess. There is no doubt, however, that Nehru spent himself extravagantly in the service of the country. Most of our achievements in the field of industry and I should say, even of agriculture, we owe to him. Even the seeds of the "green revolution" were sown by him, what with the irrigation schemes, fertilizer plants and new varieties of seeds. A more fine-grained analysis of the plans may have to go into such issues as the optimum degree of governmental expenditure, the magnitude of deficit financing and the correct mix of public and private expenditure, but I do not think a clear-cut resolution of these issues is possible.

The basic problem of the world is that the white races command 80 per cent of the resources of the world although they constitute only 25 per cent of the world's population. Moreover, the fact is that they have multiplied much faster than the rest of the world in the last five centuries.

[34] *Selected Works of Jawaharlal Nehru*, Vol. III, p. 363.

[35] *Ibid.*, see Dadabhai Naoroji, *Poverty and Un-British Rule in India*, (London, 1901).

[36] Gunnar Myrdal, *The Challenge of Poverty* (London, 1970), p. 208.

As Nehru astutely observed in 1928, the population of India increased in the preceding 50 years by 19 per cent only, but in England it did by 58 per cent. Similar relativity exists for the preceding 500 years. We are now being "taught" birth cntrol. Incidentally, Bertrand Russell congratulated Nehru in 1959 for his enlightened policies in the matter of population control, adding that too many western countries had policies governed by superstitious dogmas.[37] The white man has extended his *lebensraum* to half of the world. Meadows, *et al.*, of the Club of Rome in their book, *The Limits of Growth*, prophesy doom in a century, owing to population growth, resources consumption and environmental pollution. The predictions of the MIT group are even more gloomy. But the game, in which the "developed" countries purchase raw materials for a song, put a fat premium for their know-how, sell the product at *their* price to the "developing" countries and enjoy the bulk of the resources of the world, continues unabated.

VI

Plato, quoting Protagoras, said that man is the measure of all things. One may ask: What is the measure of man? May I propose that one measure may be the capacity to see into the future? This is the Pisgah, all prophets of science endeavour to reach. As a seer, Nehru like Russell was capital. In the welter of events, he could spot and separate the significant from the ephemeral. He lost no time in recognizing the importance of nuclear science. As we mentioned earlier, even before independence, when Nehru was in the Interim Government, his main theme while laying the foundation stone of the National Physical Laboratory, was the importance of starting atomic research. Another Indian, as early as March 12, 1944, much before the first bomb was dropped on Hiroshima on August 6, 1945, and on Nagasaki three days later, wrote that when nuclear energy was successfully used for power generation, say, within a couple of decades, India would not have to look abroad for experts. He was Homi Bhabha, then pleading for the programme, of the Tata Institute of Fundamental Research.

It was the tryst between these two men, Nehru and Bhabha, that was the most glorious chapter of Indian science after independence. Nehru gave liberally of his trust and time; Bhabha reciprocated with high talent and practical achievement. Events followed each other

[37] *A Study of Nehru: In Search of Peace* (Bombay, 1959) p. 241.

rapidly. The Board of Research in Atomic Energy, with Bhabha as its Chairman, met eleven days after India attained independence. The Atomic Energy Commission was set up in April 1948 and a full-fledged Department of Atomic Energy, with Bhabha as its Secretary, in August 1954. The measure of its signficance was that Nehru himself was the minister-in-charge of the department all along. The first atomic reactor in Asia became "critical" in August 1956, at Trombay, and Nehru formally opened the reactor and gave it the feminine name Apsara—a dancing beauty from the heavens—in January 1957. It was the dance of the neutrons, probably, that Nehru and Bhabha had in their minds. Whether neutrons belong to hell or heaven is, however, not certain.

In the meantime, USSR exploded an atom bomb in September 1949, followed by an explosion of the dreadful hydrogen bomb by USA in November 1952. The former, not to be left behind in this race, detonated a hydrogen bomb of its own in August 1953, and soon developed monstrous bombs, each with a devastating power of the order of 50 million tonnes of TNT (dynamite). England, Canada and France followed. The world lived under the spectre of a nuclear war. Russell drew up a manifesto in 1955, which, among others, was signed by Einstein, a few days before his death, asking mankind bluntly, "Shall we put an end to the human race: or shall mankind renounce war?" Another one from Asia, Nehru, now speaking full-throated the language of Gandhi, echoed back the question. It reverberated round the world. The United Nations chose an Indian (Bhabha) to be the president of the first Conference on the Peaceful Uses of Atomic Energy held in Geneva in 1955. Bertrand Russell arranged a conference of the scientists of many nations including USA and USSR in 1957 in the small Canadian town, Pugwash, to urge their governments to acknowledge that their purposes cannot be furthered by a world war. Incidentally, Nehru proposed to Professor C.F. Powell that the first conference might be held in India,[38] but it could not be held in this country owing to the intervention of the Suez crisis. However, the 13th Pugwash Conference was held in Udaipur in January 1964 but Nehru could not attend it on account of his failing health. I believe that, for the first time in history, the voice of humanity was united (only China was silent) and although no ballot was taken, the answer to the above question was unmistakable:

[38]*Science Reporter, Nehru Commemoration Number*, Council of Scientific and Industrial Research (New Delhi, 1964), p. 13.

"Mankind must renounce war." The test-ban treaty, and subsequent agreements came slowly, but they were certainly the result of universal strivings for peace.

India's nuclear capabilities were growing and shaping well. So Nehru had to make our position clear. While inaugurating the reactor, Apsara, Nehru stated the position of the Government of India unequivocally, committing also the future governments. "But we should like to say on behalf of our Government—and we think we can say with some assurance on behalf of any future Government of India—that whatever might happen, whatever the circumstances, we shall never use this atomic energy for evil purposes. There is no condition attached to this assurance, because once a condition is attached such an assurance does not go very far."

Soon after, in 1962, China delivered a swift and heavy military blow on India's north-east frontier. Still, there was no visible change in India's nuclear policy. However, in 1964, soon after Nehru's death, China itself exploded an atom bomb.

The statements of the Indian leaders, even of Prime Minister Lal Bahadur Shastri, in regard to the development of the bomb in India were somewhat vague, to the effect saying that India could but would not manufacture atomic weapons, although Shastri saw no objection to nuclear explosions being used for blasting. Now, if dynamite can be used for blasting as well as for war, so can nuclear explosives be. The western countries ultimately recognize only two things: power and efficiency. What we are trying to do in the present case is to follow some kind of a middle way which does not appeal to them. But let me not digress. What I wanted to say in brief was that the nuclear advance of the country has been owing wholly to the inspiration and far-sightedness of Nehru. There was hardly any one else in the government who had any clear idea about what the whole thing was.

VII

Nehru wanted the existing and the future governments of India to be committed to a policy of promotion of science. So, in the year 1958, Parliament passed the "Science Policy Resolution" drafted by Nehru. It proclaimed that the country's policy would be to foster, promote and sustain the cultivation of science and scientific research by all appropriate means. This was an unusual thing to do. Parliaments hardly ever pass such resolutions. But in a country which had been slumbering for a thousand years, a clarion had to be sounded again and again. In 1962, Nehru constituted the Indian Parliamentary and Scientific Committee to involve the Parliament in science. Lal Bahadur Shastri was its first chairman. As Professor M.M. Newitt remarked in the Nehru commemoration number of the *Science Reporter* of the CSIR: "Jawaharlal Nehru had the distinction of being almost the only Prime Minister of his day with any real comprehension of the fundamental importance of science and technology in the modern state; and his interest in this field was dictated not by political expediency but by a deep-rooted conviction that it afforded the only ready and practicable means of establishing a stable economy and raising the standard of living of the great masses of the Indian people."[39]

There are many branches of the tree of science and Nehru was anxious that as many of these blossomed as was humanly possible during his life. It was with his support that C.D. Deshmukh was able to set up the Central Statistical Organization and the National Sample Survey. Without these tools for the assessment of the plans, much of the planning would have had to be based on guess—work. But for Nehru, the great work of the Indian Standards Institution, under the directorship of Lal C. Varman, to introduce the metric system, would have been impossible. Perhaps, India was the first country, originally on the foot-pound system, to change over to the metric system during the present century. In 1948, he directed the CSIR to prepare a National Register of Scientific and Technical Personnel. The Defence Science Organization was set up in 1948, with the advice of Professor P.M.S. Blackett, for the scientific evaluation of weapons and equipment, operational research and special studies using scientific techniques. Much good work has been done by this organization under the leadership of Kothari and Bhagvantam. Nehru recognized independent scientific bodies, like the Indian Statistical Institute, as institutions of national importance, and established national professorships for eminent scientists. He took keen interest in the National Institute of Science of India (now called Indian National Science Academy), Indian Association for the Cultivation of Science and the Association of Scientific Workers of India. Many scientific institutions, old and new, owe their existence or progress to Nehru. I like to take as an example, the Institute of Mathematical Sciences, Madras. Its director, Alladi Ramakrishnan, has feelingly described

[39]*Science Reporter*, *op. cit.*, p. 19.

the meeting with Nehru at which he agreed to the creation of this institute. Research institutes of this kind suit a poor country like India.[40] All that one requires to run them are pen, paper, chalk-sticks, board and an active mind.

Finally, a few words about the social position of the scientist in Nehru's India. Nehru said: "The administrator has, no doubt, his place, but that is secondary to that of the scientist and engineer." He held scientists and engineers in great esteem; but there has been no widespread appreciation of the fact that the scientist must have greater scope for initiative and control of policies, if he is to be effective and if promising talent is to be attracted towards scientific work.

We may here recall the remark of Sir Edward Mellanby, who was the first director of the Central Drug Research Institute, Lucknow, after he retired as the Secretary of the Medical Research Council of UK. He said: "Recruitment of first class administrators was an easy matter compared with securing men of the best type of research.... Such men are limited in number and cannot be appreciably increased by any known method." This limited number of men must, therefore, be sought and given an honoured place in society if they are not to be lured away to pursuits of lesser consequence to the well-being of the people.

I have been concerned here with contributions of Nehru to the development of science, and the scientific culture. All these combine into a mighty significance. I have left out of account education in science, medicine and technology. Developments in these fields followed rapidly on parallel lines. Indeed, till recently, India seemed to have more engineers than it could use.

VIII

What was the total effect of the contribution of Nehru to the development of science and the scientific temper in India? During the first ten years of his prime-ministership he had a kind of Midas touch. Everything he touched glittered and glowed. In the last few years of his life, what remained was the charm of a noble serenity which accompanies a dedicated life. He was a shrewd and instant assessor of character and event. But he was a man of extreme compassion who would not force his will upon others. He worked by offering a gentle precept, and personal example of logic, insight and hardwork.

[40] *Ibid.*, p. 83.

To appreciate fully his contribution to the awakening of India, one must see the material he had to work on. An ancient people had been weakened by centuries of foreign rule. A nation fettered by centuries of servility and deadening tradition had to be aroused, stirred and made self-reliant. Nehru launched his assault upon the inertia of ages. A whole continent had to be moved up and to be kept moving. He took the country upward. But there remained much more to move.

If the results of Nehru's efforts at promotion of science and technology have not yet been fully realised, it is because many of us have not yet set down to finish the job for which he fashioned the tools. I, the scientist, the engineer, the administrator, the worker, and the man of politics failed him.

I would that I spoke the truth, but can I even discriminate?

I would that I had wisdom, but I can see only other's ignorance.

I would that I did not hate others, but I have learnt to love only myself.

I would that I was patient but I am like a strung bow, waiting for the arrow.

I want to be strong but inside I am brittle and inelastic.

I want to attain to spiritual proportions, but lack any symmetry in my nature.

I want to reflect, but I cannot recover the immediacy of the events.

I want to be morally correct but where is my inner watch and ward?

I have drunk from the heady fountains of knowledge but lack the means to apply it.

I want to be natural, but instead I hammer screws into wood.

I want to do things concrete, but my schemes are thin—drawn abstractions.

I want to say things in precise phrases but do I not cause confusion instead?

I toy with great ideas but they turn into strangers. Oh! I would that I rose to greatness; I haven't but I yet could.

E.C.G. SUDARSHAN*

THE TEMPER OF SCIENCE

I propose to share some thoughts and observations on the "Temper of Science," the human condition that fosters and rejoices in the pursuit of science and which is ultimately responsible for making science possible at all. Jawaharlal Nehru, patron of science, was fond of this phrase; and for a good reason too. It is the temper of science, more than any other factor that will bring about quality science.

I

Science is *vijnana*, differentiated knowledge. It is knowledge restricted to a particular domain, a universe of discourse which has been identified as a natural domain by the body of scientists. Physical sciences deal with the physical universe around us: with inanimate matter and its orderly and relentless laws that govern the motion of motes and mountains, of groundwater and galaxies. It deals with condensed matter at one extreme and elementary particles at the other.

The study of living systems is the domain of the biological sciences and it comprises the range from molecular biology, which deals with elementary living systems, to natural history, which deals with existing life forms. Here, too, traditional compartments are being abandoned and the life scientists roam the range. The natural question arises: are life sciences and physical sciences different? We know that all matter, whether living or dead, is subject to physical laws; but is there something called life, in addition? Modern biologists seem to say: no, all living things are dead matter but functioning in an unexpected, though natural, way.

*I am grateful to Gope Keswani. Nag Chaudhuri, B.R. Seshachar and Uma Shankar Joshi for sharing their thoughts with me.

The behavioural and social sciences deal with relation of living systems, especially of man to his everchanging environment including other living systems. These sciences select special areas for their study and identify laws which are applicable in these domains. Again one can ask: could we deduce these laws from the primary biological laws? At the present time we do not know and it seems premature to speculate on this question.

Science, as differentiated and qualified knowledge, is essentially incomplete and fragmented; but it is so pursued and dealt with, since the richness of the universe surrounding us is so great that no one person or even group of persons can hope to comprehend this richness unless some deliberate selections are made. These selections imply criteria which are themselves changeable in the light of further discoveries.

Often we tend to speak of science as authoritative knowledge of scientific laws, of facts established by science. As I understand it, science is neither concerned with truth nor with facts or laws, but with comprehension and understanding of the universe. Science does not deal with ultimate truths, just a little more light and preferably a little more sweetness; today's problem and today's solution may become irrelevant tomorrow. One strives to bring harmony and order into one's comprehended universe, one's model of the universe of discourse, and this is a process of continual evolution. This becoming is the being of science.

II

A scientist is a man enchanted by the universe, for no man in his senses, who is not under her enchantment, would undertake this austere path. A man in love with nature, who is captivated by her enchantments, is the only one who finds unending fascination in the smallest details. Anyone who has been in love would recognize this fascination with the most trifling detail about the beloved: love has the magic to transmute the ordinary into the divine, the everyday to the exquisite. And knowledge of the facts about the beloved does not detract from the enchantment, but enhances it. The facts do not get collected like a rubble heap but are woven by the admirer-scientist into a lotus and he discerns nature as enthroned in this lotus. The words that come to me are from a hymn of adoration:

dhayet padmasanastham vikasitavadanam padmapatrayataksim *hemabham pitavastram karakalita saddhemapadmam varangim sarvalankarayuktam. . . .*

However, this is only a phase of the scientific procedural mode. Observation leads to analysis, which, to the extent that the observation is new, leads to puzzlement and discomfort. In due course we discern a new entity, a new model of the system. This model tends to unify the observation and analysis with earlier observations and tends to replace the puzzlement and discomfort by delightful wonder and we feel harmony has been restored. As we move on in time, we make new observations and the cycle repeats itself. It is through this continuing investigation that we comprehend the world. We build and we destory, all for increasing harmony. Search for harmony for the scientist is through this dogged insistence, or understanding things for himself, come hell or highwater; comprehension is the sustenance of the scientist.

I would interpose at this juncture a point of digression, lest what I say be misconstrued: it is neither necessary nor possible for most of us to evolve our own individual cosmology. We have to use the community of scientists as an extension, and a substantial extension at that, of ourselves. We use our collective "wisdom," pool our findings, share the jobs and make the task possible by breaking it up into manageable bits, ask each other for critical examination of our work and generally work together as grown-up human beings are supposed to work. But I wish to enter a caveat to this picture of science as a social enterprise: ultimately each scientist has to make the decision: what is it that he has comprehended, who are his fellow scientists whose findings he will accept? This choice, this willingness to take responsibility, this integrity distinguishes the scientist from the scientific worker. In science, as in art the norm, is a "Banach norm," the excellent is contrasted with the mean, or the median. This is what distinguished Jawaharlal Nehru from his contemporaries of similar persuasions; and for science we can do no less.

III

The qualities of the man of science that emerge thus include vision, ability, integrity, energy, enthusiasm, flexibility, humanism, humility and creativity. And except for creativity and vision, these are the attributes of a person characterized traditionally as a *dhira*, a term loosely translated as a courageous man. But a *dhira*, is much more;

he is a man whose courage is as spontaneous as it is steady, born of his one-pointed determination, his *samkalpa*. The ability is not unrelated to his *samkalpa*; it is coexistent with it. It is not as if one must be a genius to be a scientist; many of us are just moderately endowed. It is, however, a clearly discerned ability born of the anguishing need to understand the world around us. Of the same mother is born the twin quality of energy, of zeal, of the urge to carry on his scientific studies and investigations. As long as it is his own puzzlement and its resolution in a newer, more comprehensive model, the scientist automatically learns to be flexible. He has to discover, not dictate. For a scientist,who has after many years evolved a theory or made a discovery, it is not a happy event to have his painstaking work upset by newer discoveries or by further deductions from his theory at variance with known results. Yet when his disappointments are over, he has to start rebuilding: the unexpectedness is also the guarantee of authenticity. Just as the farmer, whose life is disrupted by the muddy flood waters, recognizes that his soil is enriched by the flood, the scientist too recognizes the enrichment of his field.

Contact with and participation in these cycles of creation, destruction and recreation, being witness to this eternal dance of Siva, inculcates a pervading sense of humility in the scientist: and at the same time makes it impossible for him not to remain truthful, to develop his integrity in the pursuit of science. While integrity and humility are virtues, it seems to me that for a scientist, who has pursued science in a creative sense, they are minor attainments, *siddhis*, which develop along the way. Scientific work involves and inculcates in the scientist the principal ingredients of humanism which are cooperation, communication and detachment. Every problem solved creates new problems to investigate, every resolution brings to light a new landscape. The field is so extensive, the ideas so overpowering and the tasks so formidable that one has to communicate and cooperrate with others; it is an authentic humanism, since it emerges in response to a need.

I hesitate to pursue vision and creativity in depth, since these are most intimate subjects to a working scientist. I will return to these aspects later.

The working scientist may then choose as his symbol the bulldog, undisturbed by the trivial, sensitive, hardworking and pursuing with one-pointed attention his specialized and apparently narrow objective. Once that objective is reached he is again the sensitive animal.

This obsession with the essential, but limited, immediate objective is sometimes misunderstood by the non-scientist humanist, writer or critic for an inhuman, narrow, parochial preoccupation. But I humbly submit to you that this is a caricature, and if it is not to be attributed to malice it should be attributed to lack of acquaintance with the psycho-dynamics of a scientist. C.P. Snow has talked about two cultures: perhaps there is only one culture which displays itself in two ways.

IV

This brings us to the temper of science. We may distinguish six principal elements:

(1) Rationality (*Karyakarana viveka*): The appeal to reason, the removal of one's own ego and practice of detachment, the refinement of the fruits gathered by our five senses by an ego-less *pancali* in order that we may see things as they really are. This faith in the rational approach, the appeal to this *pramana* is itself an act of faith for the scientist and may be subjected to scientific investigation. Rationalism may then be identified with this self-correcting, discriminating tool.

(2) Humility (*anahamkara*): The recognition that the scientific pursuit contains in itself the destruction of the old and unworkable, the creation of the new and the useful, and the wisdom to know the difference between them. To steer clear of both credulity and stubbornness one must be blessed with humility. If you do not have humility in the beginning, the practice of science is the discipline that will generate and nurture it within you.

(3) Experimentation and innovation: (*svatantranvesana*): Even if a theory or a model is accepted generally and for some time, it is no guarantee that it is right. One must consider the possibility that things could be otherwise, lest we do not see things as they really are. All that a scientific theory or model can hope for is the certification: Not yet found wanting.

(4) Relentlessness (*nirdaksinya*): The scientists' work is never done. Hardly is one task finished when a host of new tasks demand attention. Every theory is challenged by new experiments; every careful experiment demands a satisfactory theoretical structure incorporating its findings. One goes on and on; and in this *mahaprasthana* only destiny has a greater claim on our time. My cherished recollections of Professor C.V. Raman in his library or wandering

around the grounds of his laboratory in his later years; and of the continually fertile minds and humming writing pads of Professor W. Heisenberg and Professor P.A.M. Dirac have shown me more than anything else that a scientist never arrives. In Carlos Castaneda's *Journey to Ixtlan*, Don Juan says of Don Genaro, the "man of knowledge": "There will never be any final outcome. Genaro is still on his way to Ixtlan."

(5) Integrity (*arjavam*): You cannot cheat Nature; you can only fool yourself. The scientist's methods of study of Nature breed sincerity in his pursuits. There has to be correspondence between thought and word, between word and deed. This is not to say that scientists are more sincere than, say, musicians or agricultural labourers. I am unhappily aware that perhaps the contrary is the case, alas; and to this extent we have not integrated ourselves; we have not been made whole. We have not yet achieved integration, *yoga*, since we have not succeeded in *cittavrttinirodha*. But in his pursuit of science the scientist does achieve limited integration; imagine the world if only a fraction of us succeed in allowing it to happen to our whole being.

(6) Creativity (*pratibha*): As the sixth element we recognize creativity, the seeing of things as they really are, the flash of lightning that illuminates the lay of the land, the incredible that with the flux of time appears as the inevitable. This by itself would remain only a flash unless preceded by and followed by hard painstaking effort; but with it, we are enabled to be creators ourselves. The wellsprings of creativity are beyond reason and intellect, but by their very presence command humility in the scientist.

I have talked about these six elements of the temper of science as if they are distinct things. But that, too, is a partial picture and to that extent untrue. It really is a six-faced entity, a *sanmugha*. Like the mythological *sanmugha* it is a lovable thing in one of its aspects, the giver of refuge and bestower of boons in another aspect, ever shining, ever glorious.

V

According to legend, the young Isaac Newton was lost in contemplation of nature under an apple tree when the law of gravitation literally "descended" on him, in the form of a falling apple, to awake him from his meditations and illuminate his mind to the true law of universal gravitation. But to most, if not all of us, neither bird-droppings nor cocoanuts falling on us would make us discover anything very much except at the most a severe headache. It had to involve a man prepared for this illumination by hard and relentless study of the universe. And it had to be followed by much work not only on the motion of heavenly bodies but also of the commonplace affairs of the tides. How many of us would like to undertake the detailed work involved in this, even if we had discerned the possibility?

The discovery of quantum theory at the turn of the century is another case in point. That a heated cavity emits heat and light must have been known to people for centuries; but apart from knowing that "white heat" is hotter than "red heat" why should we be concerned? Who would have suspected that the essential clue to the major scientific revolution in our times was hidden in this commonplace phenomenon? It remained for a small group of people at the turn of the century to look at this in more detail until it culminated in the discovery of the quantum of action by Max Planck three-quarters of a century ago. Planck, honoured by his peers and by his country for his extraordinary work, was not satisfied. He spent his later years trying to reconcile his shattering discovery with the rest of physics as he knew it. The returns were poor for the effort he put in: he did discover "zero-point energy," but he died without being fully satisfied with what he had been able to achieve; he sought a synthesis satisfactory to himself. Albert Einstein, another great revolutionary in science, too was dissatisfed with the degree of synthesis of physics in his time. Werner Heisenberg cannot reconcile himself to our scheme of a world where there are many species of elementary particles and fundamental interactions. As with Don Genaro, for these great men and many like them: "There will never be any final outcome."

It was known that light behaved at times as if it consisted of particles, the photons. It could therefore be argued that a heated cavity is really a box containing a photon gas. But we know how to deal with a gas, when heated. Looked at, in this way, we find that the correct treatment of the statistical mechanics of a gas is different from the standard theoretical treatment, if we are to get correct results for the hot photon gas. This change involves a new convention to count the distinct physical states of a collection of identical particles; and a more stringent notion of strict identity. Thus was born "Bose Statistics," of which the fiftieth anniversary year fell in 1974.

In addition to these landmark discoveries in physics, let me mention two scientific discoveries in which I have been personally involved.

The first concerns the discovery of the so-called Law of Universal Weak Interaction. When I went to the University of Rochester almost twenty years ago as a young graduate student (on leave of absence from the Tata Institute of Fundamental Research), Enrico Fermi's theory of nuclear beta radioactivity was a more or less accepted theory and there were known to be some other similar processes. People had talked about the possibility of generalizing radioactivity to include a variety of physical processes and of formulating a "universal Fermi interaction," but this still was considered as "interesting speculation."

During my first semester as a graduate student, parity violation was discovered in nuclear beta radioactivity following a theoretical suggestion of two young Chinese physicists, T.D. Lee and C.N. Yang. This discovery had upset most physicists; but they soon found in it a source of new information on elementary processes and a wealth of new information poured in. I was a student of Professor Robert Marshak; he suggested that this is the kind of area that was best suited to my abilities and aptitudes. I still remember reading through mountains of reprints and preprints and heaps of books to learn all that was known about the field. Our miniscule apartment in Rochester left barely room for my wife and myself and for a couple of young graduate students, whose total earnings came to the grand total of $ 1,000 per year, there were hardly any distractions. This period of intense study and the illuminating discussions with Professor Marshak (together with the causeless illumination that can only come from beyond oneself) showed me that if there was a universal weak interaction, it could be only of a special form which has since been called the Universal Vector-Axial Vector Theory of Weak Interactions. Almost immediately came new experimental corroboration of the theory and its further elaboration by Richard Feynman and Murray Gell-Mann. The second decade of this theory has shown that there are still more ingredients that should be incorporated and the theory should be generalized to include a wider class of processes. This has kept many of us almost completely occupied during the last few years.

The creative element may manifest itself in a natural and effortless way under suitable circumstances. I can recall a number of such instances. The discovery of the benzene ring structure is legendary. The organic chemist, Friedrich von Spradonitz, who was working on this structure had toiled for long without finding a completely satisfactory structure. One night as he slept he had a dream in which he saw a snake devouring its own tail: that gave him the clue and chemistry was enriched by the knowledge of the ring structure of benzene. Sir Frederick Banting, the discoverer of insulin, was obsessed by the need to find a cure for diabetes which had cruelly claimed his sister in her youth. He experimented with a numer of dogs and found that he could cure artificially induced diabetes in dogs by giving them extracts obtained from the pancreatic tissue of cattle from slaughter-houses; and in due course he identified insulin.

While much hard experimental work preceded the flash of insight, the possibility of using cattle pancreas from the slaughter-house came out of a casual conversation. In the absorbing book, *The Prize* by Irving Wallace, a doctor facing a fellow Nobel Prize winner in the throes of a heart seizure, looks around in desperation and seizes a table lamp, which he strips to make an electric shock apparatus to restore the heart action.

An instance in which I was personally involved concerns the development of the quantum theory of partial coherence. Emil Wolf, the founder of the rigorous theory of partial coherence in classical optics, is a friend of mine. One day he looked rather unhappy and I asked him why he was not his usual self. He told me that he felt that the many years of his work on partial coherence were worthless, since he was now convinced that we had to have a quantum theory of this, rather than a classical theory. It was a casual conversation and I had to go on to teach a class, but something about my friend's tone must have affected me deeply. In the evening I felt vaguely uneasy and to pass the time I sat down with a pad and pencil. All of a sudden, I found myself writing down a proof that what Wolf had done, upto that time could be shown to be quite correct in quantum theory with a natural reinterpretation of the symbols. I took my page of notes to show him the next day. He was delighted with it and insisted that I write a paper on this proof sitting in the same chair, got his secretary to type it and got me to sign it and send it off to a scientific journal. In subsequent years other people and I have improved on the proof and the scope of this fundamental connection. This discovery could not have come but for my professors at Madras who taught me optics and for the company of Emil Wolf, but still the essential discovery came by itself.

VI

I have talked about science as seen by the creative scientist, that is, about living science in which the working scientist is both the actor and the audience. The manifestation of creativity comes often without advance notice. But creativity is nurtured in an ambience that enables the scientist to acquire the necessary skills and techniques by instruction, example, experiment and accident. It is necessary for the poet to have mastery of the phrase, for the musician the mastery over sound: likewise for the scientist mastery over technique and information. To discover the antiproton we require the sophisticated experimental techniques of a super-laboratory; to bring about sustained thermo-nuclear fusion, we need the best experimental and theoretical techniques and perhaps even develop newer techniques. This kind of work that leads to the development of a helium cryostat or a bubble chamber, the discovery of the structure and functioning of bio-molecules, or the study of the further reaches of our universe need the concerted effort and teamwork of a complex of skilled and gifted people. The contribution of the scientific manager, the engineering expert and the technologist to the project may be very important. That is why we feel that great science may often be big science. Even in less hardware-oriented scientific studies, the teamwork may turn out to be essential, in that in a frontier field the nature of the questions that one asks, the kind of problems that concern one and the extent to which a discovery can be pushed and exploited; all this depends to some extent on the company one keeps. Those of us who deal with the ultimate nature of matter, space and time are keenly aware of this and grateful to any and every assistance that our society and nation provide us.

Scientific insights, like their counterparts in literature and music, are identified as such only when they are communicated and it is often this efficient communication that feeds back criticism and encouragement, provides perspective and enhances the joy of the creator. In maintaining the temper of science and the ambience of creativity it is essential to pay attention to the art of communication and feedback. And science management involves not only procurement and allocation of funds and the logistics of projects but also developing critical appreciation and the ensuring of a fair assessment of creative and substantial work within the nation and within the world community.

In literature and in music it may happen that technical mastery and virtuosity may overshadow originality and creativity. Virtuosity and mastery should be acclaimed and rewarded but not to the detriment of the flowering of originality. In science, too, there is the question of technical mastery and skill: they should be rewarded and appreciated. But, often, it happens that this is all that is rewarded. Instrumentation and hardware for the experimentalist, scholarship and analytical tools for the theorist; buildings, funds and organizations for both; these, if not seen in their proper light, become surrogate values, and tend to suffocate creativity.

In a nation like ours where resources are severely limited we have to be extremely careful in the allocation of resources to one scientific activity or another. Since science and technology are given favoured treatment, it is only fair for the nation to ask what science and technology can do for the nation. For most, the easiest answer is that it should be for the betterment of the quality of life of the people: I believe this is the proper answer. Yet one has to be ruthlessly precise in the definition of the phrase "betterment of the quality of life of the people". If we expect the space programme to be an important device in the strategy for adult literacy and cultural education, should we, at the same time insist that it be a vehicle for the development of the electronics industry or for the employment of the highly educated unemployed? We may keep these goals in mind, but it would be unscientific to treat this as of equal importance with the primary aim. If we consider that study of mathematics or molecular biology is important in their own right, let us not confuse it with accountancy or agriculture. The concern of the scientist for society should not lure him into surrendering his integrity as a scientist.

These are important and difficult questions and in this presentation I should guard against the temptation to delve into them. The increasing difficulty of locating and fostering excellence in our institutions of higher education, the paradox of the co-existence of the educated unemployed and of illiteracy and ignorance; the increasing preponderance of mediocrity in the higher reaches of the nation's intellectual enterprises; and the confusion of physical plant and technology for leadership in science: all these show that either the abler ones amongst us do not see or they lack the courage of expression: or perhaps we do not hear what they say!

Science applied to human affairs and to the exploitation of natural resources is technology. And technology naturally enters into any discussion of science in relation to society in general. But in the application of technology to social good, the control and development of technology, the choice of an appropriate technology, all these contain scientific questions. We must apply the same techniques to these questions as for a physical science programme. Science planning, too, involves scientific questions. We must bring the temper of science to bear on these questions also.

In the *mundaka upanishad* there is a stanza which talks about two birds:

dva suparna sayuja sakhaya
samanam vrksam parisasvajate
tayoranyah pippalam svadvattya
nasannanyo abhicakasiti

To me it appears that the phrase "*sayuja sakhaya*" (together in friendship) is a most happy choice for the inter-relationship of public science and private science, of science for society and science in search of insights and integrity. To me this phrase and this *sloka* evoke the true temper of science.

Science sees the world as it is, as it could be. It deals with the large and the small, selecting what it chooses and ignoring others. In this, science is like art, and we may state that creative sciencé is an art form.

Science involves communication and creativity. It seems to me that it differs from poetry only in the kind of questions that it asks: science deals with the measurable and the reproducible.

The scientist is essentially a seer. He sees the relevant, the significant, all in relation to other things in its universe of discourse. Discrimination is part of seeing and discriminating differentiated knowledge is living science. It is the temper of science that makes it possible.

It is this temper of science that makes it possible for one to be the creator, the destroyer. By destroying the obscure, the misleading, the irrelevant and the ugly; and creating in its place the clear, the relevant and the appropriate, we maintain the universe of science and guarantee harmony. What is needed for this functioning more than laboratories and research grants is the six-faced temper of science.

VII

I will conclude by retelling you an old story. In the *kiratarjuniyam kathakali* we see Arjuna preparing to acquire weapons from Lord Siva, the Auspicious One, he encounters a hunter. He does not approve of the hunter and they fight. Arjuna uses all his might to no avail and he is completely exhausted. It is while he is so totally exhausted, lying on his back without even being able to close his eyes, that he sees the flash of the crescent moon on the hair of the hunter, whom he was fighting. The hunter is no longer the hunter, but the Auspicious One. Arjuna is lost in rapture and has forgotten his duty. Yet, by the way, the *pasupata* is gained. The original purpose is served. Arjuna is in ecstasy, and has long forgotten that he lost out in his fight with the hunter.

I submit that this mythical story may well be viewed as a stylized drama of an incident in a creative scientist's life, that the *kiratarjuniyam* is a paradigm for the temper of science.

JAGJIT SINGH

SCIENCE AND SOCIETY

I personally became aware of the deep interest Jawaharlal Nehru took in Indian scientists for the first time in 1960, when he allowed me to present him a copy of my first book, *Mathematical Ideas*, and later to dedicate to him my next book, *Modern Cosmology*. I recorded my reminiscences of these two interviews, which he was pleased to grant me, in the *Illustrated Weekly of India*, immediately after his death in May 1964.

It was Nehru who first stated that the goal of our national endeavour after independence was the eradication of disease and destitution by recourse to science and technology. Almost alone among our pre-independence leaders, he knew that societies in transition or in distress from ancient days till today, from King Heron (whose director of defence services was Archimedes), through Napoleon to Lenin in our own times, have always called upon scientists and technocrats to shoulder the responsibility of reconstruction in war and peace. Lenin, in particular, reduced even his political credo to science and technology when he announced his celebrated equation:

$$\text{Communism} = \text{Soviet power} + \text{Electrification.}$$

So did Jawaharlal Nehru, when he made the Indian Parliament pass his "Science Policy Resolution", committing the nation to the eradication of our age-old poverty by recourse to science and technology.

During the decade following Nehru's death, there has been, I am afraid, a growing disenchantment with science and technology even in the affluent West, recently epitomised in the doomsday predictions of Professor Jay Forrester *et al.* It is quite likely that future historians may speak of an age of scientific discovery and technological reconstruction that began with the advent of industrial revolution two centuries ago and perished a century hence with the depletion of our fossil fuels and mounting environmental pollution.

If our civilization is indeed doomed to peter out in a century or so, it will be because of the failure of the affluent countries to cry a halt to the incessant increase in their demand for material goods they no longer really need. As Professor Jay Forrester and others have warned, if the developed countries continue to increase their demand for material goods as hitherto, life on earth may come to a horrible end around 2070, owing to either massive starvation or fatal levels of pollution. Consequently, the only way in which they could survive would be to decrease their demands sharply. For the affluent countries are spending themselves to destruction in a mad pursuit of growth that has ceased to have any meaning for them.

The pursuit of growth in the affluent countries is senseless now, because the industrial system is already more than adequate to meet the real (physical) needs of the masses like food, clothing, shelter many times over. In the absence of artful sales-campaigns, specially contrived to create artificial demand, increasing abundance would have soon reduced the interest of the people in acquiring more goods. They could not have felt the need for multiplying the artifacts—the autos, appliances, gadgets, detergents, cosmetics—by which they are surrounded. But then the stoppage of growth would mean that the power and profits of the corporations, the owners of the industrial system, would also cease to grow. It is this relentless pursuit of power and private profit that is responsible for the means-and-ends inversion whereby the industrial system in these countries has been over-blown to the point that it no longer accommodates itself to man's basic and real wants but rather increasingly moulds men to its own needs. It is increasing awareness of this means-ends inversion that is responsible for the current disenchantment with science. It is becoming more and more obvious that science and technology are no longer being pursued to serve the needs of the people. On the contrary, the people are being increasingly accommodated to the needs of the existing techno-structure that science has created.

This means-ends inversion in turn is only an amplification of that fatal flaw of capitalist production which, as Marx noted a century ago, develops technology by sapping the original source of all wealth, land and labour. During the hundred years since Marx wrote this indictment, capitalism in its struggle for survival has undergone radical changes. In particular, it has tempered its erstwhile insensate exploitation of its own labour, sufficiently to create mass affluence in the developed countries. But the more it changes, the more it remains the same at the core. It now develops technology by eroding man and his environment on the planetary scale. Unless this erosion is halted by giving technology a new turn in the service of man instead of the techno-structure it has created, the doomsday predictions of Forrester will sooner or later come to pass. The science, the demiurge of society, will then turn into a demon of doom.

It is this transformation of science, the demiurge, into science-the-demon, that has inspired the invective of literary underground in the 1960s and has been a dominant theme in the widespread student protest. I will mention here by way of illustration only four such denunciations of science that have received widespread publicity. First is Jeff Nuttal's book, *Bomb Culture*, which was written explicitly in the shadow of the "bomb." But the protest is more than a plea for a socially responsible science harnessed to the promotion of human welfare. It is an attack on a technocratic society which is seen as the coldly rational and inhuman world of technology in which human ends are lost sight of in the search for rational techniques and bureaucratic efficiency. Nuttal's attack may well be the irrational outpourings of a nihilist literary artist. But not so with Jacques Ellul in his *Technological Society*. It is a powerful onslaught on what seems to him the domination of man by "technique." Ellul's usage of technique is wide enough to include technology among others within the ambit of its sweep. But more recently the case against science and technology has been further explored and reinforced by Herbert Marcuse in his *One-Dimensional Man* as well as by Jurgen Habermas in his *Toward A Rational Society*. Both claim that technique instead of being the slave has become the master. For it determines not only means but also ends.

All these critics of science and technology argue that technique becomes the search for the most efficient, right way of optimising some abstract utility or goal of the organisation. Hence the tendency to rely more and more on "systems" and hierarchical structures with their prescribed routines and procedures and repose too little faith in the men who actualy breathe life into these structures or systems. As a result, what we have is a tension-ridden society, which, for all its underpinning by modern science and technology, tends to secure mere conformity to rules and procedures rather than overall ends, which these means were originally designed to achieve. In other words, management of our industrial society becomes a system of administration which leaves no scope for human choice and judgement. It becomes an unalloyed bureaucracy where judgements about values are excluded not merely as non-scientific but also unscientific since they cannot be proved by any appeal to experimental data.

There is nothing new, of course, about such denunciations of science and technology of which Ellul, Marcuse and Habermas are the most recent. But they do acquire a renewed credibility through sheer accumulation of social and ethical problems in the wake of increasing preoccupation of science with capital-intensive research. This is a recent phenomenon, called industrialization of science, that began to emerge during the decades following the outbreak of World War II. It has manifold social consequences.

First, it means the increasing interpenetration of science and industry with the erosion of boundaries which enabled different styles of work with their appropriate codes of behaviour and ideals to coexist. Second, it leads to immense concentration of power in a small section of community which is strongly tempted to seek growth for its own sake because growth means more pay, more promotions, more opportunities, more perquisites of office, more power. Third, it implies a large size, both in particular units and in the aggregate, with the consequent loss of networks of informal, personal contacts binding a community. Fourth, it brings into science an instability and turbulence characteristic of the world of commerce and industry in our civilization. Fifth, it often gives rise to run-away technologies like Apollo landings or monstrous aberrations like supersonic airliners, which are the outcome of efforts to correct an error by making it bigger. All these new developments, stemming from the industrialization of science, have distorted the ethos of olden times and the ideology of science prevailing during the earlier "academic" phase of science prior to World War II. It is therefore no wonder that the erstwhile vision of science as the pursuit of the "good" and the "true" has become seriously clouded. It shows itself in the pronouncements of the present leaders of science themselves, which have changed from optimism of earlier days to at least a troubled uncertainty.

The uncertainty arises owing to the increasing contact between scientist and men of affairs, which increasing industrialization of science entails and which exposes the former to new hazards which scientists never faced in the past. The reason is that scientists after all are human beings and when they are engaged in work other than pure research (as for instance in a mission-oriented project) they are confronted with the same perils as any one else involved in practical affairs. The American physicist, Leo Szilard, expressed pithily the scientist's dilemma in his new situation in the story called, *The Voice of the Dolphins*: "When a scientist says something his colleagues must ask themselves only whether it is true. When a politician, or a merchant for that matter, says something his colleagues must first of all ask 'Why does he say it,' later on they may or may not get around to asking whether it happens to be true." Because of increasing contacts between the scientist and men of affairs there is a serious risk of the scientist paying insufficient regard to the code of behaviour, which is more stringent, more sophisticated and enlightened than that considered adequate in other professions. There is no doubt that this elevated view of the ethical aspects of science has had a strong foundation in reality, in the social practice of science as well as in its public self-awareness during the earlier academic phase of science prior to the outbreak of World War II. There is equally no doubt that the pressures of industrialization of science during the past three decades have led to increasing politicization of science; even a cursory perusal of Daniel S. Greenberg's *The Politics of American Science* indicates this development. In less than a generation, science has lost its erstwhile innocence. Many who entered it as a refuge from the intellectual and moral squalor of ordinary society find, in their advancing years, that they are back in the same snake-pit they wanted to escape from. I do not know how the complex problem of politicization of science in the wake of increasing industrialization of science may be resolved. But the problem is only the other side of the growth coin to which I referred earlier. The affluent societies of the West have now become inherently unstable because of their insensate pursuit of runaway growth, which, perversely enough, is no longer a means to secure human welfare but is quite the reverse.

Fortunately, there are some indications that these developed societies have begun to realise that pursuit of growth for its own sake is merely a means-ends inversion of their economy. Consequently, it is by no means impossible that it might be rectified in course of time by increasing nationalisation of their techno-structures. For the affluent countries have now become aware of what has aptly been called the ecological peril. Everybody in these countries today is "for the environment." Laws and agencies designed to protect it multiply at all levels of government. But it is unlikely that the cost of implementing these laws, designed to clean the environment, would be paid for out of "business profit," if only for the reason that the cost is many times the total business profits. After taxes, the profits of all American business, for example, in a good year aggregate to sixty or seventy billion dollars. And mining and manufacturing—the most polluting industries—account for less than half of this. But at the lowest estimate, the clean-up bill—even for just the most essential jobs—will be three or four times as large as all the business profits. It is, therefore, obvious that if these jobs are to be done at all, there will be increasing takeover of the private enterprises by public agencies. The takeover will not necessarily be an appropriation, as the original owners of the enterprises will themselves quit as their profits begin to erode. The takeover will thus be voluntary rather than forced, like the state takeover of railways the world over, when their dividends began to dwindle. But increasing takeover of mining and manufacture by the state in the affluent countries will only aggravate the energy crisis in which they are already plunged. For every environmental task demands huge amounts of electrical energy, way beyond anything now available. This poses a difficult dilemma, particularly as power plants are themselves pollutants. And one of their major pollution hazards—thermal pollution—is something we yet do not know how to handle.

If the main peril confronting the affluent countries is the growth mania of their techno-structure with its means-ends inversion and consequential insensate energy demands to keep it going, the poor and developing countries like our own, face the opposite peril that their economies, instead of growing, are actually shrinking while their populations are literally exploding. As a result, in this bipolar world of the rich and poor nations, growth is at the wrong place. The world economy is therefore like a cancer patient in whom the unrestrained proliferation of cells of a diseased organ is choking to death the healthy growth of others. Consequently, if we were really sane, we would immediately begin to deploy our global resources—technical, scientific and material—to rectify this lethal imbalance. In other words, we would switch the global economic effort to solve the biggest problem of mankind—the problem of ridding the poor two-thirds of the world from disease and destitution in the way the rich one-third has already done in the past fifty years or so. But since such sanity is too much to expect in our turbulent world of today, each nation will inevitably go its own way as best as it may.

II

Which way will we go in India? Will we redeem the faith Nehru reposed in the Indian scientific and technocratic community when he built the national laboratories he loved to call temples of science? I am afraid I can no longer answer the question in the same confident, affirmative tone as I would have done ten or fifteen years ago. Hindsight wisdom has obliged me to revise my erstwhile views on two basic though inter-related problems that any discourse on science and society cannot possibly avoid. They are, bridging the technology gap and diffusion of scientific temper in the community to ensure such bridging.

Consider first the problem of technology gap. I have heard some people claim that in the field of science and technology India can do what other developed countries have done. We can leap from the technology gap unaided and alone, subject to certain "ifs" and "buts." But I am not one who shares their optimism, much as I would like to. Even though we have a massive complex of research laboratories, it must be admitted that they are equipped at present to attempt only those goals which can be achieved by recourse to what has been called low technology, involving small improvements in widely-used products; such as in the field of housing, road making, food, drinks, textiles, leather, etc. Developing countries like ours cannot afford to neglect high technology. High technology cannot be quickly acquired indigenously. It must, therefore, be borrowed as we borrow capital and thus take advantage of what has been worked out by those in the lead. It is not possible to imitate high technology by importing a model and then duplicating it as the Japanese tried to do in the twenties and thirties before World War II. They found that imitation led to production of shoddy goods which could not be marketed. Profiting from this experience they have gone in for whole-sale collaboration in the matter of setting up high technology. We too should have no inhibition in allowing large international corporations to set up high technology in our midst by making it reasonably worth their while to do so. Lenin had no hesitation in allowing American capitalists to make money by building great dams in the Soviet Union for power generation. Why should we? After all, economic activity is not a zero-sum game like gambling, where Peter's loss is Paul's gain, the sum of their gains being zero. Economic collaboration is a non-zero sum game where both participants can gain.

Moreover, there is no escape if we wish to install high technology under democratic auspices. For it is a feature of high technology that it is only large international industrial concerns which are able to deploy the scale of effort required to set it up. For high technology it is the size that counts—the size of market, of inter-disciplinary concentration of technical know-how, of financial resources for research and development exploitation. This is the nature of technology gap. It is a gap not of intellectual capacity, but of available resources and ability to deploy them. It follows, therefore, that while everything should be done to secure collaboration at as favourable terms as possible, there should be no artificial or ideological blocks on our part.

But if we have to seek foreign collaboration to install high technology, it must be confined to only a few essential fields which we must develop to meet the basic needs of the people, such as oil exploration, fertilizers, nuclear power generation. All other collaborations designed to cater to the needs of the affluent fringe or for mere international prestige must be totally banned. For otherwise the total cost of technology import will be too high. It is here that the problem of choosing the right technologies in developing countries like ours having mixed economy becomes extremely difficult. The danger of selecting wrong technologies in these countries is very great. Indeed, past experience shows that it is precisely such wrong type of collaborations that slip through easily because of persistent sponsorship by vested interests. For example, while Atomic Energy Commission has delayed by several years the implementation of breeder reactor technology for power generation by relying on indigenous manufacture of a sophisticated component called "Calandria" rather than importing it, import of a large number of luxury articles as well as know-how for their manufacture is still allowed. I myself, as Chairman of Indian Drugs and Pharmaceuticals Ltd., was once strongly tempted to seek one such wrong type of collaboration for the manufacture of a wide variety of new synthetic drugs in an ambitious bid to expand my corporation. I was able to resist this temptation by recalling a remark of Macfarlane Burnet, who was awarded Nobel Prize for medicine in 1960, that the contribution of laboratory science to medicine virtually came to an end two decades ago. I also recalled that Macfarlane did not regret at all that drug research had reached a blind alley. For he said, "we could be happy with no more than twenty to thirty synthetic drugs we already have in our armamentarium." Indeed, he was honest enough to frankly admit further:

> All this is unhappy stuff for someone to be writing who thoroughly enjoyed a professional career in laboratory research on infectious diseases and immunology. The biomedical sciences all continue to provide fascinating employment for those active in research... but almost none of modern basic research in the medical sciences has any direct or indirect bearing on the prevention of disease or on the improvement of medical care.

Such forthright honesty, which prompts one to see even the irrelevance of one's life-long *metier* to the real problem of today, is rare. It is the outcome of a truly scientific temper rather than a mere professional expertise. And this brings me to the core problem of a pre-scientific society like ours anxious to practise science. The problem is how to diffuse the ethos of science in our scientific and technocratic elite so as to ensure at least a modicum of professional integrity. It seems to me that before we can leap the technology gap, we must first bridge the ethical gap by cultivating the ethos of science.

III

I admit that it is exceedingly difficult to define that intangible, called the ethos of science. I also admit that I do not know if I have the complete answer. But I do think that the main attributes of such an ethos are the following:

(*a*) Rigid self-restraint against relapse into wishful thinking both in our theorising and experimentation;

(*b*) capacity to challenge established theories if they happen to conflict with facts of life while having sufficient humility and self-discipline to submit to the scientific consensus in case one's own theory does not commend itself to the scientific community;

(*c*) overcoming what may be called culture lag; and

(*d*) eagerness to share knowledge with the community without seeking any reward.

None of the aforementioned traits is natural to man. For if they were, it would not have taken millennia for the first truly scientific civilisation to arise and that too in only one place, western Europe. The scientific temper would have been the natural state of mankind everywhere and my discourse on the subject would be redundant.

Consider, to begin with, the first attribute. Self-restraint against wishful thinking is necessary because we are prone to counterfeit reality in accordance with the dictates of our inherent secret desires.

The reason is that mind will *selectively* see only what it wishes to perceive. It is *not* a camera that records everything in its field of view. On the contrary, it is like the human eye which is a highly selective receptor in what it chooses to "sense" and transmit and what it decides to ignore or suppress. Since the human mind is highly selective, one may almost say that truth like beauty is in the beholder's mind and not out there in the external world. That is why even creative scientists are not immune from strong subjective bias in their scientific theorising. History of science is littered with highly subjective and dead theories based on observations that never were. Cases in point are the canal systems "observed" on the planet Mars by the Italian astronomer, Schiaparelli, and the homunculus or manikin "seen" by the Dutch microscopists, Hartsoeker and Delempatius in the human sperm. A more recent, indeed, contemporary instance is that of Lysenko who was able to establish at least in his own country the false Lamarckian theory of inheritance on the basis of experiments and observations that are now widely believed to be fudged or faked.

As science advances, such fudging or faking is all the easier because the more complicated the experiment, the more difficult it is to draw the boundary between observation and invention. The question that arises then is this: if scientists cannot easily discriminate between fact and fiction, why have they been widely acclaimed the world over for their objectivity and solicitude for truth? The answer is that their reputation for "objectivity" and "truth" is due to the operation in reverse of the Brutus aphorism:

The evil men do lives after them,
The good is oft interred with their bones.

The subjective theories, which die in course of time, are consigned to the limbo of oblivion and the successful ones, which survive because of their objectivity alone, are preserved. But living scientists who spin theories of their own are known to select those that appeal to them out of the many possible ones for other than purely scientific reasons—aesthetic, emotional, moral and even metaphysical reasons.

If it is hard to restrain wish from fathering the thought, it is much harder to break the habits of thought once somehow established. For human brain at birth is virtually a *tabula rasa*—blank sheet—on which almost anything may be written. But once written—be it the language we learn in childhood or geometry and physics taught at school—it is almost impossible to obliterate it. This is why it needs a genius to free ourselves from the tutelage of false ideas planted in early life. They acquire the force of conditioned mental reflexes which are difficult to eradicate once they are formed. This neuro-physiological fact of our life leads to the persistence of not only old-established scientific theories but also old obsolete cultural ideologies quite inappropriate to a rapidly changing technological age.

A single instance will illustrate the stranglehold of old-established scientific theories owing to the virtual indelibility of ideas fixed in early life. Although gravity is the most indubitable fact of our daily life, the Aristotelian notion of levity, that material bodies can ascend as easily as they can descend, continued to reign supreme for millennia before it was challenged by Galileo and Newton. Even more daring was the breakthrough Einstein brought about when he replaced Newton's theory of gravitation by his theory of general relativity after patiently completing intricate tensorial calculations which took ten long years. Once such major conceptual revolutions are accomplished, one cannot easily imagine the great intellectual effort and daring needed to supplant a prevailing ideology. And yet no matter how great the daring it must go hand in hand with equally great humility and self-discipline to submit to the verdict of the scientific community in case it happens to go against one's own innovation. It speaks volumes for Einstein's self-restraint that he never used the weight of his undoubtedly great authority to suppress quantum theory merely because it did not square with his inborn belief that God does not play dice with the universe quite unlike Lysenko who used all means at his disposal to promote his own (false) theory of inheritance in the Soviet Union.

It is not merely obsolete scientific ideas that persist. The cultural ideas that we tend to imbibe unconsciously are even more persistent. This is the cause of our cultural lag to which J.B.S. Haldane first drew our attention fifty years ago. Writing in 1923 in his *Daedalus, or, Science and Future,* he made the stunning prediction that the centre of science would shift from mathematical physics to biology. And in his projections of the future, Haldane specified that progress in medicine would practically abolish infectious diseases. But because he was aware of our cultural lag he added the rider that "owing to Hindu opposition, parts of India were still quite unhealthy up to 1980 or so." Such indifference to implementing even health programmes is principally owing to the telescoping of the habits of thought appropriate to the Vedic age with the practice of jet-age technology. It is ths telescoping that is at the root of our inveterate habit of doublethink. Doublethink by the way is not an Orwellian invention. Orwell merely described what he observed in India and Burma—the amazing power of otherwise intelligent men to harbour such incompatible mixes as Marxism and *Vedanta* or engineering and astrology without any intellectual qualm or embarrassment. As Orwell makes his Goldstein describe it:

> Doublethink means the power to hold two contradictory beliefs in one's mind simultaneously and accepting both of them. The process has to be conscious or it would not be carried out with sufficient precision, but it has also to be unconscious, or it would bring with it a feeling of falsity and hence of guilt.

As a result, such hypocrisy, where a surrender is a compromise, a lie is a simplification, an act of sabotage is a distraction of the troubled mind, a mutiny is a strike, an intimidation a gentle persuasion, a hangover a migraine, becomes a national vice. It is the outcome of a conflict between the basic drives of a peasant economy trying to leap the technological gap and its obsolete ideological or value system that still believes that the world around us is all a veil of *maya* or illusion that ought to be renounced rather than remoulded. Unless this conflict is resolved, the present absence of a scientific temper among the elite, let alone the masses, will continue and even the technocrat will not learn to speak the truth. He will be like the auditor who will make two plus two equal anything that the managing director requires. J.B.S. Haldane also noticed this phenomenon in our midst when he came to settle in India as an Indian citizen. He asked in anguish the question: "Why cannot people learn to speak the truth?" "I have," he added, "taught two, perhaps three, Indian colleagues to speak the truth. It will probably wreck their careers." It actually did.

Finally the fourth trait—eagerness to share with the community new knowledge without any reward—is equally rare. Most of us are still old-time alchemists at heart, are far from being true scientists, itching to exploit for our own exclusive benefit the discoveries we seek to make. Our only Nobel Laureate scientist, C.V. Raman, for example, is stated to have disowned after the announcement of the Nobel Prize his own erstwhile collaborator, K.S. Krishnan, who was thus denied part of the credit for the discovery which had brought great distinction to Raman and India over forty years ago.

If even renowned scientists sometimes behave in a manner forbidden by the ethos of science, what can one do to promote among the laity such attitudes of mind as scientific ethics prescribes? I do not think such attitudes can be promoted either by wide dissemination of the achievements of modern science and technology or by mere preaching. As for the former, I may speak from my own experience as a writer and a reviewer of books on science. I have learnt that the worth of a book lies in the value system inherent in the writer's attitudes, not in the quantity of information which he tries to convey. In fact, it isn't one's theory or one's intention that counts, it is what one is. Too many science popularisers seem to me not to recognise the truth of this axiom. This is why while there is a glut of information as to how the computers compute and pulsars pulsate, all this accumulation of information is of little avail in promoting a scientific temper. It does not enable a layman to face the unpleasant naked truth, particularly when it happens to be the recognition of a malaise he cannot cure, nor does it help him temper his greed and jealousy, nor sharpen his intellectual curiosity, the sort of things that help build scientific temper in the community.

As for promoting these attitudes by outright preaching, all this has about as much effect on the creation of scientific temper in our midst as the exhortations to godly behaviour in our temples, *ashrams*, *masjids* and *gurdwaras*. It isn't by being told that we acquire an attitude. It is rather the listener's belief that the teller himself practises what he preaches that carries conviction. How then do we ensure that no credibility gap develops between the lecturer or the writer and his audience? Like Pontius Pilate, I simply pose the question and depart without waiting for the answer.

B.P. PAL

SCIENCE AND AGRICULTURE

It is a remarkable fact that the Indian farmer, through centuries of cultivating the land not only did not ruin the soil, but devised a system of agriculture, which in the prevailing circumstances and in the absence of scientific inputs, was a fairly successful one. As the population increased and the rain gods sometimes failed, inevitably famines occurred from time to time. It was as a result of the recommendations of the Famine Commission of 1878 appointed by the Government of India that agricultural departments in the provinces came into being. At the turn of the century, the Imperial Agricultural Research Institute at Pusa and the Imperial Veterinary Research Institute at Mukteswar were firmly established as important centres of research, and several provinces had agricultural colleges which imparted training in agriculture besides conducting research.

In its early years the Imperial Agricultural Research Institute—which after 1947 was renamed as Indian Agricultural Research Institute—had some outstanding men on its staff: names which readily come to mind are those of Howard in plant breeding, Butler in mycology, Lefroy and Fletcher in entomology and Leather in agricultural chemistry. But after the first world war Britain obviously could not spare men of this calibre. Also, a Retrenchment Commission had eaten into the vitals of the great institute, and when I joined it in October 1933, it was a mere shell of its former self. Of course, the magnificent campus was there, with its imposing copper-domed main building, the fine library, the splendid Sahiwal herd of milch cattle and the officers' club (originally confined to Europeans) with six of the best lawn tennis courts in India. I remember I was allotted a bungalow with twenty-two rooms and when I mildly complained, the British director's wife, with a twinkle in her eyes said, "Why, you can have a room for every hour of the day!"

But the staff was meagre. After the head of each of the five sections (who had the prefix of "Imperial" before his designation) there were only a few scientific posts, with poor pay scales. The pace of life was leisurely, but right from the beginning, the highly successful wheat breeding work of the institute ran like a golden thread through the fabric. Thus the variety, "Pusa 4," not only was widely grown in India but also in some other countries, notably Australia.

Very good work was also done in some of the provinces. The agricultural college at Lyallpur became well-known for its wheat breeding work and the agricultural college at Coimbatore developed into a renowned centre for rice improvement. But on the whole, agricultural research was of an average quality. One economic botanist in the U.P. boasted that he was in charge of the improvement of nineteen crops. His staff however did not consist, I think, of more than a couple of assistants and the usual complement of fieldmen and *beldars*. It is no wonder that intensive work on any major problem could not be done in such circumstances.

The then Government of India was, however, specially interested in certain commercial crops, especially cotton, which were of vital importance to industries in Britain. The Indian Central Cotton Committee set up in 1924 gave a considerable impetus to work on cotton in all its aspects.

An important landmark was the establishment of the Imperial (now, Indian) Council of Agricultural Research (ICAR) in 1929, on the recommendations of the Royal Commission on Agriculture. The constitutional changes in 1919 had made agriculture a provincial subject, but by then the central government had set up some important research institutes. The Royal Commission on Agriculture considered that a suitable agency was required to coordinate the research activities of the Government of India and provincial governments. To give the necessary flexibility of operation, the ICAR, though drawing its funds from government, was established as a registered society. However, in due course, it became also an "attached office" of the government so that in practice it was a sort of chimera, combining the disadvantages of both.

It is not therefore surprising that agricultural extension was most meagre and not at all commensurate with the importance of agriculture. In some provinces there was one person called an agricultural demonstrator in a whole district, and in times of shortage and rationing he could be called upon, for instance, to issue the kerosene ration.

Altogether, during the pre-independence period both agriculture and agriculturists occupied a lowly status. In the district heirarchy, the administrator, the civil surgeon and the police chief were important; the deputy director of agriculture came somewhere behind them. The scant respect for agriculture pervaded the scientific arena also. Pay scales were poor and scientists in the so-called pure sciences often tended to look down upon agricultural scientists. As a rule, the bright students were not attracted to agriculture, but no action was taken to remedy this state of affairs. I even remember hearing a director of agriculture of one of the provinces saying, in the course of a discussion meeting, that he "preferred third class graduates" as they were more amenable to discipline and were satisfied with whatever was given to them in the way of training, and later, of jobs.

II

Coming now to the post-independence era, I will by-pass chronology and begin by referring to the break-through in agricultural production which was accomplished a little over five years ago and which is sometimes termed as the "green revolution". Though some critics appear to gather some satisfaction by deriding this break-through, the figures speak for themselves. In 1949-50, which we may take as a convenient base year, just before the commencement of the First Five Year Plan—the total production of food grains in India was 54,921,000 tonnes. In 1970-71 the figure had risen steeply to 108,422,000 tonnes, the increase in production being spectacular in the case of wheat, the production of which was 6,759,000 tonnes in 1949-50 and 26,477,000 tonnes in 1970-71. The break-through in wheat production became visible immediately after 1966-67, i.e. after the two bad years of drought. By any standard, the increase in food-grain production, and especially wheat production, was most impressive.

Only a few years earlier, some foreign writers on problems of food and population had 'written off" India as a hopeless case because of her huge and rapidly expanding population and the stagnation in her agriculture. What were the causes that made the break-through in production possible?

If we stop looking at agriculture for a moment, and turn to the general picture of scientific progress we find that important changes had been taking place in India since the attainment of independence.

Nehru's recognition of science as a major weapon of the fight against poverty and a means of advance towards a modern welfare state, gave a strong impetus to the expansion of scientific activities. It was because of his powerful support that Homi Bhabha could build up the prestigious atomic energy organisation and Shanti Swarup Bhatnagar, in a short span of time, establish the important chain of national laboratories of the Council of Scientific and Industrial Research. It would be interesting to speculate how much the application of science to agriculture might have advanced if Nehru had been directly associated with the Indian Council of Agricultural Research in the way in which he was associated with the Council of Scientific and Industrial Research and the Atomic Energy Department. It is a pity that when these modern scientific organisations were set up, the older Indian Council of Agricultural Research was not drastically reorganised on similar lines. However, although more distantly, the scientists in the field of agricuture also felt and responded to Nehru's stirring call. On the few occasions when he came to convocations organised by the Indian Council of Agricultural Research or the Indian Agricultural Research Institute, the stimulating impact of his magnetic personality was obvious.

Let us now return to the agricultural scene. After independence, the Government of India expected much more from the agricultural scientists than had been the case in the period of foreign rule. It was evident that the whole set-up for agricultural research and education, and the machinery for advising and assisting the farmer needed to be reviewed, renovated and strengthened. The tremendous task before the country was how to change from a traditional and, to some extent, subsistence farming to modern agriculture based on up-to-date science and technology. There were more than 60 million farming families to be reached and provided with the tools and know-how of modern farming. The government decided to set up a number of high level study teams consisting of Indian and foreign scientists to go into the vast and complex problems of agriculture. I do not propose to go into details of the recommendations of these teams, nor the numerous steps taken by the central and state governments. Obviously, in such a massive enterprise as the "green revolution", many persons and agencies participated. I would, however, concentrate on three major components which made possible the breakthrough in agricultural production.

The first is the Indian Agricultural Research Institute, which, as stated earlier, had become greatly weakened. This "twilight stage" continued even after its transfer from Pusa to New Delhi in 1936 after the Bihar earthquake of 1934. A senior scientist at that time told me that the IARI had "lost its soul." Research activity still continued, but at that time the institute had no authority to carry out any extension work. When ministers and others visited the institute they referred to its high reputation in the past, but official communications from the Ministry of Agriculture to the director of the institute sometimes came signed by "section officers," and marked, "all subordinate offices of the Ministry."

The IARI had become weak but, it was still the premier institution of its kind in this part of the world. And in 1950 came a re-awakening. The institute mustered its own resources; there were weekly meetings of the director with the heads of divisions and monthly meetings of the staff research council, which began to arrange for not only coordination between the sections of a division but amongst the divisions themselves. About this time, K.M. Munshi, the Minister for Agriculture, observed that it was entirely wrong for such a major research institute to be without any extension responsibility. He decided that some villages should be given to the institute for extension activity; nineteen villages in Delhi were accordingly allocated to the institute. The officers of the Finance Ministry, however, hastened to lay down that no additional resources for this new work would be provided.

During the second five year plan period, a large number of carefully thought-out projects of the institute were approved, and this gave it a kind of blood transfusion. The institute was slowly regaining its original reputation. In 1958 the Rockefeller Foundation, with the approval of the Government of India, came forward to cooperate with the institute in two major projects, namely, the post-graduate school and a cereal project.

A full-fledged post-graduate school was set up in 1958. It was patterned on the Land Grant College System in the United States, which had proved not only the most successful system of agricultural education in the world, but also maintained high standards in research and teaching. The institute and its sub-stations were now humming with activity, and were able to play a vital role in providing trained manpower for the agricultural universities which soon started coming up. The institute was also able to provide the scientific support which the Indian Council of Agricultural

Research needed. It played an important role in helping the ICAR to formulate and implement the all-India coordinated research projects to which reference will be made later in this paper.

The members of one of the World Bank teams, which had come to India three or four years ago to see what assistance could be rendered to the new agricultural universities which were being set up, told me, during a meeting, that they believed that the IARI and the two other all-India institutes which imparted both research and training, namely, the Indian Veterinary Research Institute (IVRI) and the National Dairy Research Institute (NDRI) would have an even more important role to play in future. They had noted that with the reorganization of states of the Indian Union on linguistic basis, the recruitment and admission policies in many states had become rather restricted and they felt that the three national institutes of the ICAR would have to undertake the task of providing training at the highest level and giving an all-India outlook to students from all parts of the country. At present the IARI badly needs replanning and development of its campus, which now compares unfavourably with some of the new agricultural universities. Similarly, the IVRI and the NDRI need great support.

At this juncture I may make a brief reference to the series of commodity research institutes which came up under the ICAR to deal with the problems of particular crops, e.g., rice, potatoes, tobacco, jute, etc. These institutes which were intended to be centres of applied research on these crops, filled an important need in that they provided for a really intensive attention to the research problems of a particular commodity. Unfortunately, they concentrated only on one crop and this led to some development of inbreeding even in the thinking; it would have been better if they had been allowed at least to work on the crops which come in rotation with the main crop as the one in which the institute was interested. This drawback has since been removed and the commodity research institutes are playing an important role.

The second important agency contributing outstandingly to the attainment of the green revolution is the agricultural universities. It was obvious that the traditional universities could not really help to solve the problems of the farmers. What was required was something on the model of the Land Grant Colleges of the USA which were established at a time when teaching in Europe and America was heavily based on subjects like religion and philosophy. These colleges in America were designed to meet the needs of a quickly-developing agriculture. In India also, we needed universities where the research work is concentrated on solving the needs of the farmers, where teachers use such material in their teaching and there is an "extension" agency to carry the proven results of research to the farmers in a two-way traffic which also brings back further problems of the farmers in applying the new technology.

The first agricultural university in India came up at Pantnagar in U.P. in 1960. It was followed by universities in other states. Several universities of America gave considerable support to these new universities to help them develop along the lines which experience had shown to be the best. The ideal agricultural university is one with a single campus on which there is a college of agriculture, a college of veterinary science, a home science college, a college of basic sciences and humanities and a college of engineering, the last one being added only if necessary. It was expected that when agricultural university was established, the state government would transfer research and teaching in agriculture and animal husbandry to it and also extension education. Where this has happened, the universities have been successful, notably those at Pantnagar, Ludhiana and Hissar. But some universities have made little progress because either research was not transferred to them or only a small part of it was transferred. This situation needs speedy spectification if these universities are to play their important roles in the agriculture of the country. The agricultural universities are important because research and teaching are better imparted in a university atmosphere than in a government-controlled department of agriculture. In fact, it is the coming of the agricultural universities that made it possible for the ICAR to successfully launch its all-India coordinated projects.

Before leaving the subject of agricultural universities it is necessary to point out that in some states the "model act" for such a university drawn up by a high power committee of the Indian Council of Agricultural Research has not been adopted in regard to several important features. It is particularly important that the boards of management in the universities should consist primarily of scientists and educationists. It is also desirable that in a country where we have so many scientists and educationists of high calibre that the Vice-Chancellors should be drawn from this category rather than from the ranks of the administrative service as is largely happening at present. I would like at this stage to focus attention on an important point which has often escaped the notice of policy makers at the highest level. In some universities there has been a tendency to limit admissions to post-graduate classes to B.Sc. (Ag.) or B.V.Sc. only, and again, to recruit professors and teachers only from among those who have a B.Sc (Ag.) or a B.V.Sc. degrees. This system excludes a large number of persons who have been trained in the pure sciences and can be a source of strength to the university. For various reasons some students are not able to go to an agricultural college or veterinary college, but they may be highly qualified in science and may later find an attraction in that field. In other parts of the world this kind of mobility is encouraged. The agricultural universities have a wide range of courses and practice of student counselling. Therefore, if a student wishes to make up for the deficiency in a particular field for study, this can be easily arranged for. That being so, there seems to be no good reason for debarring a large body of people from the pure science stream either from joining post-graduate classes in agriculture and animal husbandry or from being appointed to appropriate teaching and research posts. If this restrictive tendency is not immediately checked, its results, which may not be perceptible at present, may be far-reaching in the long run and adversely affect agricultural research and teaching in India.

The third major factor responsible for the agricultural transformation is the re-organization of the Indian Council of Agricultural Research. I have mentioned that the ICAR had become, in course of time, an important wing of the government secretariat. It had no authority over the central research institutes, which were controlled by the Ministry of Food and Agriculture. It also had little control over the commodity committees for certain crop plants which had been set up, though the fact that the vice-president of ICAR was the ex-officio president of all these commodity committees, provided a sort of link.

In 1963, an international agricultural research review team set up by the Government of India made far-reaching recommendations on the basis of a thorough study of the position in India. These recommendations included transfer of all centrally-supported research institutes in agriculture and animal husbandry to the ICAR; the adoption of a new recruitment policy and a complete reorganisation of the Indian Council of Agricultural Research including its governing body. Another recommendation was that a career scientist should be the chief executive of the Council with the designation of

Director-General. That such far-reaching and drastic recommendations were accepted and quickly implemented was because C. Subramaniam, the then Minister for Food and Agriculture, was a staunch believer in science. With its reorganisation, and with the support it received from the research institutes under it, and particularly the IARI, and with the coming up of the agricultural universities, a stage was set for the formulation of the all-India coordinated research projects.

The concept of the all-India coordinated research project was developed in India, and I am not aware that such a pattern existed at that time in any other country. In the past, resulting from the fact that agriculture was a "state subject," there were a number of research institutions in the states, some of them quite good, some quite weak. There were also research institutes controlled by the central commodity committees. They were all highly sensitive about their autonomy, and it was found that it was not easy to carry out any important research activity on a really coordinated basis. But in the all-India coordinated projects, as now formulated by the ICAR, there was no question of anyone becoming subordinate to anyone else and the new pattern was readily acceptable.

Briefly, the strategy was that in the case of the particular crop which it was sought to improve, the country was divided into broad agro-climatic zones, with major research stations in each zone; there were also some sub-stations, to look after special areas which did not fit well into the broad zones. The programme of work was decided at a meeting between central and state scientists after full discussion. The ICAR agreed to provide funds for the extra staff and extra facilities required, but it did not assume control over centres other than those located in its own research institutes. In other words, if any research centre under the coordinated scheme lay in a state's territory, it continued to be administered by the state government or by the agricultural university, as the case may be. Other features were the appointment of a full-time project coordinator to go round the country and identify the bottlenecks that were impeding progress and rectify these in a speedy way. Finally, there was an annual workshop meeting at which the results achieved in the previous season were reviewed and the new programme made for the next season. This provided a basis on which scientists from the centre and the states could work together and it has proved so successful that scientists and administrators from other countries have visited India in the recent past to study the working of these projects.

At one time it used to be said that Indian scientists do not know how to cooperate with each other, but the all-India coordinated projects of ICAR are a shining example of really effective cooperation. In view of the very great significance of the all-India coordinated project concept, while I was in the ICAR, I took steps to see that such projects were formulated for all the important crops of the country, and I was very happy when the scientists specialising in the animal sciences also decided to adopt a similar approach. It is the successful working of the all-India coordinated projects with the background of the agricultural universities and the ICAR re-organization that has made possible the agricultural transformation which is still being called the "green revolution". It came about because with the new set-up, capable scientists using modern technology and with international cooperation, where necessary, developed strains of economic plants that smashed the old genetic yield barriers. Further, by inter-disciplinary cooperation, they also developed a suitable technology for obtaining the best results from the new strains of high-yielding potential. But at this stage, I must point out that whatever the scientists might have done, it may not have resulted in a rapid, large-scale transformation but for the fact that the Government of India had, a Minister for Agriculture, and a Secretary for Agriculture who were appreciative of science and technology, and Indian farmers proved willing and able to adopt the new technology. In fact, it has been one of the most pleasant surprises that the farmers, who were believed to be old-fashioned and conservative, took up the new technology readily and with great skill, while it was the Department of Agriculture which proved to be conservative.

I have earlier mentioned, very briefly, just a few figures to show, that there has been a massive improvement in agricultural production. Those who question this fact are being neither correct nor grateful for what has happened. But it is certainly pertinent to inquire why further increase in production after the year 1970-71 has not taken place, and why the remarkable increased production had taken place in wheat only and had not occurred to that extent in other crops. First of all, it must be pointed out that agriculture is very complex and very susceptible to a large number of factors and particularly the supply of water. In a large part of our country which is not irrigated and has insufficient or badly-spaced rainfall the yield of crops is reduced considerably. This is a different situation from that in a mill or a factory where, if certain machinery is installed and inputs provided, everything goes on steadily. It is true that there have been some "dips" in the curve of agricultural production after 1970-71 but these have taken place at much higher level than they did in twenty-five years ago.

In the case of wheat, as compared to other major food crops, there were some advantages in that the areas which contributed most to the increased production were Punjab, Haryana and Western U.P. where the crop is grown in the *rabi* season, when there are practically no insect pests of importance, and the most serious disease i.e. rust, has been kept in check by the use of resistant strains. Also, the farmers in the area referred to, are in a better position to invest and take up the more intensive agriculture. Rice, however, is grown in the *kharif* season when the weather is subject to violent fluctuations in rainfall, cloudiness, etc. At this time, insect pests thrive and there are difficulties of water management. In the case of sorghum (*jowar*), the high-yielding hybrids are liable to be attacked by insect pests for which a really economic control method has still to be developed. Further, as is well known, there have been conditions of severe drought for about two years in many parts of the country, and there has been a shortage of fertilizers and other inputs.

There is a belief held by some that the farm holdings policy has also been partly responsible for the lack of increase in productivity in certain areas like north-western India after 1970-71. This view cannot be lightly dismissed. Though there are countries like Japan and Taiwan, where the farmers with small holdings are prosperous, their climatic conditions and the whole range of amenities like service co-operatives make this possible, and it is not easy in a monsoon country like India to make all these available to the large number of farmers in the country. It is important that the question of land ceilings in agriculture should be very carefully re-examined, keeping in mind the fact that in order to feed our large cities and also those states where soil and climatic conditions do not permit them to be self-sufficient in food, it is necessary that there should be farmers in the more fortunately-endowed areas who will be able to farm so well that they will have surplus grain production. Unless the size of the holding is such that investment in a tractor, a tubewell, and pesticides etc., pays off, the farmer will be reluctant to spend on inputs which are essential for a high level of farming to produce surpluses.

There has been criticism in some places that the high-yielding varieties strategy which was launched in 1966 and which gave spectacular results has benefited mainly the rich farmers. But at that time it was obvious that the new technology had to be applied, wherever the chances of success were greater. The country was badly in need of food and vast sums of money were being spent on import of food-grains from abroad. It was natural therefore that those farmers, who had facilities like irrigation and farm machinery and who were in a position to invest in fertilizers and pesticides, reaped the maximum benefit. Those, who say that, instead of concentrating on a smaller area where yield increase would be the highest, the same result could have been achieved by spreading out the new strategy in a diluted form over a bigger area, ignore the fact that at that time we just did not have the organisation to do it. There are over 60 million farmers in the country, and the task of reaching them, and providing them with the necessary inputs and expert advice at the right time, was a gigantic one, even now we do not fully have the means for it.

Having achieved a break-through, it is obvious that the next stage was to bring in the other farmers—medium farmers and small farmers and give them as much assistance as possible through the extension organisation. In fact now, with the shortage of fertilizers and many other inputs, the view is gaining ground that we could achieve quite good results by some moderation and judiciousness in the use of fertilizers, irrigation water and pesticides. I understand that this aspect is being actively pursued by the policy makers.

III

Scientists working in the field of agriculture share the handicaps common to other scientists in this country, such as lack of adequate apparatus and the great difficulty in obtaining spare parts. Much of the high-class apparatus in use in our laboratories is imported, and whenever this needs repair or even a small spare part is required, the work comes to a standstill. We do not yet seem to have evolved a method by which, at least for cases where large sums of money are not involved, the essential spare part can be obtained expeditiously. Our laboratories also suffer from lack of proper planning. Whereas laboratory planning in advanced countries has made great progress, in India it has been often left to the Central Public Works Department to provide whatever they are able to give. Proper planning of the campus and laboratories is an important matter. An outstanding example of a campus, which is beautifully landscaped and has fine laboratories and a very good library, is that of the Punjab Agricultural University at Ludhiana.

Agricultural scientists also require some facilities as distinct from scientists working in the traditional universities or research institutes dealing with other branches of science. For instance, to do really good work on crop plant physiology, growth chambers and glass-houses with light and temperature control are necessary. Horticulturists in particular need glass-houses with such features for certain aspects of their work on fruits, vegetables and flowers, but at present even the prestigious Indian Agricultural Research Institute does not have such a facility. Horticultural research centres in temperate countries have acres of glass-houses. In our climate we do not need so many, but the fact remains that a certain number of properly designed and equipped glass-houses and growth chambers are essential.

One other feature of agricultural research institutions in this country to which attention may be drawn is the great excess of non-scientific and non-technical staff. Owing to historical reasons, and the feeling that in agriculture you need a large number of people to look after plants in the field, there has been an accumulation of staff at lower levels. A part of the time of the senior scientists is spent in administrative and routine duties relating to this large component of non-technical staff, which one does not find in laboratories of advanced countries. In fact, the large population of such people in the corridors of certain laboratories detracts from the scientific atmosphere of the institution. I am not suggesting that these people should be dismissed, but in planning for the future we should try to see that our scientists have the minimum of administrative and non-technical staff, and the maximum of up-to-date laboratory facilities.

Mention has already been made of the weakness of extension staff in the pre-independence era. After that, India has developed a large-scale community development programme, but the agricultural component in this is still weak. It was because of this that, when the new high-yielding varieties and the new agricultural technology became available, it became necessary for the research scientists themselves to plan and carry out what is called the National Demonstrations Scheme. This scheme was of great importance in that a large number of demonstrations properly conducted all over the country in the farmers' own fields helped to make them aware, in a short time, of the new advances that they could take up. One of our eminent agricultural experts has said:

> We need to build up at the rural level, structurally and functionally, a microcosmic replica of what the agricultural university system provides at the State level. It is not enough to have an agency only to organise inputs (seed, fertilizer, pesticides and others), or just to conduct demonstration of this or that innovation, or to do propaganda work, or to mount occasional campaigns, drives and crash programmes.

He suggests that in every tehsil or taluka and in fact in every block, there should be, what he calls, "a functional trinity," which will operate in unison in the areas of adaptive research and demonstration of the latest agricultural technology, practical vocational education to farmers and to their sons and daughters, and an effective agro-service. This is something that we need to do quickly and on the required scale.

In the recent past, grim warnings about food shortages and famines in the near future in several parts of the world, have come from several eminent authorities including the Director-General of the Food and Agriculture Organization. Also, there has been a great deal of concern at the population explosion. To quote Robert McNamara:

> The problem of excessive population growth is, by half a dozen criteria, the most delicate and difficult issue of our era—perhaps of any era in history. It is overlaid with emotion. It is controversial. It is subtle. It is immeasurably complex. It is an issue, finally, that is so hypersensitive giving rise to such diverse opinion—that there is an understandable tendency simply to avoid argument, turn one's attention to less complicated matters, and hope that the probem will somehow disappear. But the problem will not disappear. What may disappear is the opportunity to find a solution that is rational and humane. If we wait too long, that option will be overtaken by events. We cannot afford that. For if there is anything certain about the population explosion, it is that if it is not dealt with reasonably, it will in fact explode; explode in suffering, explode in violence, explode in inhumanity.

It is obvious that while planning for greater production of food grains and other economic materials, measures to control the rise in population must be taken up most urgently and in a really massive way.

In the context of the grave situation that confronts the world, we have to formulate both a short-term strategy and a long-term plan to meet the needs of this country. In the short-term strategy there are many many things that we have to do, such as reclamation of waste lands, formulating a really effective technology from semi-arid areas, and so on. In the words of another eminent agricultural scientist, our urgent needs are "first to develop and introduce in each ecological area an agricultural production technology, which will lead to increased productivity based prominently on the use of renewable resources and the wise husbandry of non-renewable resources."

A large part of our country has the grave disadvantage of having to depend on rainfall, which is received during the short period of two to three months. Further, the existence of alkaline and saline areas and inadequate supplies of fertilizer, are also handicaps. Nevertheless, we also have many assets, among which are abundant sunshine and a large volume of water, the great range of soil and climate, the remarkable amount of plant and animal wealth, and finally the large number of competent scientists and technologists. We have got an impressive network of agricultural universities, research institutes and demonstration-cum-training centres. According to a study made by the Yale University, the payoff from investment of agricultural research in India has been one of the greatest in the world. But we have to do much more in the future. Let us very briefly consider what we should do.

In my opinion what is most important is, first of all, for every one to recognize the paramount position of agriculture in our country. Man cannot live without food, and we have one of the largest human populations to feed. We also have one of the largest cattle populations in the world. It is necessary that the agencies responsible for agricultural research and agricultural education are supported by the government in a way which is second to none. Science and education are twin instruments by which our traditional agriculture can be converted rapidly into a really modern agriculture, capable of satisfying the enormous demand for food and materials which will be required. There should be no delay in ensuring that the pay-scales and prospects for agricultural researchers and teachers are in no way inferior to those in other organizations. Otherwise, we shall not be able to attract to agriculture a reasonable proportion of the best talent in the country.

It is time that we made a really long-term projection of the future requirements of our agriculture (using the word agriculture in its broadest sense), and the steps required to deal with developments in the decades to come. One is impressed with the thoroughness with which some advanced countries faced the problems of the energy crisis; they critically reviewed the existing position regarding their resources and made projections of what had to be achieved by planned actions in the future. Our whole programme of research and education must likewise be thoroughly and critically reviewed. Unimportant areas should not be allowed to take away our limited resources. We should concentrate on what is really important. For instance, we have to pay much more attention and provide financial resources to basic research with the objective of putting a greater input of science into agriculture than at present. While more immediate researches deal with the maximisation of food production with the present tools, in the future we need basic scientific knowledge to enable us to go further.

S.H. Wittwer points out that even in the United States, the "two most important energy free (there is no charge fcr solar energy) but energy-producing biochemical processes on earth, namely, photosynthesis and biological nitrogen fixation, both intimately bound with the production and carbohydrates, proteins, fibre and energy, are receiving only token research and development priority and support." He adds: "Photosynthesis is the most important biochemical process on earth. By it the sun's electro-magnetic energy is converted to chemical energy stored in plants. It remains today as the world's most important renewable energy producing process."

This is the kind of research that we must include in our plan for the future. There are several other aspects, for example, the utilisation of solar energy, the study of meteorological phenomena in relation to agriculture, problems relating to forests, fisheries etc. All the while we must keep in mind that we need greatly to increase not only production but also the employment potential. There are numerous other problems and many other considerations, but time does not permit me even to list them. The kind of long-range, perspective plan I have in view can be proposed only by a high level, well-balanced, interdisciplinary team of scientists. It cannot be done if these scientists can spare only a few occasioned hours from their other duties. It should be possible, by suitable arrangement to pull out these people for a few months to concentrate on the preparation of a really outstanding well-considered plan. If we can do this and then implement with courage and determination both the short and the long term plans, we may have some basis for hope and even optimism. It is said that the optimist is an endangered species. Surely, it is not a species that we in India can allow to become extinct.

In stressing the role of science I have not forgotten that there is considerable concern in the world about certain aspects of the use of science which have led to destruction on an alarming scale. But science is indispensable for achieving many of the things which we desire for the betterment of mankind. What we have to see is that it is wisely used.

Disraeli long ago remarked with reference to some opulent countries that, by the "aid of a few scientific discoveries they have succeeded in establishing a Society which mistakes comforts for civilization." In this country we have a proud heritage of a civilization coming down to us from the dawn of history. If we are careful and judicious, we can avoid the mis-applications of science and use it for bettering the lot of our country and our fellowmen. In this way we could achieve, in due course, Nehru's dream of modern India.

S. VARADARAJAN

SCIENCE AND INDUSTRY

India owes its present position, in respect of the number and excellence of its scientists in a wide variety of fields, to the imagination and vision of Jawaharlal Nehru. Notwithstanding the criticisms that have been voiced from time to time regarding the effectiveness of our investment on science we are well ahead of many developing nations, and have moved within the short span of a quarter of a century to the level of competence in understanding modern science, which is equalled only by the most advanced countries. There has indeed been a great investment on science, in men and resources, and perhaps we have not yet exploited fully this investment. In almost every field of pure or applied science, we have experts of a very high calibre. We have now to examine in what way this immense wealth of expertise and the strong motivation and idealism amongst our scientists can be used more effectively for the growth of our economy and the improvement of the quality of life of our people. Just as we have been rising in our scientific stature, we have also grown as an industrialised nation.

II

If we look back on the development of science in India, we will find that there was very little organised science before the second world war. Science was largely limited to universities and some institutes of agriculture and of communicable diseases. There were also one or two pure research institutes. University research, although it was of lesser magnitude in those days, had one great quality, viz., excellence. India can well be proud of the outstanding contributions made in theoretical and experimental physics, and has produced a number of giants. One cannot help recalling the names of Bose, Raman, Saha, Bhabha and a few others.

Our science education was improving steadily, although slowly.

The emphasis was on pure science, such as physics, chemistry and biology. A few universities, such as Benares, Bombay and Calcutta attempted to introduce new courses in applied science, but applied science was not considered altogether respectable ; and had a secondary place in our value system. This is not surprising, because our industrial growth was too small to make much use of science. The second world war, however, provided a challenge to our country, which had for the first time to manufacture many goods. The Government of India constituted the Board of Scientific and Industrial Research, which later developed into the Council of Scientific and Industrial Research. Technology suddenly became more respectable. After independence, the need for the trained personnel was even better recognised. Most educated Indians shared the aspiration that India should become a modern industrialised nation. Soon after independence, we sponsored each year over sixty candidates to go overseas for training in research and technology in a variety of fields.

Jawaharlal Nehru was a great believer in science and its uses for transforming society. He saw the great opportunities science offered. Fortunately, men of science were available, who could convert his aspirations into achievement. There came into being a chain of laboratories under the aegis of the Council of Scientific and Industrial Research, manned by some of our ablest scientists. These laboratories had spacious surroundings and modern equipment; there was much excitement and a spirit of adventure in this new investment. The early years after independence also saw the establishment of the Department of Atomic Energy and its laboratories.

It is not enough to have laboratories for doing research. The country needed people to man its industries and one of the first tasks in the 1950s was the establishment of major institutes of technology. The first of these was set up in Kharagpur and was followed by similar institutes at Bombay, Madras, Kanpur and Delhi. The institutes of technology provided excellent education for talented young men. At the same time, our organisations in defence grew in size and expanded. The result was that a large body of well-trained scientists and technologists in virtually every modern field became available. Some of them worked outside the country in complex and sophisticated enterprises and institutions of higher learning, and won laurels there.

No other developing country—and very few among the developed countries—possess today such a rich resource in variety and excellence of skills and experience. In 1951, Indian universities had less than a thousand students engaged in a full-time study of the sciences. Today, the number is more than of 1.2 million. Nearly 87,000 graduates and 45,000 post-graduates in science are now being turned out every year. The country is also producing 10,000 to 12,000 engineers every year. The number of post-graduates in science which was 17,000 in 1950 has now increased to nearly 200,000. The number of degree holders in engineering and technology has also grown from about 22,000 to 200,000. All this is a rich resource for manning our industries and technological development programmes.

Science education in India today is not confined to people at the top stratum of our society. The interest in science education is enormous. Approximately 1.6 per cent of persons in the age-group 17 to 23 are now receiving full time university education in science. That means, that in India today, one in sixty amongst our young men and women, is being trained in science and technology.

If we look at the amount of investment we have made in material resources, the growth in scientific research and development is impressive. From an annual figure of only two crores of rupees in 1947, our research and development costs have now grown to approximately Rs. 250 crores a year. The average annual expenditure during the fifth plan period will be between 400 and 500 crores of rupees. While agriculture receives a good proportion of this total expenditure, the outlay in industrial costs is of a very high order. Of this expenditure, approximately 10 per cent is spent by industries in the private and public sectors and 90 per cent by central and state governments. This has a certain bearing on the relationship between science and industry. The research and development outlay also represents ½ per cent of our gross national product (GNP) which often is said to be too low and I hope to deal with this later on.

Now, the processes started by Jawaharlal Nehru were not "one-time" events. They have been formulated into a steady but firm policy for science and the support of science. Nehru was a believer in science and in the temper of science. The scientists had a ready access to him and he gave them material and moral support and a great deal of freedom to develop their plans and institutions. The Council of Scientific and Industrial Research and the Department of Technology were the tangible expressions of his faith in science as an instrument of social and economic transformation. He gave his time liberally to the cause of science and attended every session of the Indian Science Congress.

This policy has been continued by the Indian government and Jawaharlal Nehru's successors have extended their strong support to science. Faith in science received formal recognition through the adoption of the "Science Policy Resolution" by the Indian Parliament on 4 March 1958; this resolution envisaged the use of science in every possible way for the good of the people of this country. Nevertheless, there have been, from time to time, some misgivings about the value of scientific inputs. There have also been frustrations among scientists. Some of the scientists, who were used to research facilities and the sophisticated organisation of technology in the West, have found our system of administration rather slow. Differences in emoluments and working conditions available in India and in most developed countries have been mentioned as a principal cause of the so-called "brain-drain." Controversies raged among our scientists themselves on the value of one another's contribution and approach to the use of science. In the late 1960s, even, a certain amount of demoralisation in the scientific community could be detected.

There were, however, some compensations. The "green revolution" produced a resurgence in agricultural research. The atomic energy development called for exceptional skills and organisation, and the scientists responded to the challenge. The wars into which India was drawn in 1962, 1965 and 1971 demonstrated the importance of science and technology for national security. The debate on science policy and practice culminated in the national conference on science and technology in 1970. This subsequently led to the formation of the National Committee on Science and Technology, and the constitution of a separate Department of Science and Technology in the Government of India. It is now accepted that long-range planning of scientific research is necessary; one can detect the receding of the din of controversy at least for the time being.

The upshot of all this has been that scientists have gained power and prominence in administration and in some of the technological and industrial enterprises. We find today that in national defence, electronics, space, atomic energy, petroleum, chemicals and in several other public enterprises, scientists have been closely associated with the decision-making process; indeed they hold formal positions of importance and responsibility in several ministries and public sector corporations.

III

If we now examine the way in which the other side—the industry—has developed, we may notice some parallels. The industrial revolution of the West touched us only in a limited way during the British regime. It came to us through the setting up of the railway and irrigation networks, mines, textile and jute manufactures. These were necessary for our economic survival; they were the obvious means of ensuring the security and unity of the country. They were also the means by which markets were provided for goods manufactured elsewhere. Very little effort was, however, made to bring an industrial technology into India. Looking back at the period, prior to the World War II, it seems amazing that we made so few of the things that we needed. We did not make even pens, pencils, bicycles and motor-cycles. We manufactured steel but hardly any other metal. We manufactured only a few chemicals. We made some explosives necessary for the ordnance factories, some vaccines for curing diseases and for the prevention of diseases in a small way. Apart from that, our sophistication in industrial production was very small. The second world war provided an opportunity, but the real progress came after 1947. Here again we owe much to the vision of Nehru. Even before independence he had been associated with the National Planning Committee. He realised that if we wanted to go ahead, we could not do so in a haphazard manner. During the 1950s a variety of basic goods—metals, cement, construction materials, basic chemicals, petroleum and drugs—came to be manufactured in India. This introduced us to a wide variety of technologies.

The very process of rapid industrialization required the import of capital goods and this depleted our exchange resources. Thus began a process, which we now call, import substitution. This gave a new impetus to the local technology. We had also to look at the problem of producing capital goods in the country, because the volume of capital goods that we required was very large. We now make not only many of our consumption-goods, but our capital equipment too. We still find that the knowledge required for converting our raw materials into finished products still depends on technology, which we do not originate. Therefore, there is much concern for the assimilation of technology, and perhaps for evolution of our own technology. The Indian government's policies for industrial development have also been codified.

The Government of India, adopted not only a "Science Policy Resolution," but also an "Industrial Policy Resolution." The latter spelt out *inter alia* the policy for foreign collaboration, recognised the importance of the public sector in "basic" areas, and also the development of small-scale industries.

IV

Now, we may come to the relationship between science and industrial development. As early as 1950, the Government of India felt the need for obtaining the best possible advice on industrial development in order that India could acquire what suited her needs. This led to the establishment of a special agency, the Directorate-General of Technical Development, to ensure orderly growth and optimum utilisation of scarce materials for the maximum good. Its function as a "cell" for technical knowledge has, however, changed over the years, and attempts have been made to bring it back to its original role.

What have been our aims in the field of industrial production? We started off with consumption-goods. We paid some attention to national security. We then realised that we wanted capital goods. We also felt that we wanted some types of technology for self-reliance and security. When technologies were not available to us from abroad, we tried to develop them ourselves; the most spectacular demonstration of this has been in the activation of a nuclear device in 1974. But in all these efforts we have not probably paid adequate attention to the need for exports to keep the balance of payments. Over the years, our investment in the public sector has grown steadily. There have been criticisms of the way in which this sector has functioned. There is no doubt that it has a predominant role. It is of a size comparable to large international enterprises. It has the capabilities to compete internationally, and the process has now begun. The "Action Committee on Public Sector" has made exhaustive studies of the working of the public sector and made a number of recommendations to make it function more efficiently.

We have now two separate sectors, one for growth in science and the other for substantial growth in technology. We have made considerable progress in industrial development during the last twenty-five years. We are now manufacturing goods of every kind such as basic metals, chemicals, plastics, engineering goods, ships, drugs, aviation materials, electronics, fertilisers, pesticides, power equipment. We had very little experience in these fields before 1947. Our technologists and engineers have brought about a virtual revolution in self-reliance, in most instances, through the assimilation and adaptation of technology which originated elsewhere.

It must be conceded that the fruits of scientific research are not being translated sufficiently rapidly into industrial applications, nor are we quite certain that our present utilisation of science is necessarily of immediate or maximum relevance to our industrial growth. This raises the important question of the connection between our competence in science and industrial growth in our country. It is often asked: "Are we doing enough research and development ? Is the amount that we spend, which represents ½ per cent of our Gross National Product adequate in comparison with other countries ?" Such comparisons can be misleading. Our economy is not fully monetised and, therefore, our GNP figures may not be comparable with those of other countries. Our research and development costs are relatively low because per man costs are low. Our salaries are low, and research and development costs are largely made up of man-power salaries. Comparisons of costs of research and development therefore need to be cautiously made. It would be much better if we made comparisons on the basis of research effort and man-power rather than on that of money spent. The research and development expenditure statistics returned by the government as well as by various industries often include such elements as technical services. It may, therefore, not be strictly correct to talk about our "low research and development investment." We must take into account the actual size of our investment and the actual man-power employed in research institutions which would be comparable with the countries like Sweden, Denmark and Holland.

It is not suggested that our effort is too great; but to base the argument merely on the figures of expenditure would be misleading. It is important to note that scientific investments in India have been largely made in government-supported institutions, outside the private as well as public sector industries. This contrasts with the experience of most other countries, where scientific research has played a great part in the improvement of industry and the development of totally new enterprises.

The rapid growth of science and industry in India in different and separate sectors, independent of each other, has produced many frustrations for scientists. If we look at our own figures, the investment in industry on research and development is very small indeed. The "Action Committee on Public Sector" has also reviewed this and they have come to the conclusion that this investment is extremely small. Yet our total investment in research is increasing. In the fourth plan period, we spent Rs. 435 crores in government investment in research. During the fifth plan period, this will increase to Rs. 1,560 crores. Unless we remedy this situation with regard to research *within* the industry, our progress will be hampered, and we are bound to feel some further frustrations.

I am not suggesting that our scientists' competence, devotion and sincerity are in doubt. We have often made too simplistic an approach to the whole problem of innovation and have assumed that innovation in laboratories can be converted into profitable innovation. We had imagined that economic and social benefits would flow automatically from laboratory science without the complex institutional framework for translation of science and research results into such benefits. Where we had organisational framework for complete innovation and change—such as in the nuclear energy development programme in the Atomic Energy Commission—the results have been highly satisfactory. Where such a framework did not exist, the results have not been spectacular. Obviously, the management of our research and technological development and its relationship to industrial development deserves a close examination.

We have often neglected the success, which we had achieved in many areas through technological developments. Take, for example, our whole communication and transport network. Our railways have tried to carry between two to three times the number of passengers and goods that they carried about twenty years ago. Our postal and telephone communications services have had again a similar growth. Yet they have achieved all this without substantilly increasing the network of railway lines and tracks and very often, only through a number of technological improvements. These developments are not talked about very much, but they represent examples of "in-house" technological development and success. There has been increasing emphasis on such research in industrial units in recent years.

This is also true of several private and public sector industrial units where there is "in-house" research. If we are to fully appreciate this problem, we must understand the nature of applied science which is relevant to industry. The pursuit of science, i.e. pure science, is an intellectual activity, propelled only by a sense of curiosity, a spirit of adventure and competition with other scientists. The pursuit of applied research cannot be regarded in the same fashion. Applied research is an investment for economic and social benefits. Because of the high element of uncertainty that necessarily exists in scientific exploration, the investment in applied research must be considered a high-risk investment, leading perhaps to frequent failures, but undeniably capable of yielding spectacular returns from time to time. Applied research must no longer be regarded an expenditure, but as an investment and, therefore, should receive the consideration to other forms of capital investment. While setting up a factory, we ensure that the whole infra-structure exists, such as market demand, capital costs, and returns. Applied research also deserves the same consideration, it must be regarded primarily as an economic activity, although of a very special nature involving science as a major input. In planning and execution and translation of its benefits a whole set of other people besides scientists, such as economists, social scientists, financial managers and experts in production and marketing come into the picture. Economic activities are always subject to cost-benefit analysis within the framework of a limited time-schedule, and applied research must also be examined in this way. Besides, applied research has many other characteristics which make it different from the pursuit of pure research.

Applied research involves many sciences and skills, to achieve a particular objective. We are brought up to believe in pure science, that individual recognition is vital. But when we accept cooperation in applied research to solve a problem, it is necessary that we ensure the subjugation of individual aspirations or the pursuit of individual expertise in subordination to a common cause. It often involves the learning of another science, perhaps not even a science, but an alien technology or even an alien profession such as accountancy and finance. Applied science requires the formation of temporary teams of different experts, the acceptance of leadership within the team, discipline and whole-hearted willingness to pursue common objectives. It would be useful to refer to examples of similar activities which require the same sort of approach.

We know that as a country we are eminently successful in the visual dramatic arts. We produce hundreds of films, plays and these often require the coming together of many artists, musicians, who perform under the direction of a single director. They are financed by a producer, who, while he appreciates the art and its excellence, is also conscious of the return that he is going to make on his investment. We must also see that this type of approach exists wherever competitiveness and unique situations prevail such as in national defence. We have seen already that our armed forces are capable, when called upon to come together as a unified force, and use a wide variety of skills and expertise and communicate with each other, accept the leadership and discipline, and win wars. We have, however, not yet accepted such an approach among scientists, nor have we created the institutional framework and the philosophical background for pursuit of these new types of relationships.

We have demonstrated amply that we have the ability to form such groups in times of stress or when the competition is sufficiently great, as for instance, in the recent production of atomic device. I would, therefore, like to compare the activity in applied research similar to a project-type activity such as "Engineers India." Such project-type activities would appear to have certain characteristics in common. Firstly, you require many experts; you require them only for a limited period of time; you do not require all the experts all the time. You can use only certain skills at certain times and yet you must see that they are gainfully employed. Secondly, you must see that their morale is high and although the activity itself is representing group-activity, individuals who contribute must be suitably rewarded. Now, this requires value-judgments and some organisational changes, which we have not completely adopted.

We have also to see how science can be valued in a special way in each industry. After all, we often buy from other countries, technology and industrial property rights; these are given in the form of patents for revealing fully the nature of innovations made. We often feel in this country that patents inhibit innovation and invention. If we believe that we have excellence in our technology, we have got to be inventive and original; we need strong encouragement. We must see that our inventions are protected, that our inventors are given encouragement, and that we export the best of our inventions, so that the people in other countries can use them and reward us suitably. We neither have a suitable mechanism or institution for the sale of our technology, nor for identifying the innovations that we make in this country. I, for one, cannot believe for a moment that, having embarked on an industrial investment of this magnitude, which is enormous compared to most other countries both in men and resources, we are not producing inventions. I am sure that every workshop, every chemical industry, is making inventions. But we do not recognise them. We have no mechanism, and until we institute proper mechanisms and upgrade our systems for recognising and valuing industrial property rights, we will continue to degrade the very important developments we are making.

We must also recognise that industrial innovations are capital, not only in a loose way, but capital in the investment sense, because they can be sold again and again without the loss of their substance. Having learnt to buy a great deal of technology at a tremendous cost, we must learn to sell our technology. I also believe that this will have an indirect salutary effect. It will produce a degree of confidence in our research and development and in our policy, which will ensure that our industrialists, who often go elsewhere, will look more carefully at our own country and see how best we can use it. Our industry, which is now mature and understands the principles of management and complex organization, involving a variety of functions such as production, engineering, industrial relations, finance and planning, is sophisticated enough to assimilate the uses of science for producing benefits.

To sum up, we have a great deal of strength in our science. We are capable of managing large industrial enterprises of complex nature. The best way in which science and technology can benefit industry is through the institution of "in-house" research and development. We should see that our innovators are recognized through a true understanding of industrial property rights and by promoting the culture of cooperative effort between the scientists and technologists and all others, concerned with this process of innovation. We must see that people who become leaders in this endeavour are adequately rewarded and recognised.

Not only in India but everywhere in the world there is resistance to change. Those who attempt change and succeed in introducing change deserve recognition and support. Both as a scientific society and as a general society, we must institute systems, by which we truly pay respect to those who effect these changes.

It was Jawaharlal Nehru who had the vision to create great institutions in science and to initiate great developments in industry in this country and to bring these together to function with greater strength and understanding in order that we may emerge quickly as a nation, capable of producing goods and services relevant not to other countries in the past, but to our own needs in India today. We hope that some of the new paths we chalk out in the near future may be worthy of emulation by other nations. Our success in combining science and industry would depend on how far we would experiment with and introduce new philosophies to bring out the existing potential in our scientists for the development of our industry.

V.S. KRISHNASWAMY

DEVELOPMENT OF NATURAL RESOURCES OF INDIA AFTER INDEPENDENCE

Any discussion of the development of India's natural resources during the last quarter of a century raises at least five questions. What was our heritage of resources at the time of independence? How far has this heritage been added to through the application of science and technology? How far has the country benefited from their utilisation? How does the Indian performance compare with the other countries of Asia and Africa? And, finally, what have been the difficulties in the way of speedier achievement of objectives in this field as outlined in the five year plans?

Jawaharlal Nehru's conviction was that science and technology could be the only effective tools for transformation of a backward nation like India into a progressive one. I recall an incident which gave me an inkling of his great interest in science and its application. In the summer of 1948, when he visited the site of the Hirakud project in Orissa, I was asked to organize an exhibition portraying the contribution of geology to the investigation and the design of this great multi-purpose project comprising the longest dam in the world. Consequently, the role of geology was sought to be explained by presenting, in a petrological microscope, thin sections of rocks displaying the characters that helped in the choice of the right type of aggregate for concrete. I tried to explain these thin sections but the crowd of people that had followed Nehru, hid the natural light falling on the mirror of the microscope. When this difficulty was pointed out to the Prime Minister, he said that this did not really matter: he quietly turned the mirror away from the direction of the crowd, and with great familiarity and ease, handled the focusing adjustments of the microscope and studied, with sustained interest, the fascinating colours and textures that a chip of rock is capable of showing when viewed in transmitted polarised light and when it has been ground thinner than thin paper. Later, when I took him round the display of drill cores of foundation rocks, as laid down on the ground on long asbestos sheets, and the crowd was following him like the enchanted rats in the Hans Christian Anderson story of the "Pied Piper of Hamelin," K.N. Katju, the then Governor of Orissa, who was following Nehru, suggested that instead of going round, he could cross over the asbestos sheets and thus save time. Nehru declined to do so: he said that if he were to do this, the entire crowd following him, would do likewise, and thus spoil the beautiful specimens that had been so painstakingly arranged for him.

II

In this paper I shall try to refer to only those natural resources that are derived from the earth and are largely related to the lithosphere. Hence resources of land and sea, that require biological inputs, like agriculture, forestry and fisheries have been omitted from this purview. The compass of resources presented will essentially be that of an earth scientist's, and, therefore, I would be dealing only with the mineral resources, water resources (both surface and underground) and energy resources, like hydro-power, thermal power and geothermal power. As a matter of collateral interest in this review, brief attention will be paid to other energy resources like solar power and tidal power.

The mineral resources of a country constitute the bed-rock on which the super-structure of a sound economy can be built. After the attainment of independence, it was essential, therefore, to establish the extent of this bed-rock and to prove its strong and weak spots. In other words, the extent of our mineral resources for national development had to be outlined, and the sectoral resources, in which we were having abundance and in which we were deficient, had to be identified. In this task, the operations of the national resource survey and evaluation agencies, like the Geological Survey of India, the Indian Bureau of Mines, the Oil and Natural Gas Commission and the Atomic Mineral Divisions of the Atomic Energy Commission (A.E.C.), besides the national laboratories entrusted with the task of mineral benefiation, treatment and better utilisation, played a notable part.

In 1947, we had iron ores in abundance (total reserves being 21 billion tonnes and one-fourth of the total world reserves) ; coal (22 billion tonnes of all grades down to a depth of 300 metres); manganese (100 million tonnes of all grades and occupying second or third position in world production) and large reserves of ilmenite in the beach sands of Kerala, and mica. In fact, during the last quarter of a century, these mineral resources have contributed to a major share of our mineral production and export. In 1948, for example, these five minerals contributed as much as 97 per cent of our mineral production. The total value of our mineral production was worth Rs. 64 crores and the value of our exports of all minerals—in eleven major minerals—was Rs. 15 crores or roughly 25 per cent of the total value of mineral products. We were very deficient in reserves of minerals for base-metals (copper, lead, zinc and aluminium) and the reserves of these minerals in the early years after independence, were around three million tons of copper ores, two million tons of lead-zinc ores and some 30 million tons of aluminium ores. We were also very deficient in fertiliser minerals like rock-phosphate, apatite and pyrite (for extraction of sulphur). The only deposits of apatite measuring up to roughly one million tonnes, partly as mineral and partly as phosphatic nodules, were known. In the case of strategic minerals, like molybdenum and tin, we were totally deficient. In case of energy resource minerals like oil, we had only two Assam oil fields at Digboi and Badarpur, which were producing in 1947, approximately 230,000 tons of oil per annum (five per cent of our requirement); no gas fields were in utilisation at that time. Other energy resource minerals, like uranium, were little known or assessed, although we had abundant resources of thorium on the beach sands of Kerala.

Twenty-five years later, the picture is different. In regard to ferrous mineral resources, our total iron ore reserves are assessed now at 29 billion tonnes, of which the proved and indicated reserves of hematite and magnatite ores have gone up from six billion tons to ten billion tons. Much of our endeavour in proving iron ore reserves by detailed drilling and by other exploratory methods has been sparked off by the need to feed the four new steel plants that have been established and the three that have been proposed as also to feed the export trade. Regarding other ferrous minerals, we have improved our reserves of chromite ten times, to nearly 14 million tons; and we have discovered new deposits of nickel ore at Sukinda in Orissa, with about 15 million tons of ore, in which we had practically no reserve in 1947.

In regard to base-metal mineral resources, we have, through persistent efforts, discovered new fields in Rajasthan (Khetri and Rajpur-Dariba); in Madhya Pradesh (Malanchkhand); in Andhra Pradesh (Agnikundala) and in Tamilnadu (Mamandur) besides proving the indicated reserves of the Singhbhum copper belt, the only one that was known and was producing in 1948. Our total reserves of base-metal minerals now stand at 246 million tons of copper ores: nearly eighty-fold increase in our resource position since 1948; 100 million tons of lead-zinc ores, a nearly fifty times increase and around 230 million tonnes of aluminium ores (with 142 million tons of measured ore), again, a roughly 100 times growth as compared to our reserve position in 1948.

In regard to fuel and energy resource minerals, our total reserves of coal and lignite stand at 80 billion tons up to a depth of 600 metres, as against one-fourth of this quantity as assessed upto a depth of 300 metres in the early years. Our stock of good coking coal, not requiring blending, have gone up from two billion tons to six billion tons. Our coal fields now number 80, as compared to some 31 fields as was known in 1948 and cover about 1.5 per cent of the total area of our country. We have discovered some new coal fields, such as the Barjora coal field in West Bengal; proved many new coal seams in existing coal fields of which special mention must be made of the Geological Survey of India discovery of 140 metres thick Jhingurda seam in the Singrauli coal-field of Madhya Pradesh—Uttar Pradesh belt which is the second thickest seam known in the world; and have proved further extensions of the existing coal fields.

In the case of energy resource minerals, India is beginning to occupy a significant place in the oil map of the world. The work of the Oil and Natural Gas Commission has resulted in the location of 26 sedimentary basins in the country, which can be considered as prospective sources of oil—these basins spread over an aggregate area which is one-third of the land area of India. The Oil and Natural Gas Commission has done commendable work in vigorously pursuing efforts aimed at oil exploration, and till now, seven of the twenty-six sedimentary basins have been covered by exploratory drilling, the two of them, viz., the Upper Assam and Cambay basins, understandably, accounting for a major share of this exploratory endeavour. The earlier discovery of the Cambay oil field (guided by the preceding geophysical surveys as carried out by the Geological Survey of India) and the more recent discovery of favourable prospects for encountering deposits of oil off-shore, are important developments. With twenty-six oil fields and six gas fields located now, India's oil reserves are assessed around 130 million tons and the gas reserves at around 60 billion cubic metres. These reserves are 500 times more than the reserves as known in 1948.

In regard to uranium ore deposits, it has been estimated that the resources proved in the last twenty-five years are around 25 million tons with the uranium oxide content of 15 thousand tons. Other than the Singhbhum and Khetri copper fields, the new fields of uranium ores that have been located are in the Kulu area of Himachal Pradesh and in the Siwalik foothills.

In the field of fertiliser minerals, in which we were very deficient earlier, we have located and proved new deposits in Mussoorie, Uttar Pradesh and Birmania, Maton and Jhamar Kotra in Rajasthan, the last two mentioned deposits being the rarely known ones of pre-Cambrian age, having high grade rock phosphate. The total reserves of fertiliser minerals are now estimated to be around 75 million tonnes, including all the deposits mentioned above, of which 25 million tonnes can be taken to be of the indicated and measured category.

In the case of pyrite and pyrohotite, our reserves have gone up from just one million tons, as assessed in1955, to around 50 million tons in 1973, the new find being at Saladipura in Rajasthan. Regarding gypsum, used in the fertiliser and cement industry, extensive deposits, aggregating nearly 1000 million tons have been located in the country now, of which nearly 83 per cent is located in Nagaur in Rajasthan.

We had no known deposits of potash in 1948. Intensive search for this valuable fertiliser mineral was taken up during the last seven years and prospective sedimentary basins in Rajasthan are under exploration. In 1973, as part of the Puga Multi-purpose Project for Area Development of Ladakh, potash-rich brine had been located in a desiccating lake there. This find is of great importance, and further efforts are being planned, with a view to probing deeper into the origin of potash in the brine and to establish whether or not deposits of potash do really exist at depth. It is too early, however, to come to a conclusion, and we have to wait, our fingers crossed, until scientific investigations in the coming year or two either establish or disprove the existence of sizeable deposits of this valuable mineral in India.

It will be apparent from the foregoing review that we have substantially added to our heritage of mineral resources in the first quarter of the century after the attainment of independence. Even taking into account the assets we have created in the case of a few categories of minerals mentioned above, and extending oil and uranium minerals the addition is to the tune of Rs. 3200 billion (using 1969 rates) as against nine billion rupees, which was the value of these ore reserves as available to us at the time of independence. This is an achievement which speaks for the effort of the earth scientists of the country, working in the various national survey and research organizations.

III

It will now be appropriate to review the manner in which we have utilised our mineral resources—these wasting assets—for development of our country. In 1972, half of the value of our mineral production was derived from exports, as compared to one-fourth in 1948. However, in 1972, we were also obliged to spend an amount equal to that gained from exports, towards the import of minerals, particularly oil and non-ferrous metals. There are, therefore, major gaps in our mineral assessment and production.

As regards coal, a review of the targets of production versus actual performance over the four five-year-plan-periods, indicates that although we did fairly well in the first two plan periods, we were not able to put in adequate productive endeavour during the third and fourth plans; the effect of this backlog is telling on our economy at the present time. However, with the more dynamic approach in the matter of increased production, and more particularly, in speedy and effective transportation of coal, using even our waterways, we should be able to turn the corner in this critical field of our developmental activity.

On the credit side of the utilisation of our mineral assets, are the establishment of four new steel plants at Bokaro, Durgapur, Rourkela and Bhilai, utilising our vast iron ore reserves; the proposed additional steel plants at Vishakhapatnam, Hospet and Salem during the future plan periods; the endeavours being made for the establishment of the Koyna and Korba aluminium plants, to utilise our bauxite reserves; the steps taken to initiate early production of copper, utilising the ores discovered at Khetri, Agnikundala, Rakha and Malanchkhand; the establishment of zinc smelters at Udaipur and near Dhanbad; the commissioning of several oil refineries to utilise our indigenous oil production besides the imported crude; and the establishment of a number of coal washeries to improve the extent of utilisation of our coal deposits.

It may be useful to compare India's efforts at utilisation of mineral wealth with those of other developing nations of Asia and the Far East. A comparison of production of non-ferrous and ferrous minerals, coal and oil indicates that but for the performance of Japan and China, our endeavours are comparable with those of other developing nations in Asia and the Far East. The comparison of coal production between China and India is unflattering to us. Thus, while both the countries started off on the same footing in 1948, China produced 200 million tonnes of coal, while we are still struggling to reach the production target of 165 million tonnes at the end of the fifth five year plan.

This takes us on to the last aspect of mineral resources of the country, *viz.*, the directions in which we should proceed in future, gaining from our experience of the last quarter of a century. Basically, as K.D. Malaviya has aptly put it, in a recent article on "Fuelling India's Future," there should be "a restless dedication to the cause of production."

There also seems to be ample scope for cutting the enormous time-lag between the discovery and initial proving of a mineral deposit as a prospect worthy of sustained developmental endeavour through the detailed investigation until the stage of actual exploitation of mineral production is reached. In some of the developed countries, this "lead-time" is as low as five to seven years. We seem to take twice as long. It would be worthwhile to attempt a scientific analysis of the "lead-time" for various types of mineral deposits (bedded type, replacement type, vein type etc.), taking into account relevant conditions and constraints, including organizational and structural patterns. This analysis may help us to identify the bottlenecks which have plagued us in the past.

In the field of development of earth science it is not often realised that mineral production of today is the result of mineral exploration endeavour of yesterday, and likewise, for increased mineral production and industrial development of tomorrow, there should be no slackening of efforts in the provision of funds for such efforts by our national survey and research agencies today. The efforts of these agencies have resulted in the addition of mineral assets of the country excluding oil and atomic minerals to the tune of 3200 billion rupees. The investments in the developmental activities of these agencies in the five year plans, now constitute a very, very small percentage of investment. Nevertheless, the benefit gained is appreciable, and with larger inputs we may be able to reap an ample harvest of mineral production tomorrow.

IV

India, with one-fifth of the world's irrigated area, occupies a leading position in the world in the field of irrigation. In the 1950s, when we launched upon an era of planned development, the foremost requirement was the rebuilding of the agricultural economy of the country with large-scale inputs in the field of irrigation, especially because seventy-five per cent of our population lives on agriculture and fifty per cent of our national income is derived from this source.

The total water resources of India are estimated at 1675 billion cubic metres (1356 million acre feet) of which the utilisable water resources have been put at 550 billion cubic metres (450 million acre feet), or roughly, 40 per cent of our total water resources. Since 1947 we have used 205 billion cubic metres or roughly 45 per cent towards created irrigation potential and for power generation, flood control etc.

It would be pertinent here to examine the manner in which we have utilised, for irrigation, the 40 per cent of the assets that nature has given us in the shape of utilisable water resources. Of India's total land area of 327 MHA, only 55 per cent i.e. 181 MHA is cultivable. Again only 25 per cent of the total land area i.e. 82 MHA (which is 45 per cent of the cultivable area) is irrigable.

In 1951, at the commencement of the first five year plan, we had only 9.76 MHA with assured irrigation supplies. This went up by 21 per cent to 12.2 MHA in 1956 at the end of first five year plan; by 15 per cent of first plan potential to 14.3 MHA in 1961 (second plan); by 13 per cent of second plan potential to 16.5 MHA in 1966 (third plan); by 11 per cent of the third plan potential to give rise to 18.6 1969 (end of the annual plans). In 1973, we had been able to raise the potential at the end of the annual plans to give a figure of 20.3 MHA. Thus, although in twenty-two years of planned development, we have added a total of 10.6 MHA to the then existing irrigation potential (9.76 MHA), which is about 108 per cent and our growth rate in regard to irrigation potential is 0.8 MHA per year which is one of the highest growth rates in the world, yet it would seem that the actual performance in increasing the potential every five years has been progressively less and less. On the contrary, the population of India, in twenty years from 1951, went up from 360 to 548 millions. Clearly, we have not been able to add irrigation facilities sufficiently fast to keep up pace with our growing population needs. Even more disappointing is the fact that the utilisation of the proved irrigation potential that has been created has not kept pace with availability of the potential. Thus, in 1973 only 82 per cent of the potential created in twenty years had been utilised.

On the credit side of utilisation of water resources, it must be conceded that out of the 600 major and medium irrigation projects, that were taken up since 1951, we completed, till 1973, 360 projects, or, roughly about 60 per cent of what we sought to achieve. The progress in completion of the irrigation projects could have been better, though it must be acknowledged that the results in the field of design and construction of major and difficult projects in the Himalayan terrain e.g. Bhakra-Nangal and Beas Dams have been laudable. The total outlay on major and medium irrigation projects was significant: Rs. 2670 crores during the years 1951-73.

As in the case of our mineral resources, there has been a considerable time-lag between preliminary investigations and the sanction of the irrigation projects, their actual completion and actual utilisation of the benefits created thereby. Several constraints, such as shortage of foreign exchange, equipment and construction materials, came in the way. To the extent we are able to reduce these constraints in future we would be cutting down the "lead time" of our projects. The late S.K. Jain, who was Chairman of the Central Water and Power Commission, used to tell me that the period of construction of a major project in India is the square root of the cost of the project. I have applied the rule of thumb in a number of cases, and found it to be generally correct. Can we reduce the "lead time" to the cube root or 4th power of the cost of the project? If we could do so, we would be enormously accelerating the pace of progress in the utilisation of our water resources.

In the case of the minor irrigation projects (costing between rupees 25 and 30 lakhs) we had created an irrigation potential of 6.4 MHA in 1951 by utilising surface water resources. In twenty-two years of developmental activities in this direction, we have roughly doubled the irrigation potential (12 MHA) which accounts for one-fourth of the total irrigation potential of 40 MHA created by all categories of irrigation projects, namely, major, medium, minor and ground-water. The potential created by minor irrigation projects is about half that of 20 MHA created by the major and medium irrigation projects put together. In view of the considerably smaller financial outlay, and the shorter time required for completion of minor projects, relatively greater emphasis, on minor irrigation would seem to be desirable.

The net irrigation potential that can be created from surface water resources, through major, medium and minor irrigation projects (including ground-water) have been assessed at 60 MHA out of 82 MHA of irrigable area we possess. In the first twenty years, independent India has utilised all surface water resources to create an irrigation potential covering 32 MHA (20 through major and medium and 12 through minor irrigation projects). Hence, we have still roughly 50 per cent of the total irrigable area to be developed with our surface water resources, by means of future irrigation projects.

V

Although some prognastic computations of probable annual ground-water recharge from rainfall and run-off figures were put forward by A.K. Khosla in 1949, no comprehensive and detailed estimate of total ground-water resources and annual replenishment thereof, utilising direct evidence and other available methods of ground-water evaluation has been made. The third five year plan document, relying upon indirect evidence, put the annual replenishment to ground-water reserve from rainfall recharge to the 300 MAF. A recent first approximation appraisal (1969) by K.V. Raghava Rao and Ramesan of Central Ground Water Board has placed the net annual ground-water recharge at around 220 MAF, out of gross annual recharge of 300 MAF; the difference being owing to allowances for unfluent seepage, evapotransportation losses, losses in desert areas etc. Out of this net annual recharge, the annual ground-water draft for irrigation and industrial and public health uses has been placed at 90 MAF, thereby, having a balance of 130

MAF, which should be sufficient to cater to future additional irrigation of at least 16 MHA from ground-water resources.

Upto 1973, the total irrigation potential created from ground-water resources has been estimated at 12 MHA. Hence, our ground-water resources, as estimated, can serve our needs for another twenty-five to thirty years. However, the present estimate of ground-water resource is not claimed to be comprehensive or complete in all aspects, and has rightly been termed as "first approximation." It is possible that after we complete systematic studies of the ground-water resources of the country, by detailed basin-wise analysis and through water balance evaluations for each of these basins, we may be able to arrive at an estimate of usable ground-water potential for future irrigation and developmental needs, for a period much longer than twenty-five to thrity years, as indicated above.

Ground-water, is, in fact, nature's greatest gift to India in the Indo-Gangetic and coastal alluvial and deltaic tracts, besides the large area encompassed by inland sedimentary basins; intermontane deposits and suitable, fractured or weathered zones in hard rock terrain. With the creation of the Central Ground Water Board and its direct association with the Ministry of Agriculture (and now with Irrigation as well) it is expected that this natural resource will soon be completely assessed. Air-borne survey data should be advantageous in delineating the extent of the prospective zones of ground-water accumulation.

A comparison of Indian performance in water resource utilisation with that of the ECAFE countries indicates that in 1963 India led the 16 ECAFE countries in the total irrigated area, followed by Pakistan, Japan, Iran and Thailand. Information relating to 1973 was not readily available at the time this paper was written (Table 1).

If one were to review the expenditure on water resources development in the countries of the ECAFE region, the following information can be quoted for twelve countries, the data analysed relates to the periods as indicated (Table 2).

It will be seen from the above that India stands sixth on the list of twelve ECAFE countries from the point of view of percentage expenditure on the water resource development in terms of total expenditure on economic development; while, in terms of per capita expenditure, in view of our large population, we stand eighth amongst the twelve countries of the ECAFE, Japan, leading the list.

Table 1[1]

Country	*Irrigated area as percentage of arable land 1963*		*Irrigated area 1963 10^3 ha*	*Position as per Irrigated area*
Australia	3		969	VI
Burma	4		555	XI
Cambodia	2		62	XV
Ceylon	21		324	XII
China (Taiwan)	72		624	IX
India	15		24,766	I
Iran	14		2,300	IV
Japan	53		3,229	III
Korea, Rep. of,	31		657	VIII
Malaysia:			243	
Malaya	9	225		
Babah	7	12		XIII
Barawak	0	6		
Nepal	1		52	XVI
New Zealand	11		81	XIV
Pakistan	38		10,761	II
Philippines	8		937	VII
Thailand	17		1,667	V
Vietnam, Rep. of,	6		613	X
Total			47,840	

[1] *Review of the Water Resources Development in the ECAFE Region 1953/63* (E/CN, 11/WRD/Conf.7/L.6).

VI

Nearly sixty per cent of our water resources are derived from the Himalayan rivers, while forty per cent are contributed by the peninsular rivers. The Himalayas, though largely devoid of mineral resources (so far as it is known today), have provided a great potential for power development. The first hydro-electric survey conducted in 1919 estimated the potential of our river systems for power development at only 3.5 MKW. However, the detailed hydro-electric survey carried out from 1953 to 1958 by the Central Water and Power Commission placed the hydel power resources at 41.14 MKW at 60 per cent load factor, which was distributed as given in Table 3.

Table 2[1]

Country	*Average annual expen-diture on economic develop-ment plan (million US $)*	*Average annual expen-diture on water resources develop-ment (million US $)*	*Percentage of water resources develop-ment expenditure*	*Annual expen-diture on water resources develop-ment per capita (US $)*
Afghanistan	194 (1962-67)	58.5 (1962-67)	27.00	3.6
Burma	121.6 (1963)	17.7 (1965)	14.6	0.8
Ceylon	209 (1963)	19.4 (1968)	9.3	1.8
China	366 (1963)	31.6 (1963)	9.4	2.7
India	4,370 (1961-65)	545.0 (1961-65)	12.5	1.2
Korea, Rep. of,	495 (1962-66)	43.7 (1962-66)	8.8	1.6
Japan	—	1,200 (1963)	—	12.5
Malaysia	171.0 (1961-65)	29.4 (1961-65)	17.2	4.0
Singapore	60.2 (1963)	6.3 (1963)	10.5	3.6
Nepal	29.4 (1962-65)	5.2 (1962-65)	17.7	0.5
Pakistan	246 (1960-62)	107 (1960-62)	43.5	1.1
Thailand	250 (1963)	65.7 (1963)	26.5	2.3

[1]*Proceedings of the Sixth Regional Conference on Water Resources Development in Asia and Far East* (Water Resources series, No. 28, p. 30)

Table 3: Hydro-power potential of India

River Basin	*Hydro-electric power potential in MW at 60% load factor*	
Ganga	4828.7	4.9 MKW
Brahmaputra	12486.4	12.5 ,,
Indus	6582.0	6.5 ,,
West flowing rivers of South India	4345.5	4.3 ,,
East flowing rivers of South India	8629.9	8.6 ,,
Central Indian rivers	4287.0	4.3 ,,
	41155.00	41.1 ,,

Even the above survey cannot be considered to be a complete assessment of our water resources for power development; because, when this hydro-electric resource survey was done, adequate topographical and hydrological data were not available for the upper reaches of the Himalayan rivers. Thus, for example, recent detailed studies of Himalayan river basins in Himachal Pradesh have enhanced the power potential to 8 MKW, from 2.91 MKW, as was estimated during 1953-58.

Even if we take into account only continuous sources for perennial (as distinct from seasonal) supply of hydro-electric power, India's potential, distributed region-wise, is as follows:

Table 4 : Region-wise hydro-power potential

Region	*Total Potential*	*Potential developed or under development*	*Percentage of total development in Region*
Northern	6349 MKW	1470 MKW	23%
Western	4301 ,,	564 ,,	13%
Southern	4858 ,,	1932 ,,	40%
Eastern	1616 ,,	344 ,,	21%
North-Eastern	7479 ,,	22 ,,	Less than ½%
Total	24603 ,,	4334 ,,	18%

The percentage of total utilisation of our water resources for power for the whole of India indicates that we have as much as 82 per cent of our resources lying still unutilised. The southern region has utilised the maximum of 40 per cent of the power potential; the north-eastern region seems to have utilised the lowest potential of 0.5 per cent.

In examining the question further on the manner in which we have utilised our hydro-electric power resources, we had just 1.27 MKW of installed capacity in 1947. This was because of a stagnant economy under foreign rule with limited industrial and agricultural expansion and restricted demands for supply of power to some of the urban areas. When we started on planned development in 1951, the total installed capacity was 2.3 MKW. The following table portrays how we have progressed in the matter of utilisation of our power resources since 1951, when we embarked on planned economic development.

Table 5

Progress in utilisation of power resources

Plan	*Period in years*	*Targetted installed capacity*	*Achievement of Target in MKW*	*Percentage of shortfall in target*	*Percentage of increase in installed capacity over previous plan period*	*Total installed capacity in hydro MKW*	*Percentage of hydro to total installed capacity*
Pre-Plan	1951	2.3	—	—	—	0.51	25
I Plan	1951-56	3.6	3.42	5	50	0.94	25
II Plan	1956-61	6.9	5.65	20	62	1.92	39
III Plan	1961-66	12.7	10.17	12	60	4.10	40
Annual Plans	1966-69	No target	14.30	—	40	5.90	41
IV Plan	1969-74	19.37	18.90 (anticipated)	2	32	7.22	40
V Plan	1974-79	35.40	—	—	87	13.62	39

A perusal of the performance data presented above will indicate that although we have increased the installed power capacity over a period of twenty-three years, by nearly 8.5 times, our net additions to the preceding periods of achievement have generally remained at less than 50 per cent except during the second and third plan periods. It would also be seen that our short-falls in the targets have been low (less than 5 per cent) except for the second and third plan periods during which the short-falls were of the order of 10 to 20 per cent. In view of our past performance, it will require a Herculean effort to be able to increase our output of power from 18.90 MKW to 35-40 MKW i.e. by nearly 87 per cent in the fifth plan period, as has been proposed.

As in the case of mineral resources and water resources for irrigation, the gestation period for hydro-electric power projects has been very long. The reasons generally ascribed to such long gestation periods are: non-availability of foreign exchange, equipment and material, and lack of thorough and extensive field investigations in the pre-construction stage, which led to inadequate design necessitating modifications while the work was in progress. If one were to state the view-point of an earth scientist associated with these projects for resource development, in many cases, it would seem that in the anxiety to push a project through to the level of governmental sanction, the requisite geological and other investigations are not completed. The result is that, quite apart from the unavoidable surprises that nature has always in store, even with the best possible and extensive investigations, particularly in the Himalayan terrain, there have been avoidable surprises, which have led to extended construction time and increase in project cost. Remedial measures have been undertaken in this connection and a number of projects have been included for detailed investigations with the help of equipment obtained under U.N. Special Fund Scheme. It is also hoped that with the increasing collaboration of geo-scientists in the phases of preliminary investigation, design and detailed investigation of the power projects, it would be possible to cut down the gestation period of these projects at least in future.

In 1970, A.G. Jhingran made a comparison between the performance of India and some countries of the ECAFE region. The following figures have been taken from his lecture entitled "Some Thoughts on Energy Challenge."

Table 6[1] : Country-wise figures for hydel power in 1970

		Installed capacity Million KW	*Energy generated Million KWH*	*Potential Million KW*
Developed Countries	Australia	3.784	10.124	9.765 (a)
	Japan	19.993	30.090	38.013
	New Zealand	3.075	11.266	15.000 (b)
Developing Countries	Afghanistan	0.185	0.321	20.000 (c)
	India	6.390	25.293	41.156 (d)
	Iran	0.517	1.671	1.700 (e)
	Pakistan	0.666	2.914	10.400
	Republic of Korea	0.329	1.221	2.174 (f)

(*a*) Mainly based on the average flow of rivers at various load factors.

(*b*) Maximum economical output based on mean flow.

(*c*) Economic potential at 60 per cent load factor.

(*d*) Based on firm proposals for power development for each river basin and corresponding to 95 per cent availability. Data represent economic limit of power potential under prevailing conditions.

(*e*) Average flow.

(*f*) Economic potential at 40 per cent load factor.

[1]ECAFE document E/CN-11/NP/Conf. (1) ICEC/L. 5, 1974.

It will be seen that India is far ahead of other developing countries in the eastern hemisphere in the field of hydro-power generation and comes second only to Japan, which, however, had an installed capacity three times that of India for a country much smaller in size and having much smaller population. Jhingran concluded that "all that is needed is a more energetic drive and faithful effort for accelerating the tempo of work in this field of power generation."

Utilising Jhingran's data again, it is seen that in regard to present utilisation of hydro-power resources, Japan heads with 50 per cent, Australia 40 per cent; Iran 30 per cent and India takes the fourth place with 16 per cent utilisation of resources in terms of potential, which would indicate that we still have a long way to go in regard to full utilisation of our hydro-power resources.

VII

Because of our substantial steam-coal reserves, we should have had no major difficulty in increasing thermal power production, though other factors such as design and availability of equipment, foreign exchange, transportation etc. have also to be taken into account. The thermal power capacity in India increased from 2.48 MKW at the end of the first plan to 3.73 MKW (increase of 50 per cent) at the end of the second plan; to 6.04 MKW (increase of 62 per cent) at the end of the third plan; to 8.11 MKW (increase of 34 per cent); at the end of the annual plans to 10.74 MKW in 1974—at the end of the fourth plan (increase of 32 per cent). Obviously, we started off very well with incremental capacity at the end of the second and third five year plans, but our performance did not measure upto our growing requirements. This became evident in the power crisis we faced in 1973-74.

The percentage share of thermal power in the total installed power capacity in the country has also steadily dropped from 72 per cent in 1956 to 66 per cent in 1961, to 59 per cent in 1966, to 56 per cent in 1969 and to 54 per cent in 1973. The downward trend in incremental capacity created in the last eight years is disconcerting, but with the new proposals for super-thermal plants and with other measures for maximum utilisation of thermal energy through increased unit sizes and other technologies, it should be possible to reverse this trend.

VIII

The late Homi Bhabha stated, thirty years ago, with great foresight that "when nuclear energy has been successfully applied for power production, in say, couple of decades from now, India will not have to look abroad for its experts but will find them ready at hand." The Government of India, in the resolution for creation of the Atomic Energy Commission, stated that "India should be able to produce all the basic materials required for the utilisation of atomic energy and build a series of atomic power stations which will contribute increasingly to the production of electric power in the country." Justifying this expectaion, the first nuclear power station at Tarapur started generating power in October 1969, with an installed capacity of 420 MW. Two more nuclear power stations are under construction, namely, the 420 MW station at Kota (partly producing) in Rajasthan; and another station of an equivalent capacity at Kalpakkam near Madras. The first unit of the Rajasthan station is already in operation. The fourth atomic power station is proposed to be built at Narora in U.P., for which site investigations and design studies are in progress. In nuclear power technology, India, in fulfilment of Bhabha's faith, has reached a stage of near-complete reliance on indigenous expertise, which is being reflected in the Kalpakkam and the Narora power stations. Developments in this field are expected to be intensified, so that from 1990 onwards, nuclear power may be in a position to contribute significantly to the total power production.

The available nuclear energy resources of uranium in India are considered adequate to sustain production of 10 MKW in primary power reactors. This is likely to increase by hundred times through the use of secondary, tertiary and breeder type reactors. Thus the ultimate power production from uranium resources may well be twenty-five times the presently known hydro-resource potential of the country. In addition, our thorium reserves are one of the largest in the world and are estimated at 4.5 lakh tons. If we succeed in applying breeder reactor technology, using these thorium reserves, 12 billion KW of installed capacity may become available. This along with power production from primarily uranium reserves, would represent a nuclear energy resource potential nearly two hundred times more than that of our hydro-power potential.

Even if during the next two decades additional hydro-power resources are increased by further work in the upper Himalayan reaches, twenty times the currently established figure of 41 MKW, nuclear energy resources will still be fifteen times more than the probable increase in our hydro-power resources. The crucial role of nuclear energy in developing power potential in the country in future years is thus clear.

Comparing the performance of India with other ECAFE countries, we can really be proud of the leading position we have in this field. Known atomic energy resources are confined to Australia, India and Japan, while data for China are not available. Of these countries, Australia had not started on power production till 1971; and Pakistan has commenced nuclear power generation only after 1971. Japan had 3 per cent of the total electrical energy from nuclear energy resources. With the leading position that India occupies, both in the matter of nuclear energy resources and nuclear technology, and with the band of dedicated scientists we have in this field, India should be able to make increasing use of nuclear power in order to meet the challenge of power supply in the future.

IX

In the field of solar energy, the position today is what it was thirty years ago. In India, the average intensity of solar radiation, as received on the earth, is around 600 calories per sq. cm. per day, which corresponds to about 10 billion KW hours per sq. km. per year, and is nearly 5,000 times the present total energy consumed in the country. The possibilities seem to be enormous, but the problems of tapping so plentiful a source of energy are its intermittent and variable nature and the need to store the energy, whenever it is available. Also, unlike other conventional sources of energy, solar energy needs no transportation, but has to be used at the place where it is available.

In India, low-grade thermal devices, such as solar water heaters have been tried, but not with much success. Australia has made considerable research in this field. The next stage of utilisation of this resource is by direct energy-conversion devices, utilising photo-voltaic effects. Technology in this field in India has not reached the stage where such devices can be used economically. Proposals for research in utilisation of solar energy are under the consideration of the Department of Science and Technology and a "breakthrough" may reasonably be expected during the next decade.

The potential in tidal energy is generally assessed by analysing tidal data. Wherever the tidal range exceeds 5 metres, electric power generation is theoretically possible. France, U.S.A., Canada, U.K. and Argentina are countries where tidal energy is being harnessed for power generation. Some tidal power stations are also reported in the U.S.S.R. and China. The world's first large-scale tidal power station with an installed capacity of 240 MW was constructed in 1964-67 at Rance on the Brittany coast of France.

In India, the Gulf of Cambay, the Gulf of Kutch and the Sundarbans are promising areas for tidal power. The total range in the Gulf of Cambay is from 8.5 to 10 metres; and around 5 metres in the Sundarbans. The size of a power station that can be conceived in the Sundarbans is assessed at only 150 KW; while in the Gulf of Cambay (near Bhavnagar) a 30 MW capacity plant, using tidal power, has been considered feasible. There are several hurdles in the way of developing this form of energy. These include technological know-how in the country and the high initial cost of a tidal power station, which is six times that of a thermal and three times that of a hydel power station of equal output.

Etymologically, the term geo-thermal energy connotes the heat of the earth. Geo-thermal energy is basically the energy that is related to the heat content of the earth's crust, and could be defined as energy that is contained in or extracted from all sources of sub-surface natural heat up to a depth, not exceeding the limit of economic exploitation and which could be used for practical purposes.

The surface manifestations of geo-thermal energy are geysers, fumaroles, hot springs, volcanos etc. In 1965, I wrote a paper analysing the availability of this energy resource in India and suggested further exploration. In 1968, a Hot Springs Committee, of which I was a member, analysed some 250 hot springs of India and grouped them into five prospective belts, on the basis of their temperature, structural and geological associations and their likely potential. These belts are the North-West Himalayan belt; the West Coast belt, extending through Maharashtra-Gujarat; and the Central Indian belt, covering the Narmada-Tapti down-faulted valley; the East Indian belt covering parts of the states of Bihar, Bengal and Orissa, and the South Indian belt, with isolated sections covering parts of the Godavari valley and other areas. Priority in exploration of geo-thermal resources was given to the Puga geo-thermal field in

Ladakh, and the Manikaran geo-thermal field in Himachal Pradesh, both in the North-West Himalayan belt.

Following the recommendations of the Hot Springs Committee, the National Committee on Science and Technology had reinforced the above recommendations in 1972, and suggested a plan of action. In 1973 the Geological Survey of India formulated a Multi-purpose Area Development Project in the Puga Valley of Ladakh and drilled ten wells to a depth of 130 metres maximum. Six of these wells produced about 80 tons of steam per hour, with temperatures of 130°C and pressures of around five kg per square centimetre. These results were considered promising and, there is a proposal to instal one megawatt experimental geo-thermal power station, for studying the operational and design problems. Further work to evaluate the geo-thermal reserves of this field is in progress. In the Manikaran and Sohna geo-thermal fields of Himachal Pradesh and Haryana respectively, preliminary drilling to assess the geo-thermal gradients has also been taken up by the Geological Survey of India. So far no spectacular results have been attained.

Geo-chemical analyses of the hot springs in the various belts have indicated temperature of reservoirs in some cases to the tune of 250°C. This is indeed very encouraging, and detailed, systematic, geological, geo-physical, and geo-chemical studies, along with shallow drilling, have been planned for evaluating the extent of the fields and the geo-thermal gradient that can be obtained. It is, not possible with the available data to assess the total quantum of energy that can be obtained from various geo-thermal belts. It is however, desirable that this form of energy resource in our country should be fully explored.

It has been demonstrated that atleast in the case of the Puga valley geo-thermal field, the resources should also be utilised for purification of borax and sulphur, besides space heating. Currently, experiments are underway to demonstrate its utility for hot-house cultivation in winter temperatures going down to-50°C. Successful utilisation of geo-thermal energy has taken place in many countries of the world; notably in Italy, which has been producing power from this source for about fifty years now; it has an installed capacity of 390 MW while New Zealand has an installed capacity of 170 MW. The U.S.A. has also taken vast strides in the utilisation of geo-thermal energy in recent years, and is currently producing 302 MW. In the

ECAFE countries, Japan had an installed capacity of some 45 MW three years ago. Mexico, one of the recent entrants in this field, has about 75 MW capacity.

To sum up, India has been blessed with a variety of natural resources. While we have done fairly well in developing these natural resources during the last quarter of a century, a great deal more remains to be done.

R. RAMANNA

DEVELOPMENT OF NUCLEAR ENERGY IN INDIA: 1947-73

To understand the development of the utilisation of nuclear energy in India, it is useful to recall the organisation of science as it existed in India before independence. Pre-war scientific developments in India were concentrated, not unexpectedly, in the universities. The biggest impact of science in our universities came from Calcutta University and owes its origin to its great Vice-Chancellor, Asutosh Mookerjee. It was owing to his inspiring organisational genius that the country can boast of Raman, Saha and others. However, the structure and organisation of those times was essentially for individual scientists to flourish. Research on a wider scale involving industry and team-work just did not exist, and one can only guess that it was neither encouraged nor looked upon with favour. There was, however, one exception to this: the Indian Institute of Science, Bangalore, but even there the time was not ripe for large-scale technological research. It is, however, good to recall that it was in this institute that H.J. Bhabha,the founder of the Atomic Energy programme in India, did much of his early thinking for a new science structure in the country.

That the organisation of research in universities by itself, as it existed during the pre-war years, was insufficient was realised by a group of scientists working during the war period. Among them were H.J. Bhabha and S.S. Bhatnagar. It was during these years that Bhatnagar dreamt of a chain of national laboratories in various disciplines all over India. At about the same time, Bhabha was planning a centre of excellence in nuclear science at Bombay. He was already aware of the possibilities of the energy contained in the atom and expressed it in his now well-known letter to the then chairman of Dorabji Tata Trust in 1944, in connection with the establishment of Tata Institute of Fundamental Research:

When nuclear energy has been successfully applied for power production, in say, a couple of decades from now, India will not have to look abroad for its experts, but will find them ready at hand.

Real developments in nuclear science can be said to have started with the foundation of the Tata Institute of Fundamental Research (TIFR) with the funds provided by the Trustees of Dorabji Tata Trust. Later, the Bombay government put in its contribution, and finally the central government, which now provides nearly 99 per cent of its recurring budget. This institute started off in a small wing in a flat in Peddar Road, mainly to provide the necessary facilities for Bhabha's own work in cosmic rays and theoretical physics. But with the coming of independence, he clearly saw that the TIFR could provide the base for a nuclear energy programme and that he would have to expand the facilities of the institute to include other branches of physics, and disciplines such as chemistry, biology and engineering. At his instance and with the help of Bhatnagar, the Atomic Energy Commission was formed in August 1948 with the following charter:

(1) To take such steps as may be necessary from time to time to protect the interests of the country in connection with Atomic Energy by exercise of the powers conferred on the Government of India by the provisions of the Atomic Energy Act;

(2) To survey the territories of the Indian Dominion for the location of useful minerals in connection with Atomic Energy; and

(3) To promote research in their own laboratories and to subsidise such research in existing institutions and universities. Special steps will be taken to increase teaching and research facilities in nuclear physics in the Indian universities.

It will be observed that the first priority in the charter was given to the survey of natural resources, particularly materials of interest to the atomic energy programme such as uranium, thorium beryllium, graphite, etc. A special unit, Rare Minerals Division, was set up at Delhi with the help of the late Professor Wadia. The next priority was given to the basic sciences, particularly physics, chemistry and biology, with the purpose of providing facilities for training high quality research scientists. The eventual aim was to set up as early as possible a research reactor. It was realised that this by itself would not be sufficient for a nuclear programme unless there was simultaneously a programme for instrumentation, particularly in electronics. Bhabha clearly realised very early in the programme that no high quality research was possible without good instruments and the very act of their being produced in India was itself progress. It was for this purpose that a unit called the Electronics Production Unit was started in the Tata Institute of Fundamental Research. This production unit formed the nucleus of the large corporation now in Hyderabad known as the Electronics Corporation of India Limited.

To give a feel of the atmosphere of that time, I may be permitted to quote from my reminiscences. Considering that a number of people had been recruited directly from various training centres abroad and some enthusiastic good students from Indian universities, it is not easy to explain what it was that made all the people at that time, work as a team and discuss their problems with one another with absolute freedom. This was certainly different from the atmosphere that existed in other institutions and universities where the tendency was to work in separate compartments. It is possible that good team-work was achieved by Bhabha's quick perception and understanding of various disciplines and by his talking to people in different sections at all levels. He used to make a shrewd assessment and appreciation of each man's work and was able to instil a truly cooperative spirit. Thus the foundation was laid for a multi-disciplinary cooperative work even in the fifties. The spirit and tempo of research was kept up by inviting many distinguished scientists from abroad and India, and the Wednesday colloquia at TIFR were often great intellectual events. The names of Dirac, Pauli and Bohr come to my mind.

While this foundation was being laid for a strong base in pure science and work in electronics instrumentation, there was a clamour all over the scientific circles in the country as to whether this was indeed leading us to one of the aims of the Commission of setting up a small reactor. I recall Bhatnagar bemoaning to Bhabha in London in 1953: "Will I ever see a reactor in India before I die." Our first reactor came into operation in 1956, a year after the death of Bhatnagar.

In order to have a country-wide discussion of our atomic energy programme, particularly about the choice of a reactor, its siting and the difficulties of setting up one indigenously, Prime Minister Nehru called a conference to which distinguished Indian scientists were invited. This was held in Delhi during the winter of 1954 at the Nationl Physical Laboratory. We, who were heading various divisions, were also asked to speak on our subject of specialization. At this conference, I recall the presence of M. N. Saha, S. N. Bose, K.S. Krishnan and several other distinguished physicists, chemists, engineers and industrialists from all parts of India. On that day, one could feel tension in the air. The location of Atomic Energy Establishment at Bombay was being questioned. The choice of the reactor type and the entire programme of developing our atomic energy materials came under criticism. Jawaharlal Nehru carefully listened to all the arguments, particularly to the various proposals on the type of reactor we should try and build by ourselves. With all our youthful enthusiasm, we must have made an impression on him. Certainly Bhabha had the entire discussion under control, but it was Krishnan, who was the last speaker, who clinched the argument in his usual humorous vein by quoting the story of Jacobi and his student. I quote it because the story made a big impression that day:

> Yesterday, I mentioned the instance of a man, a young man, who had joined for research the great Mathematician Jacobi who was the brother of the great Orientalist. The young man had been with him for several months without having started any research work. When the teacher asked him about it, he said 'I have not yet read all the earlier literature on the subject.' Then the Professor turned to him and said, 'Dear man, if your father waited to see all the girls before marrying one, where would you be? I would like you to make a start somewhere. You can get on with the scientific problems and proceed.' I would also say just the same thing. Because the subject involves so many different disciplines, it needs cooperation from all quarters and a certain amount of sympathy is also necessary.

This conference should be considered as one of the most important ones on atomic energy held in India, as it consolidated the scientific opinion in the country in favour of the steps taken by Bhabha towards the fulfilment of our programme. It was also quite clear that Pandit Nehru had given his full support to the programme publicly in the presence of all the scientists, some of whom had been very critical.

Owing to Bhabha's close contacts with European scientists and his influence among leaders of science in Europe, he was in constant touch with technological developments and possibilities abroad. He had managed to have an agreement for cooperation with France long before such agreements existed in this particular field outside the then nuclear countries. It was with the cooperation of France that we learnt a lot about reactor materials, reactor control, neutron physics etc., particularly in regard to natural uranium systems. But all this still had not placed us in a position to build a reactor of our own.

However, sometime in 1954, after one of his fairly frequent tours of Europe, Bhabha came back with the proposition that Sir John Cockroft had offered some enriched uranium fuel elements for building up a "swimming pool" type reactor and that an agreement had been reached on the loan of this fuel. It was, however, to be a challenge in that we had to build the rest of the reactor, which included the civil engineering work, design of the tank, and electronics control systems and prepare for its utilisation entirely by ourselves. This reactor was also to be built in competition with the Lido reactor at Harwell. It is interesting to recall that we went "critical" earlier by a few days than Harwell. Since the whole project was a challenge, everybody looked keyed up, and it was one of those operations which was carried out with a tremendous gusto. The building for the reactor was constructed in less than a year, and because of this hurry it turned out that neither the roof nor the walls were leak proof against the monsoon. The "swimming pool" tank was also built in record time, and by August 1956 the reactor was actually ready for "criticality" trials, the whole operation having lasted just one year.

At the first trial in which Bhabha himself took part, it became difficult to try out various configurations of the uranium fuel in the water because the tank was still new and the water was not sufficiently transparent. Though we worked during the whole of the second night, the reactor just would not go "critical." This was because we had left a very big water gap at the centre, not knowing enough about such neutron multiplying systems. This was realised on the third day and the whole loading operation was re-enacted on the fourth day, and on that fourth afternoon the reactor went "critical". We could now claim that we had a "critical" reactor, the first in Asia, built entirely by ourselves except for the enriched uranium fuel. I also recall that within a few minutes after the reactor became critical, Prime Minister, Jawaharlal Nehru was informed of it over the phone.

I have dealt in some detail with the Apsara "criticality" because it made a tremendous psychological impact on the country in favour of the development of modern technology. Though a lot of equipment for the reactor had been designed and made entirely by ourselves, there were still many who were unwilling to believe that we could ourselves establish a modern technology in the country. The country seemed to be covered in a cloak of "non-self-reliance." Most people seemed to think that everything had to be imported from abroad, whether ideas or equipment.

We realised that to cash in on the success of Apsara we had to take a series of steps to make ourselves not only self-sufficient in quality but in quantity also. Even before the Apsara went into operation, the Indian Rare Earths Ltd. was producing uranium and thorium compounds of high purity. It was decided to build a uranium metal plant immediately; this turned out to be vital in our programme for self-sufficiency.

II

At the Geneva Conference in 1955, Bhabha played a very important role in emphasising the importance of nuclear power for developing countries and of the possibilities of fusion. It was during this conference that a generous offer from Canada was made to us of the gift under the Colombo Plan of a NRX type reactor, a natural uranium and heavy water system.

I recall the heated discussion which Bhabha had with us in Geneva in 1955 on the choice of the NRX type reactor for Trombay. While all of us, including H.N. Sethna, N.B. Prasad, A.S. Rao and myself, were keen on the NRX type reactor, because it was a natural uranium heavy water system and therefore a type which in principle we could fuel ourselves; for some reasons, Bhabha seemed to favour the Dido reactor, an enriched uranium heavy water system, a type which was in operation at Harwell. He may have been influenced by the views of Sir John Cockroft. As a concession, he suggested that we could have both types of reactors. We all impressed upon him that India was not sufficiently advanced at that time in manpower and other industrial facilities to have two high flux research reactors going. Finally, Bhabha agreed. I have referred to these discussions to indicate how decisions were taken by Bhabha and how he was willing to accept suggestions from young colleagues.

With the starting of construction of the NRX reactor, a decision seems to have been taken (in which I was not involved) for setting up a reprocessing plant to process the plutonium produced in the

Cirus reactor. Earlier, a decision had already been taken to produce the fuel necessary for even half of the first charge of the Cirus reactor. At this time, the Canadians were insisting on some sort of safeguards for the fuel that they were going to supply us for this reactor. When it was pointed out that we could probably make the fuel elements ourselves, they wrote warning us that this involved a very difficult metallurgical operation, which had taken them considerable effort, but we were welcome to try and produce it; but in case we failed we could seek their help. From the tone of the letter, it was clear that they feared that we would not be able to make fuel elements of the required quality and expected that we would eventually have to go to them for buying the fuel. As it turned out, the fuel elements produced at Trombay were even better than the Canadian fuel elements. This event was probably the first case in which our own technology established itself in the front rank of world technological developments. Our contributions to basic sciences had long been appreciated in knowledgeable circles, but of sophisticated technology developed independently of foreign help, this was certainly the first major example. Obviously, our metallurgy and radio-metallurgy laboratories must have been some of the best in the world.

No record of the developments of atomic energy in India will be complete without some reference to the problems we had in getting the Cirus reactor "critical." A few days prior to the dedication ceremony, the reactor got into trouble, in the sense that for some unknown reasons the cooling channel of the fuel used to get choked. This, as we discovered later, was owing to bacteria developing because of local conditions in the water at our ambient temperatures. At that time, the Canadians were unable to identify the source of the trouble, and they left the reactor to us and went away. The cause was identified by our biologists and chemists and suitable remedies were undertaken so that the reactor could function at its rated capacity of 40 MW. Since then, except for some minor problems for a very short period, the reactor has worked in an exceedingly satisfactory way. I must, of course, give due credit to the original designers of this type of reactor, the NRX, as well as to many scientists of international repute such as John Cockroft and W. Bennett Lewis.

The setting up of the reprocessing plant at the same time, when Cirus became critical caused some eyebrows to be raised, for it gave India clearly a nuclear option. At the opening ceremony of the plant, Lal Babadur Shastri offered this plant ιo countries of

Southeast Asia for reprocessing their fuel in case this was required. However, this offer so far has not been utilised by any of the countries. It was made clear that the plutonium reprocessed in this plant, would be used for building future types of reactors, particularly fast reactors. The fast breeder reactor using plutonium is now a very important part of our programme.

It was getting clear to us that in our power programme we would be leaning on natural uranium heavy water systems, particularly as a result of experience of Canada's generous offer of that country to share the know-how with us. The Cirus reactor was followed by the Zerlina reactor (1961), which was designed and built to obtain reacter physics information on heavy water moderated natural uranium fuelled reactors. It was built entirely by ourselves.

While the programme of research reactors and its utilisation was forging ahead, decisions were taken to develop all aspects of atomic energy for peaceful purposes. In fact the atomic energy programme in India at that time was designed to act as a spring-board for modernising the scientific effort in the country. An ambitious programme of isotope preparation was prepared and sophisticated laboratories for studies in transuranium chemistry, highly specialised laboratories for physics, particularly neutron physics, various aspects of solid state physics, solid state chemistry, and for the preparation of pure materials were all established. An intensive programme of biological research including genetics, mutation-research, agriculture and medical research was also initiated in a big way. This is by no means a complete list.

During the years 1955-60, while the Apsara reactor was set up and other important facilities were in the process of construction, it can be said that they constituted the "meat" required for setting up of an organisation. Besides this, it was during this period that the real foundation for a proper base in science was established in the country by a proper reorganisation of the administration to make it more responsive to scientific research and the establishment of training programme based on need-orientation to provide for the necessary specified manpower.

III

The administrative set-up for science management as it existed in the country, particularly in the government, was essentially of the law-and-order type inherited from the British days. It was by no means suitable for quick implementation of imaginative decisions on scientific problems. It was also quite insensitive to the requirements of research scientists. It was Bhabha who first examined the existing structure and set in motion a series of reforms. The first and the most important change was the transfer of the secretariat on atomic energy from Delhi to Bombay so that the administrators could be of direct service to the scientist by being on the spot, and did not take decisions at places far removed from the scene of actual work.

That the secretariat is not supreme and the scientists must have the final say was another innovation. For this purpose, the Trombay Council and the Trombay Scientific Committee, though they had different names at that time, were formed. The joint decisions taken by the scientists were then passed on for action to the administrators whose business it was to see that they were implemented. If, however, the decisions could not be taken within the existing framework, studies were carried out as to how that framework should be altered. After all, there was nothing so sacred about the existing framework that it could not be altered. This was an important new concept which seemed to shock the administration of those days. Unfortunately, even now the attitude, that the old rules are unchangeable and everlasting, persists and a quick implementation of any programme requires much juggling to overcome man-made constraints. I am afraid that the right administrative atmosphere still eludes us and the traditions of an administrative system really meant for collection of revenue and income-tax, or maintenance of law and order is still forced on scientific organisations. It is not just that the administrators must get on with a set of high-level scientists that creates the right atmosphere. It is that the administrator must be of service to the entire community of scientists working on a project. Unfortunately, because of the statutory powers and traditional authority of administrators they tend to treat scientists, particularly the junior ones, more as tradesmen from whom work should be extracted.

Since the inception of TIFR, it was clear to us that the training offered by our universities was totally inadequate for an atomic energy programme. We had at first managed to get very good people from the universities. However, because of the increasing number and size of universities, it was becoming more and more difficult to locate good people. It was for this purpose that a training school was started in 1957. I was closely connected with this programme. The foresight with which it was started has paid us rich dividends. It has provided the base for all our projects and many trainees from this school hold important positions. In fact, a large number of people who took part in the recent peaceful nuclear explosion experiment were from this training school. The school provides not only a place for training bright people and orienting them towards atomic research, but also gives them the necessary atmosphere to develop a sense of loyalty and team-work. It also provides a set-up of brilliant young men, who behave like question-masters to their senior colleagues, and thereby provide an intellectual background which is the only way in which an aging scientist can remain youthful in the field. Besides this school, other training programmes, including training in Canada for the Cirus reactor, and the power reactors assured the Indian atomic energy programme the manpower base without which rapid development could not have been achieved.

Bhabha used to say that we could justify all the expenditure on atomic energy only if we could generate useful electric power at a low cost. From the early days of atomic energy he set himself the task of costing nuclear power. His contributions to the Geneva Conference of 1955 show his absorbing interest in the need for and cost of nuclear power in the developing countries. He had to fight a hard battle, because his European colleagues were against him in this matter. When it became clear that light water enriched system of the BWR type was already economical in comparison with thermal stations, under certain circumstances of distance from the coal fields, Bhabha involved himself with a series of negotiations with the US Atomic Energy Commission for the establishment of the Tarapur reactor. This reactor actually started giving power to the Maharashtra and Gujarat grids after his death. Whatever difficulties the Tarapur reactor has faced, (which in my view are highly exaggerated because the reactor has behaved no better or no worse than other nuclear power stations in the world), it has provided an important source of power for the Maharashtra-Gujarat grid without which industry in the two states would have been in a complete mess. The recent decision to make fuel elements for this reactor from imported enriched uranium (in UF 6 form) is a courageous decision taken in the same spirit as Bhabha's original decisions.

Our close association with Canada led us to the choice of heavy water natural uranium power reactors (Candu type). In this choice, I think we can consider ourselves to have been lucky as it has led us to the right system and unit size required for India under the present conditions of our industry. The Site Selection Committee for the location of nuclear power reactors,—(I believe site selection committees for conventional power reactors have recently been set up),—which was formed in August 1961, made a series of recommendations, as a result of which Kota and Kalpakkam were chosen as locations for the first two power stations. It was clear even at that time, that while Kota would be built with Canadian assistance, Kalpakkam would be made almost entirely from Indian resources. The unit size of 200 MW was naturally dictated from the first Canadian power station at Douglas point. It has now been shown that the unit size of 500 or 1000 MW would make electricity cheaper to the extent that it would compete with thermal power even at coal pit-heads. If, however, we have in mind the size of the present grid systems and the capability of our industry, 200 MW would still be of value for some years to come. Five hundred MW stations are in fact being designed by us, but would come into operation only after the Narora reactors.

IV

It has always been the aim of the Indian atomic energy programme to utilise the large quantities of thorium that exist in the country. Unfortunately, thorium cannot be used as a fuel as it will have to be irradiated in a reactor to produce sufficient quantities of U^{233} which can then be used as a fuel. The production of U^{233} in normal reactors is a very slow process. However, nuclear physics provides a most exciting answer to this, in the sense that it is possible to build reactors using a fast neutron spectrum in which more fuel can be produced than is actually burnt. Such reactors are called breeder reactors. In these reactors if thorium is used as a blanket around the core of the reactor, large quantities of U^{233} can be produced. There are, however, many problems connected with this type of reactor, including the economics of breeding. The other problems referred to are reactor stability, reactor safety and radiation damage. Reactor safety in fast breeder systems is particularly important in view of the fact that sodium is used as the coolant for extracting the power inside the reactor. In Bhabha's programme, the fast breeder reactor was the last big item he had envisaged. A fast breeder test reactor is now under construction at Kalpakkam and is just coming out of the ground. It should be operating by 1977-78 and by the early 80's, we shall have obtained considerable operating experience on such systems to be able to design a power breeder reactor to come up in the late 80's. A power breeder reactor will go a long way to help conserve our fuel supplies for nuclear power, since it produces more fuel than it burns. If the experiment succeeds it will have a big impact on fuel economics.

In this brief sketch of developments of atomic energy I have not mentioned several other developments which have gone a long way towards making the Indian nuclear programme a self-sufficient one. The chain of heavy water plants which has been set up all over the country will make us independent of imports of heavy water. The Uranium Corporation of India set up in October 1967 is responsible for all the mining and processing of the available uranium ore in the country. The very large nuclear fuel complex at Hyderabad which has been set up entirely by our own scientists and engineers is something the country can be proud of. It makes several types of sophisticated fuel elements for our power and research reactors, and also produces materials of high purity of immense value to our industry, *e.g.*, zirconium, and titanium. If in fact, I were asked to point out a large establishment next to BARC which had led us to a high degree of self-sufficiency in an atomic power programme, I would mention the nuclear fuel complex.

An atomic energy programme is incomplete without waste-handling facilities. They are essential because atomic reactors produce hazardous radio-active wastes which are to be treated and stored very carefully. Practically at every power plant, we have a large waste disposal unit to take care of the hazard aspects of atomic energy programme. I have a feeling that several countries believe that we are somewhat over-cautious in our health physics and protection programmes, but in the particular case of atomic energy, I think it is better to err on the safe side.

As a measure of our self-sufficiency in very sophisticated technology, it may be pertinent to mention the completely indigenously fabricated atom-smashing machine called the 60 Mev Variable Energy Cyclotron, being set up at Calcutta. This has a curious history. For several years, the nuclear scientists had been asking Bhabha for his encouragement and support in building a big cyclotron to provide the necessary facilities for the large number of nuclear physicists available in the country. For some reasons, he had been very hesitant about this programme. However, he set up a committee to report on the various types of cyclotrons in existence and their possible uses. A report was prepared and at the same time a conference of all nuclear scientists was called at Bombay in August 1964 to take a decision on the programme. After hearing the case presented by the scientists, Bhabha fully agreed with us for providing such a facility. As a result of this, a very sophisticated variable energy cyclotron, with practically all the components made in India either at Trombay or in the public sector like BHEL, Bhopal and Heavy Electricals, Ranchi, is reaching the final stage of completion at the salt lake site at Calcutta. The machine is expected to go into operation early next year. Though this cyclotron was originally planned to be a nuclear physics facility, it has now become clear to all of us that it will be one of the most important tools for the study of radiation damage in solids of special value in a fast reactor programme. Yet, when we were in the process of trying to convince Bhabha of the usefulness of this machine and had almost succeeded in doing so, for some unknown reasons, foreign scientists used to write to him dissuading him from giving any encouragement for this project. I have never understood this negative interference from some foreign scientists for a programme which we now know will be of immense value to physics and our pure research programme, the most inexplicable part being why these foreign scientists at the same time were permitting their own scientists to build such a facility in their own country.

The first phase of our atomic energy programme lasted from 1948 to 1956 when the Apsara went critical, the second phase of planning and construction of large facilities lasted from 1956 to 1966 when Bhabha died. From 1966 to 1974 is the phase of construction of power stations and utilisation of large research facilities.

I have briefly described the developments in atomic energy in the last twenty-five years, taking us to the year 1973. There has recently been added interest in our atomic energy programme since we carried out a peaceful nuclear explosion on May 18, 1974 in the desert of Rajasthan. This was an experiment in which the design, planning and execution were all done with Indian resources by our own boys. Had Bhabha been alive, he would have strongly supported the aims of our experiment of May 18, 1974, and I can say from my long personal association with him that he was keen on understanding all aspects of peaceful uses of atomic energy, including nuclear explosions. We have shown that at a low cost one can carry out a peaceful nuclear explosion which is fully contained. We have described elsewhere its possible uses, but we still have to carefully study the behaviour of radio-active substances underground. The drilling for getting such information is in full swing.

We must all recognise that all these achievements of Bhabha and his colleagues during the last twenty-five years would have been impossible but for the steady support and encouragement given by Nehru whose faith in science was immense. I hope the scientists in the Atomic Energy Commission have been worthy of his confidence. I am happy to say we have received the same support from the present Prime Minister; her genius for clear and well-defined decisions has helped us to make our contributions to the further development of our country in the atomic field.

J. MAHANTY

SCIENCE IN THE UNIVERSITIES SINCE 1947

The state of scientific research in the universities cannot be adequately reviewed in isolation from political, social and other factors that have influenced the development and growth of universities before and after independence. Such a comprehensive study is, however, not the object of this paper, which seeks to review, from a somewhat limited and subjective angle, the status of research activity in sciences in the universities.

Science was in the curriculum of all the universities in under-graduate and post-graduate levels in the British regime. Before the establishment of post-graduate teaching departments in some of the universities—for which the lead was taken by the Calcutta University during the period 1915-17 under the stewardship of Asutosh Mookerjee—some of the premier affiliated colleges housed the science departments. The Presidency College of Calcutta, for instance, was the venue of the researches of J.C. Bose in physics and plant science, and of P.C. Ray in chemistry. With the establishment of post-graduate science departments in the universities, scientific research progressed under the leadership of outstanding scientists. Notable names in this connection are: C.V. Raman in acoustics and optical spectroscopy (Calcutta); M.N. Saha in astrophysics, thermodynamics and nuclear physics (Allahabad and Calcutta); S.N. Bose in quantum statistics (Dacca and Calcutta); S.S. Bhatnagar in chemistry and chemical technology (Benares and Punjab University, Lahore); Birbal Sahni in paleo-botany (Lucknow). This leadership had a quality reminiscent of that in the legendary *ashram* system of ancient India, with an intensely personal relationship and loyalty between the leader as the *guru* and the junior scientific workers in the group. Much of the Indian contribution to basic sciences originates from the effort of this period, and, as we shall see, the calibre of the subsequent work has seldom exceeded that of what was produced during this period before independence.

This was the legacy we inherited with our independence. In the scientific effort in India in the immediate post-indepencence period, both within and outside the universities, the one person whose ideology and vision was crucial was Jawaharlal Nehru. His early background in science, acquired as a student in Cambridge, combined with frequent interactions with the savants of British science in the pre-war era, had given him an awareness of the importance of scientific research in national development in all aspects, and a unique awareness of the ambivalence of science in its capacity to unleash forces, the full impact of which the scientists often cannot anticipate. Perhaps more than any other Indian of his time, he was aware that the days of scientists working for their own intellectual satisfaction in relative isolation, and with relatively meagre resources support, were fast coming to an end; giving way to a different kind of effort characterized by a much larger scale of resources support on the one hand, and on the other, requiring a policy framework in which the social, political, economic and other implications of the scientific effort are better understood and articulated.

An interesting question is, to what extent and how effectively Nehru's awareness of such problems determined the course of scientific research in independent India. There are many facets of this question, but we are concerned here with two. The first is the initiation of a process of systematic resources support to the universities for the growth of their academic and research activities. The second is the genesis of something like a national science policy for providing the framework for the development of scientific activity in the country in the immediate post-independence period. The latter has undergone a process of formalisation, a process that has been accelerated after Nehru, and has culminated in the Science and Technology Plan prepared, in 1974 as part of the fifth plan.

II

There were nineteen universities in India in 1947, and out of them, only eight had reasonably developed post-graduate science departments, all having been established after 1915. The teaching of science in the remaining universities was done through the affiliated colleges, and even in those universities which had science teaching departments, some of the affiliated colleges played a competing role. In the period of explosive growth in the number of universities in the post-independence period, it was realised that the states would not be able to provide the required resources for the development and growth of the universities, and the central government must step in, in a systematic way. The significant step taken by Jawaharlal Nehru and Abul Kalam Azad (who was the Education Minister) was the establishment of the University Grants Commission in 1953, which had been recommended by the Radhakrishnan Commission (1948-49). Starting modestly, the UGC enhanced the scope of its activities quickly and by the end of the decade, it became the most important organ of the central government in formulating and implementing policies concerning university education in the country. The number of universities has increased at an average rate of about 2.5 per year during the last twenty-six years, and a similar increase has been there in the number of affiliated colleges (see Table 1). The pressure for this increase is

Table 1: Development since 1961

	1961-62	*1966-67*	*1971-72*
Number of universities	49	77	95
Number of colleges	1783	2749	3896
Number of teachers	63053	93251	139204
Number of students	1155380	1949012	3262314

In 1970-71: Post-graduate science teaching was imparted in 88 university colleges. Total number of science departments was 433. The number of affiliated colleges with science courses was 1468.

often of political and non-academic character, but it has imposed a formidable burden on the UGC which fortunately has not cracked up under this pressure. By and large, the UGC has played a satisfactory role in promoting general development programmes in the universities, and has also worried itself about the maintenance of suitable standards of education.

On the specific matter of promoting and supporting scientific research in the universities, the effectiveness of the UGC is less clear. Most of the newer universities started with, or eventually established, post-graduate teaching and research departments in sciences, and many of the older ones also did the same. An important policy decision taken by the UGC in the early sixties was the establishment of

Centres of Advanced Study in some of the science departments, which already had acquired reputation for the excellence of their research output. This programme was subsequently extended to include the social sciences and the humanities. Table 2 summarises the situation

Table 2 : Centres of Advanced Study in the Sciences (1971)

Astronomy 1 (Osmania)
Mathematics 4 (Bombay, Panjab, Calcutta, Madras)
Chemical Technology 1 (Bombay)
Geology 2 (Panjab, Saugar)
Physics 2 (Delhi, Madras)
Radio Physics & Electronics 1 (Calcutta)
Marine Biology 1 (Annamalai)
Chemistry 1 (Delhi)
Botany 2 (Delhi, Madras)
Biochemistry 1 (I.I. Sc. Bangalore)
Zoology 1 (Delhi)

	1969-70	1970-71	1971-72
UGC grant for CAS	Rs. 44.85 lakhs	Rs. 48.44 lakhs	Rs. 56.18 lakhs
UGC total grant for science in universities	Rs. 3.60 crores	Rs. 3.45 crores	Rs. 4.04 crores

regarding the Centres of Advanced Study in the sciences in 1971-72. Since it was found impractical to support scientific research in all the universities at an adequate level under the budgetary constraints faced by the UGC, this decision to identify and support excellence, where it existed, was a wise one. In retrospect, it would be entirely appropriate to state that a substantial part of good research in the universities in the post-independence era has either been done in these centres, or has been stimulated by them through scientists who have been associated with them. Mention may be made particularly of the Centres in Delhi University in Physics, Chemistry, Botany and Zoology; in Calcutta University in Radio Physics and Electronics; in Saugar University in Geology; and in Panjab University in Mathematics, among others. All these centres have proved themselves for the quality of work produced in them. A most refreshing aspect of this programme is the recognition by the UGC of the fact that institutions, like individuals, grow, mature and then decline, so that periodic evaluation of the activities of the centres is important, and when necessary, a centre that has become senescent should cease to be recognized as such. This sort of evaluation has been made of a few centres lately.

In the early phases of the operation of the UGC, Nehru and Azad depended heavily on their trusted adviser, S.S. Bhatnagar, who was the first chairman of the UGC. He had already demonstrated a most extra-ordinary organising capacity as the Director of the Council of Scientific and Industrial Research (CSIR), by establishing a chain of national laboratories, and it is conceivable that both Nehru and Azad were expecting a similar phenomenon with regard to the universities under Bhatnagar's stewardship. Bhatnagar died in 1956, and the subsequent approach of the UGC in the matter of supporting science in the universities has already been summarised above. It is perhaps true to say that, although Nehru was passionately interested in seeing science develop in the universities, he could not give this problem sufficient attention due to his other pre-occupations. He left the policy framework for the universities to be evolved entirely through the efforts of the Ministry of Education and the UGC. As stated earlier, the UGC has done as well as can be under the budgetary constraints it faced. However, it is an interesting unanswered question as to what would have transpired if Nehru had time to bring into this process of evolution of the policy framework, his grasp of the problems the universities faced, and his understanding of the problems of science in relation to human affairs in the grand scale that only he was capable of.

III

One index of the performance of the universities in scientific research is the rate of growth of the number of research students, for much of the research in the universities now-a-days is tied up with the doctoral thesis research of the students. This tie-up is unfortunate, since it has serious repercussions on the scope and quality of research activity. However, as an indicator of the sheer volume of research the number of research students is important. In all disciplines, the number of research students has increased dramatically since independence. It was around 922 in 1949-50, 4366 in 1960-61, 13311 in 1970-71 and now it is around 15000. Approximately 40 per cent of these numbers refer to those researching in science subjects. There has been a slight levelling off during the last five years—the main cause for this is supposed to be insufficient job opportunities for Ph.D.s, although the reasons are probably more complex. The number of staff members in the universities who are actively engaged in research has undergone a similar increase.

The number of Ph.D.s, awarded in science subjects was 765 in 1966-67, 990 in 1967-68 and 1020 in 1968-69, and this number is increasing in the same manner as the total enrolment. The total number of Ph.D.s, produced in the decade 1951-61 in a few science subjects was: Chemistry 1129, Physics 395, Botany 266, Geology 45, Mathematics 157 and Zoology 277.

The quality of doctoral work, however, is alarmingly low. This aspect received attention from the Kothari Commission (1964-66) which reported that most of the Ph. D. thesis deal with topics which in formulation and scope would be considered to be behind the times by ten to twenty years. The more serious aspect of this problem is that the close tie-up of scientific research activity in the universities with Ph. D. theses imposes a constraint that just about eliminates the possibility of a rise in the level of the work. By the very nature of it, a research topic suitable for Ph.D. thesis level deals with a solvable problem, one that can be completed to an acceptable stage in a finite period of time. Very rarely, even in the advanced countries, a Ph.D. thesis deals with a frontier-line unsolved problem, the solution of which would require a degree of maturity and insight unobtainable in the average research student. Since in recent years guiding a number of Ph.D. students is considered to be an index of academic and research performance and is an important consideration in matters pertaining to the career advancement of the faculty members, almost all research in the universities is at this level. This situation is in sharp contrast to that obtaining in the pre-independence era, when many scientists in the universities used to do substantial research on fundamental problems all by themselves, unfettered by the consideration of producing a large number of Ph.Ds. The work of S.N. Bose in quantum statistics and of C.V. Raman, among others, deserves special mention in this connection. It is not surprising, therefore, that although there has been a tremendous increase in the volume of research in the universities, the quality has been rather lower than what had been attained in the pre-independence period. It is not intended here to suggest that the above is the only cause for this deterioration. We shall see that other factors have also contributed.

IV

In the evolution of science policy in the immediate post-independence era, the roles of S.S. Bhatnagar and H.J. Bhabha were crucial. Nehru and his principal advisers, including Bhatnagar and Bhabha, were keen to promote expansion in two directions. The first was to create facilities in the form of well-equipped laboratories, a well-paid cadre of scientific civil service and so on, and it was expected that these steps would stimulate research activity in science and technology at a level commensurate with the development needs of the country. The second was to assess the scientific manpower needs and develop facilities for the education and training of scientific personnel. The latter was studied by the Scientific Manpower Committee (1947), many of the recommendations of which have been adopted in the plans pertaining to technical education. In respect of the former, the important decision seems to have been that the kind of research productivity which the government wanted could be achieved only outside the universities. The three organisations which were responsible for the main thrust in this direction were the Department of Atomic Energy (DAE) under Bhabha; the Council of Scientific and Industrial Research (CSIR) under Bhatnagar, and the Defence Science Organisation (DSO) under D.S. Kothari. At a slightly later stage similar institutions were created in the fields of agricultural sciences and medical sciences.

It is not clear whether Nehru personally subscribed to the view that the universities could not meet the research needs of the country. In fact, the Scientific Policy Resolution that he steered through the Parliament in 1958 does stress the important role of educational institutions in the training of scientific personnel in particular, and in the general scientific research effort in the country. But he left the matter to his advisers. In retrospect, it seems that the policy framework for promoting scientific research that emerged in these early years after independence left the universities out. It would probably be wrong to presume that Bhabha, Bhatnagar and others did not think of the universities deliberately. All of them were academics, at least in their background, and had excellent rapport with the academic community. But in their anxiety to ensure a rapid rate of development they did not give enough encouragement to the universities to play a concrete and meaningful role in the national scientific effort. In fact, during the decade 1947-57 there seems to have been a steady flux of scientists from the universities to the laboratories of CSIR, DAE, DSO and other governmental organisations, owing to better salaries and facilities which these institutions offered compared with the universities. This left the universities gasping. They were deprived of the leadership provided by these scientists in research, and there was deterioration in standards all around. At a rather late stage the flaw in the policy seems to have been recognised, for Bhabha in 1955 made the comment:

> It cannot be disputed that the cost of building the national laboratories on the lines followed by the Council of Scientific and Industrial Research has been the weakening of the universities by the drawing away of some of their good people, which is their most valuable asset.

The amount of direct support for research given by the government to the universities, both in this phase and subsequently, has been rather small. The full dimension of the disparity in the scales of financial support to the universities and to the laboratories of CSIR, DAE, etc., can be seen from the following facts (*i*) The total annual grants from UGC to *all* the Centres of Advanced Study in the sciences is less than the annual budget of *any* of the major national laboratories of CSIR. (*ii*) During the period 1966-7 to 1973-4, UGC has given grants totalling Rs. 56.30 crores to 66 universities, and only a small part of this could be used for promoting scientific research, the bulk of the grants being allotted for general developmental purposes. This amount is comparable with the *annual* budget for research support in any of the major scieniific bodies under the government such as CSIR or DAE. The CSIR and DAE give small research grants to individual scientists in the universities on the basis of their proposals which are evaluated by appropriate panels. Research fellowships have also been made available to the universities by these two organisations. At present CSIR gives about 400 senior fellowships and 1300 junior fellowhips every year. However, the budgetary provision for this kind of support has been an insignificant part (of the order of two per cent) of the total budget of the supporting agencies. It must be emphasized that even this meagre support for research in the universities has paid ample dividends in keeping alive the science departments in the universities under rather difficult circumstances. It is, of course, difficult to understand why the good salary scales, provision of good laboratory equipment and other facilities initiated by the government in CSIR, DAE, DSO and other agencies were not matched by a corresponding scale of support to the universities.

The process of formalisation of our national science policy has continued after Nehru and has now culminated in the Science and Technology (S & T) Plan, which is a part of the fifth five year plan. The S & T Plan is a magnificent effort by our scientists and technologists towards systematically assessing the needs of our country and suggesting suitable programmes of research in twenty four "sectors", each dealing with a particular segment of national effort. Although some parts of the suggested research programmes would presumably be carried out in the universities, only one sector out of the twenty four, the one dealing with research support, extension and education with a proposed outlay of Rs. 63 crores (as against Rs. 187.85 crores for CSIR, Rs. 155.33 crores for DAE, and Rs. 1725.61 crores for the total S & T Plan) is concerned directly with promoting development of education and research and related facilities in educational institutions. This outlay, together with the trickles from the outlays for the other sectors that will flow into the scientific research effort in the universities will, in the most optimistic estimate, be less than perhaps five per cent of the total outlay of the Science and Technology Plan. This will be supplemented to some extent from the outlays for the UGC and the Ministry of Education in the fifth five year plan.

One cannot help feeling that it was the judgement of the government and the scientists associated with it that the universities could not be depended upon to deliver the goods, and the main thrust of our scientific effort should be through scientific organisations directly under the government.

V

The gist of the analysis done so far is as follows: (*i*) On the eve of independence only a few universities had organised high level activity in the sciences. (*ii*) After independence there has been a tremendous increase in the number of universities and the volume of scientific research activity in them, and UGC has played the dominant role in systematising resources support for this. The scale of support to the universities from the government, however, is much less compared with what is given to other sectors of national activity, and the quality of scientific work in the universities had not improved as much as the quantity. (*iii*) The national science policy that evolved after independence has given a boost to the scope and scale of scientific activity in the country, but the universities play a minor role in them.

Considering the facts that the actual outlay of resources for supporting science in the universities remains rather small compared with that for the other sectors, and that in the immediate post-independence period the growth of scientific organisations under the government caused a drain of scientists from the universities, and that there is obviously a lack of confidence on the part of the government in what the universities can achieve in this respect, it would be interesting to review how the university scientists have performed in the face of these impediments.

An important indicator of this performance is the awards and fellowships of learned societies won by university scientists compared with the scientists in government organisations. Out of the nine Fellows of the prestigious Royal Society of London elected after independence, four are from the universities. About 65% of all the Fellows of the Indian National Science Academy (formerly the National Institute of Sciences of India) elected after independence are again from the universities. Approximately 40% of the winners of Bhatnagar awards (which were instituted in 1958 by the CSIR to recognise excellence of work done in India by Indian scientists) are from the universities.

Another indicator is the publication record in international scientific journals. It has not been possible to collect precise data on this, but at least 50% of the scientific publications still emerge from the universities.

As stated earlier, the quality of the scientific work produced in Indian universities has been sometimes questioned. There is no doubt, however, that a few scientists and some groups have had substantial success in exploring the frontiers of their respective fields. Professor G.N. Ramachandran's work at Madras University on the structure of some proteins and on conformal transformations of some biologically important polymers is outstanding. Mention may also be made of the work of Prof. A.N. Mitra of Delhi University on the three-body problem; of the scientists at the Institute of Radio Physics and Electronics of Calcutta University on ionospheric physics and the physics of electron devices; of Prof. M.S. Kanungo of Benares Hindu University on aging in relation to enzyme activity in various organs; of

Prof. T.R. Seshadri of University of Delhi on the chemistry of natural products, and a few others.

Considering the wide disparities in the outlays on research in the universities and in government organisations, the above indicators should prove conclusively, that from the cost-effectiveness standpoint, the performance of university scientists is significantly better than that of the scientists in governmental organisations. Even if we make an allowance for the fact that the above indicators favour the university scientist over his counterpart in a government laboratory, who is supposed to work on specific objective-oriented projects which may not lead to publishable results, there does not seem to be any justification for the lack of confidence in the scientific capabilities of the universities on the part of the governmental circles.

VI

A notable recent development is the proposed new pay scales for academics which removes the salary disparity between scientists in the universities and those in government organisations. Although in the past this has been one of the factors causing a brain drain from the universities, the real problems are the lack of laboratory facilities and equipment, library facilities and technical service personnel, and other facilities in the universities. These points have been emphasized by the Kothari Commission. The resources support needed to help out the universities in these respects is far more than what is planned now.

One of the arguments advanced by the science planners now-a-days is that in a poor country like ours, most (according to some, *all*) research should be goal-oriented in a very precise way and should be in areas of direct relevance to the needs of the country. Since universities are supposed to work in a free atmosphere with emphasis on the academic and basic features of the scientific problems tackled in them, a natural consequence of the above argument would be to gradually de-emphasize the role of the universities in scientific research and have the research conducted in government organisations under tighter supervision. This argument is not based on facts. In most countries of the world, whenever universities have been asked to tackle problems relevant to national needs with adequate resources support, they have generally done the job well. The role of the universities of Chicago and California (Berkeley) in the U.S. Atomic

Energy Programme is an illustration. At the moment, the university laboratories here are so ill-equipped and so ill-provided with resources that they cannot sustain even the so-called academic and basic research at a reasonable level. But our intellectual resources, the basic raw material for scientific research activity, exist and are continually being generated in the universities. The freedom and productive interchange of ideas that characterize the university community are particularly suited to foster the sort of research we need, because the scientific and technological challenges that must be met in our country require a high degree of ingenuity, originality and adaptability in our scientists. In fact, on a number of occasions university scientists used to this atmosphere of work stopped being effective after joining government organisations. However, we have *no* example in India of any university, however good, which has been supported for scientific research by resources on a scale comparable with any of the laboratories of Council of Scientific and Industrial Research or Department of Atomic Energy. In this situation it is obviously unfair to assume that the universities cannot play an effective role in the scientific and technological development of our country.

A method of resources support to the universities which has worked particularly well in the western countries, notably in the U.S.A., is supporting research in them through substantial research contracts given by government agencies. Sometimes universities are asked to run large research laboratories meant for specific research objectives: examples are, the Argonne National Laboratory run by the University of Chicago, the Lawrence Radiation Laboratory and the Los Alamos Scientific Laboratory run by the University of California. A very desirable fall-out of this approach of involving universities in large-scale research is that an awareness and appreciation of national problems permeates into the higher education system, both at the level of the faculty and the students. Now that the Science and Technology Plan has identified areas in which research should be done and also has suggested the scale of outlay, it would be entirely appropriate to adopt the policy of supporting the universities to carry out most of the research in them, thereby building up the facilities in them and using them in the manner they ought to be used in national development.

There are broader questions today affecting the universities all over the world, such as the continuing usefulness of the institution of universities in their present form as part of the educational system.

In our country there is attack on the "eliticism" and alienation from the common man of the university community. The present attempt is to tackle this by fiats of political action backed by the power of the government. A less painful and perhaps a more lasting solution may be obtained by involving the universities in a direct way in national problems. Support of science in the universities should be viewed in this context.

B.D. NAG CHAUDHURI

SCIENCE AND DEFENCE

It is said that generals prepare for the last war and the scientists for the next. Both of them have their limitations and may end up by preparing for something that turns out to be quite different from reality. However, over the last seventy years and particularly since the end of the first world war, science has played many roles. During the second world war, it became clear in Britain, Germany, Soviet Union and the United States that war had to be sustained not only by the men in uniform, but also by those who worked in factories and laboratories.

In our country, science for defence came to be understood in a much fuller sense only after independence. Jawaharlal Nehru's contacts with Professor Patrick Blackett and the influence of Dr. D.S. Kothari led to the formulation of the first scientific activity connected with defence. I do not propose here to deal in chronological sequence with what happened during the last twenty-five years in the area of science as related to defence, but shall only refer to some of the roles that science has to play in defence.

It used to be thought—I am afraid many of us still continue to think—that science has only one role to play in defence that of developing and improving weapons and war equipment. This is however, only a part of today's relationship between defence and science. The development of, say, a new kind of a shell is important in the sense that there may be a "felt need" for it by the armed forces. But this accounts for only a fraction of scientific work which can benefit national security. An organisation for national security should work not only, for the "felt needs" of the armed forces but within a much wider conceptual framework of national purpose, national potential and national needs. Probably, the classic example of scientific work, initiated by a nation outside the "felt needs" of the armed forces was the work initiated by President Roosevelt in 1940 on the Manhattan

Project. There was no element of a "felt need" of the American armed forces in either the formulation of the project or its execution. The number and variety of roles that science is called upon to play in the total concept of national security depend largely on the techno-economic stage of development in the country concerned and the sophistication that it can bring to bear on the concepts of security and on the exercise of sovereignty. Science has a role, one might say, of preparing for the unexpected in war, a role which we have not played in any real measure. Science has a role not only to prepare for the next war, but also to understand and translate the evidence of technological superiority, wherever it is possible to have it, in such a demonstrable manner that it affects the morale of the fighting forces, which is an important element in the fighting ability of a nation.

In fact, if we look at the development of new weapons by the United States, the United Kingdom, and France—and these are the countries which I had occasion to study rather closely—only a few of them were developed at the instance of the armed forces. For example, the nuclear propelled submarine, which is now a "must" in the fleets of almost all major powers, was not developed because any nation's navy felt its need. In fact, when Rickover wanted to build the first nuclear submarine, the severest resistance came from the United States Navy. Similarly, the radar, the heat-seeking missiles and many other forms of equipment were not developed because they were the "felt needs" of the forces. However, even before their development was complete, they were readily taken over by the armed forces. The resultant burden of defence expenditure was willingly accepted.

Here is another type of exercise which might be of interest. It was only after the 1960s that the growing burden of defence expenditure—particularly again in the three countries I mentioned earlier, the United States, the United Kingdom and France—drove political leadership to look closely at the escalating costs of defence and to seek to cut them without jeopardising national security. This led to a whole series of investigations. Two of these are the best known, one in the United States and the other in the United Kingdom. The first was undertaken in the United States by McNamara, which resulted in his being appointed Secretary of State for Defence, and the other by the Rayner Committee in the United Kingdom, which resulted in Rayner being named the Chief Procurement Executive for some time. These two men were themselves technologists of high calibre with a lot of management experience. Their knowledge of defence was limited, but their major task was to suggest methods of reducing the cost of defence without dimunition of national security. As a result of these inquiries a fairly large reduction took place in the allocation of funds to the Department of Defence, in USA due to McNamara, for which he was sometimes called by unpleasant names. In the United Kingdom, Rayner's efforts did not acquire such a bad stink; nevertheless they caused a lot of heartache.

It is interesting to note that France also carried out similar exercises. In all these investigations there is a strong component of scientific, technological and economic assessment, which was incorporated in the rational examination of security, of threats, of approaches to meet them in different ways and in trying to identify the optimal method of doing so under the financial, technological and other national constraints. However, it may be recorded that soon after these reductions in the cost of defence effected through the efforts of Rayner in one case and by McNamara in the other, there was a spurt in defence expenditure partly offsetting the earlier gains.

In India, the defence expenditure rose barely by about 60 per cent between 1947 and 1961. By 1961 it was about Rs. 313 crores per year. In 1972-73, it was about Rs. 1,600 crores representing a more than five-fold increase in eleven years. K. Subrahmanyam, in an article on India's defence expenditure, showed that this represented a relative rise in the Indian defence budget as a proportion of the gross national product (GNP) from about 2 per cent in 1961 to 3.7 per cent in 1972. Between 1946 and 1961, the defence budget had remained more or less static, at about 2 per cent of the GNP.

Now, we must recognise that this 3.7 per cent of the GNP, which we spend on defence represents a small fraction of the GNP of other nations of the world. Countries like Sweden spend 3.7 per cent of their GNP, France slightly more, Britain slightly less, and the United States somewhere around 7 per cent. So the defence expenditure varies from about 3 to 7 per cent in many cases. We might claim that the expenditure in India does remain a smaller fraction of the GNP, than that of many other nations of the developed world. Nevertheless, our defence expenditure does represent one of the highest amongst the developing countries with a low per capita productivity, and may be difficult to sustain over a long period of time, or in times of economic stress. The military or the political necessity of the increase in expenditure is undeniable. However, the fact remains that such large increases have been accepted without much effort to rationalise defence expenditure, as has been done in the United States, the United Kingdom, France and in several other countries. Such an effort with proper incorporation of economic and technological inputs is as important for modern defence as it is for the economy as a whole.

The problem has another serious aspect for India, as indeed for many other countries, and was discussed at the Pugwash Conference in 1974. The defence expenditure is not the only burden on the tax-payer. Another, and sometimes heavier burden is the net outflow of foreign exchange without countervailing advantages in economic inputs or satisfaction of social needs. This retards economic growth, and in critical circumstances, entails additional expenditure to provide for national security. The contrast between an unfavourable foreign exchange situation and its relation to the inherent technological strength of a nation can perhaps be explained by taking the examples of India and Sweden. Sweden is a highly developed country and India is a developing country. Both the countries spend about 3.7 per cent of their GNP on their defence. Both the countries have GNP which are roughly close to each other. However, the burden on the economy of Sweden is much less than it is on India for two very simple reasons. There is hardly any net outflow of foreign exchange on military purchases from Sweden; in fact there is a small net gain. Secondly, the national per capita income in Sweden is more than Rs. 24,000 per annum compared with Rs. 600 in India; the defence burden on the common man, therefore, becomes much larger in a developing country like India than in Sweden.

In the scale of global assessment of national security, Sweden undoubtedly would be placed much higher than India, inspite of the fact that the same proportion of national resources is spent on defence in each country. Therefore, the point that I would like to make is that in the global assessment of national security, the assessment of indigenous technology and its fullest utilisation to meet assessed threats to security, is a very important consideration and that the most rational combination of techniques to meet probable threats to security in an optimum manner is an important task. Scientists and technologists have played such a role in carrying out this task in many countries of Europe. There is no reason to suppose that Indian scientists and technologists would not be able to play an equally important role in the task of optimization, which will give greater military strength within the same techno-economic constraints or equal military strength at lower cost. However, these exercises are difficult and arduous, and require the fullest cooperation between the scientists and the armed forces in the matter of soft as well as hardware needs of the armed forces.

II

The role of science in defence thus covers a wide range. It starts with the improvement of weapons, which has been defined in many textbooks of defence development as the pursuit of incremental gains through continuous scientific research and development effort. The ultimate exercise is an elaborate scientific and techno-economic analysis, covering several disciplines to suggest approaches to defence, which will be techno-economically optimal under the prescribed objectives of security. Between these two, the global and the incremental, there are many other levels at which science gets involved in defence: the most direct perhaps is the adaptation of new materials, new techniques and new knowledge for building new or improving existing military hardware.

This is familiar to many of us. Any of these new materials or techniques or knowledge discovered in any area, in any country, whether in civil industry or in military establishments, may offer some advantage by incorporating these in certain equipment or logistic systems or in life-support systems, and so on. We know that an invention of a new high-temperature alloy can lead to the development of a better jet engine or a better rocket engine. Similarly, the development of a new fuel has very much the same effect. When both features are combined, you have the combination of incremental gains, which is not just the addition of two gains, but a much larger advantage. This is the entire philosophy of the continuous pursuit of incremental gains in existing equipment. The areas of aeronautics, jet engines, missiles, aircraft, etc., are areas where the philosophy of incremental gains has been pursued consistently for the last thirty years in most of the major countries of the world and has resulted in a tremendous development of supersonic jets and a plethora of missiles, not only by the super-powers but by smaller powers as well.

Now, this pursuit of incremental gains is a task which calls for great perserverance. It is not a task which one can take up today and give up tomorrow. It has to be a constant pursuit for many, many years.

In fact, an interesting visitor to Delhi, is a man called, Von Braun, who now works with the National Aeronautics and Space Administration in the United States. He has been an annual visitor to this country for the last several years. He was one of the main developers of the V-2 missiles in Germany during the last phase of the second world war. He was taken to the USA. He joined the NASA and made a substantial contribution to its work. He is, in fact, one of the leaders of Apollo Space Programme. I have had several occasions to meet him and have had long conversations with him. He told me that the continuity in the pursuit of incremental gains is one of the startling features of the American effort, the like of which he had not seen either in Germany or UK. Though there may not be any obvious connection, between the Apollo Programme of NASA and the V-2 of the 1940s, he said if one goes deeper into these two systems, one would recognise that there are innumerable small steps between the two, which are recognizable in many areas of the structures of V-2 and Apollo. It is the totality of the small changes, that had produced most of the big changes we see in America's space programme. I asked him whether he could recall any single large and dramatic step or innovation that changed or enhanced the Apollo Programme as different from the V-2 of the earlier days. He said that the only thing he could think of, and perhaps the biggest innovation, was the development of the inertial system. This was the best answer he could come up with, and he added that even the inertial system was not very new or revolutionary because gyro-compasses were well known, when the inertial system was being discussed for rockets or for guidance of rockets. He said that he was familiar with gyro-compasses from the twenties of this century.

Another area, which we should not neglect, is that of the support of logistics, of testing of many small things. Of these which we have tended to overlook, but which have excited the imagination of many outsiders, I should single out the effort by Indian scientists at Leh, which has made possible the rearing of chicken and growing of vegetables and cereals in Ladakh. I had not rated these developments very highly, but they have been mentioned to me over and over again by competent observers. The net gain to India has not only been in the logistic situation in Ladakh, but also in a scientific achievement which has impressed observers who see it in a larger perspective.

The fact is that the perspective changes depending on the distance from where you look at things. The incremental gains which I have talked about, which Von Braun always preaches, is one of the most difficult things to pursue consistently. One of the sad things in India is that both in defence and in civil industries there have been innovations which have been lost. In the United States and the Soviet Union, one comes across this rather interesting phenomenon that the endeavour has always been to use new innovations in some manner, because if innovations are not used, you are not only depriving yourself of a present possibility, but of the entire logic of incremental gains. In our country, there has always been an axiom that a new innovation is to be accepted and used only if it is economically viable, and if it is as good as any in the world. In other words, we start from the premise that innovations are too risky, and perhaps not always techno-economically worthwhile: this attitude inhibits their use and the philosophy of the step by step incremental gain system, is never brought into operation. A perfectionist attitude is, however, dangerous in industries, especially those connected with defence.

III

Apart from these two or three areas that I have described, there are other areas like the formulation of concepts or ideas for a modified weapon system to serve specific tactical or strategic purpose. Now, this is rather depressing because, while much of this knowledge exists in India, it has never been applied in this particular way. The development of infra-red sensors and the gallium arsenide lasers, is fairly well known. Similar developments have taken place in this country, but we never took them as objects of defence interest till some scientists in other countries began to consider them seriously as objects of defence interest. Today, they are extremely important in that they are extensively used in terminal guidance systems or guidance of stand-off bombs or aiming of artillery or ranging. It has become almost a vital thing to use them. And yet one recalls that for many, many years the laser systems were talked about in the world of scientists, but because nobody else was bothered about them, neither the scientists had the incentive to think of them in terms of war or weaponry, nor did the military say, "Well, you have got something: tell us how you can use it for our system."

The other areas with which we are familiar are the areas of importance such as systems analysis and operational research methods combined with specific knowledge of physical and other engineering systems to study and analyse specific military problems involving use of weapons and tactics. One finds out the least cost logistic solution to supply or to air-drop mix of aircraft and guns and surface-to-air missiles to protect an area. All these are very standard exercises in many countries and yet they continue to be neglected in our country. The increasing sophistication is rather important because we have tended to go into, what are merely computer exercises instead of seeking new light, new elements which will enable us to short-circuit some of these rather tedious calculations by new insights in solving some of these problems.

In my opinion, there are at least five different kinds of areas of problems of defence in the solution of which science and technology play a substantial role. They are firstly, the part that I have laboured most, the incremental improvement, the pursuit of incremental improvement of weaponry by continuous research and development effort. Secondly, the application of science to the amelioration or solution of problems of logistics. Thirdly, the utilisation of new scientific developments in materials, techniques and concepts related to substantial modification or integration of these. Fourthly, the use of generalised scientific and mathematical techniques to find optimal solutions to specific problems related to logistics and things such as search patterns, power patterns, flight paths and so on. Finally, and this is an area which is of great importance, the scientific and technical study to understand what we mean by national security, and to provide as a result of such study, more cost-effective solutions of weaponry and equipment within the defined framework of national security.

Today, science has become mixed up with defence in a variety of ways. Tomorrow this is going to be even more so. There will be no retreat from this inextricable mixing of science and defence. Some of the interests of defence are perhaps best served by close association between defence and science, not only within the structure of defence, but in a wider association with the entire technology and science of the nation, that is, in a certain sharing of ideas, even in broader concepts of tactical and strategic understanding of what national needs in terms of defence are.

There is also a need from the side of the scientists to understand a little more deeply and thoroughly—in fact a lot more deeply and thoroughly than they do now—as to what is meant by defence; what the constraints are and what demands are made on science by it. Only these two together can produce an external view which can act as some sort of a corrective, because the internal view is a view which does not have, except for its own internal checks and balances, a consideration of the totality of the country in its mind. A concurrent external view helps defence to find an equation with the nation as a whole and enables defence to correct its appetite in a certain sense in proportion to the nation's capacity to a large extent. And the external view to be of any use to the defence must be well-informed enough, scientifically and technically, and have some knowledge of defence needs and capabilities. This is something that I would like to stress because without both the internal and external views, our defence, our national security will suffer oscillations between the two extremes of too little or too much, particularly in the context of continually rising costs and foreign exchange outflows for defence. Therefore, this sort of external view will help to correct the weakesses that may creep into the system in various ways.

In conclusion, I may quote what one of the greatest strategists—indeed not a strategist but a purveyor of strategy—Clausewitz said, that unless the military system finds an equation with the intellectual leadership of the country, the cause of war can never be made just. I think that there are more ways of interpreting what Clausewitz said than what is apparent.

M.S. THACKER

DEVELOPMENT OF TECHNICAL EDUCATION IN INDIA

If one were asked to name the most dynamic force in the known universe, one might grope for an answer. Is it the force hidden in the atom, in the sun or in any other matter? In my opinion the most powerful force known to man is still an idea. Long before he became Prime Minister, Jawaharlal Nehru thought that science could solve the problems of hunger and poverty, of insanitation and illiteracy, of superstition and deadening customs and traditions, of vast resources running to waste, of a rich country inhabited by a starving people; that the future belonged to science and those who made friends with science. The growth of science and technology in India is a development of this idea. Nehru urged the scientists to descend from their ivory towers and concern themselves with the effects of their own discoveries on the destiny of their poorer brethren. He wanted the scientists to do all they could to stimulate development for plenty and peace.

Nehru was anxious that education, especially technical education should assume the proportions of a mass movement, that technical institutions should be multiplied and made more accessible, and in this process the individual should be offered a diversified choice. He stripped science of its romanticism, put it to work in the context of Indian resources, and produced results of economic value to the nation in the post-independence era. By establishing a chain of national laboratories, technical institutes and the Department of Atomic Energy, he laid the foundation for a partnership between Indian industry and science. The task of educational reconstruction on a national basis both in science and technology really started in 1947.

During the last quarter of a century, a phenomenal expansion of technical education has taken place in India. A first-rate infra-structure of trained manpower has been developed to help the country deal with existing and future problems of national reconstruction. The implementation of the three five year plans placed heavy demands on qualified engineers and technicians in all phases of national reconstruction, for industry, irrigation, power, and transport, communications, and defence programmes. Technical education perforce had to assume a major role to realise the planned objectives.

In 1947, we had only 38 engineering colleges, with seats for 2,940 students for the first degree courses. The number of polytechnics was only 53, with seats for 3,670 students. Today, we have 138 engineering colleges at the first degree level with a capacity for nearly 25,000 students each year. The number of polytechnics has risen to 284 with seats for 50,000 students for the diploma courses. There are about 65 institutions offering master's degree courses in a wide range of subjects, in engineering and technology, with over 4,000 places.

Accurate expenditure figures for the pre-1947 period are not available, but it seems the expenditure was not significant. During 1947-64 expenditure on technical education went up to Rs. 32 crores in the first five year plan, Rs. 48 crores in the second, and Rs. 41 crores in the third.

In would be interesting to recall that industrial schools came into existence in Calcutta and Bombay around 1825. But the first authenticated account we have is that of the industrial school established at Guindy in Madras in 1842 attached to a gun factory there. A school for the training of overseers was started at Poona around 1854. The first engineering college for the training of civil engineers was established at Roorkee in 1847 and granted diplomas. In 1856, the Calcutta College of Civil Engineering was opened; two years later the engineering school at Poona was renamed Poona College of Engineering and was affiliated to the Bombay University. The engineering school at Madras, renamed Guindy College of Engineering, was affiliated to the Madras University. A national institute, College of Engineering and Technology at Jadavpur, in Calcutta, started courses in mechanical engineering in 1908.

At the turn of this century, the late J.N. Tata visualised the benefits of science and scientific research to India and founded the Indian Institute of Science at Bangalore in 1908 to develop post-graduate instruction and research in all branches of knowledge, especially those which were likely to promote the industrial and material welfare of the country. In 1915, the Indian Institute of Science started courses in electrical technology, leading to the grant of certificates considered equivalent to a first degree in electrical engineering. Subsequently, associateships at the master's level were instituted. The Benares Hindu University started degree courses in metallurgy in 1917. And in 1921, a course in chemical engineering was introduced at the College of Engineering and Technology, Jadavpur.

An All-India Council of Technical Education consisting of representatives of the departments of industries of the central and state governments, scientific and technical institutions and public men was constituted. Within itself the Council formed several boards of experts on technical subjects in specified fields. Also, four regional committees, one each for the north, south, east and west zones, and a coordinating committee to coordinate the work of various technical study boards and the zonal committees were instituted with powers to take decisions on behalf of the council, when it could not meet. This gave a strong spurt to technical education, as a whole, in the country.

The Indian Institute of Science contributed to institutionalise the concept of progress through research. The post-graduate courses in important branches of engineering, with research facilities, provided a pattern for universities and other institutions to emulate.

II

In his address at the Indian Science Congress, Bangalore, in 1951, Jawaharlal Nehru observed: "I shall help in every way the progress of scientific research and the application of science to our problems in India." On the occasion of the opening ceremony of the Fuel Research Institute, Digwadih of the C.S.I.R. (Council of Scientific and Industrial Research) he stated: "I suppose the putting up of fine and attractive buildings does some service to science. . . . It is human beings who make science, not bricks and mortar. Properly equipped buildings, however, help the human beings to work efficiently. It is, therefore, desirable to have these fine laboratories for trained persons to work in and for persons to be trained for future work. . . . It [science] wants to help industry, though not merely for the sake of helping industry but also because it wants to create work for the nation, so that people may have better living conditions and greater opportunities for growth."

The Government of India had earlier appointed a committee known as "Sarkar Committee." It considered whether we should have several regional technical institutions or one central all-India technological institution with affiliated colleges spread over the country. The result of its recommendations was the establishment of five major technological institutes—the Indian Institutes of Technology.

The Indian Institute of Technology, Kharagpur, the first in the chain of five higher technological institutes, started functioning in 1951. The Indian Institute of Technology, Bombay and the Indian Institute of Technology, Madras admitted the first batch of students in 1958 and 1959 respectively; while the Indian Institute of Technology, Kanpur and the Indian Institute of Technology, Delhi started functioning in 1960 and 1961 respectively. In each of these five institutes provision was made for the education of 1,400 to 1,600 students at the under-graduate level and 600 to 800 at the post-graduate level. These institutes received generous assistance in equipment and experts from the U.S.S.R., West Germany, the U.S.A. and Great Britain.

The I.I.Ts, as these institutes are commonly known, have also established facilities for post-graduate research in various disciplines leading to master's and doctoral degrees. As a part of their industrial activity, service to industry is provided in the form of testing and certification according to national and international standards. Faculty consultancy is being encouraged and industrial consultancy centres are established, or are in the process of being established to promote linkages with industries. Projects of industrial interest are undertaken in the laboratories. Grants for specific research programmes are entrusted to them by the University Grants Commission, the Council of Scientific and Industrial Research, Indian Science Academy, Ministry of Defence and other bodies.

Fifteen regional engineering colleges subsequently came into being, one in each state as a joint and co-operative enterprise of the central and the state governments, during the last ten years. They are located in each of the major states, viz., Warangal (Andhra Pradesh), Durgapur (West Bengal), Surathkal (Karnataka), Jamshedpur (Bihar), Srinagar (Jammu & Kashmir), Allahabad (Uttar Pradesh), Surat (Gujarat), Calicut (Kerala), Rourkela (Orissa), Jaipur (Rajasthan), Kurukshetra (Haryana), Tiruchchirappalli (Tamilnadu), Silchar (Assam), Nagpur (Maharashtra) and Bhopal (Madhya Pradesh).

The establishment of the Indian Institutes of Technology for advanced studies and research gave a strong impetus to post-graduate engineering education in our country. Within a period of ten years there was an enrolment of over 1,100 students in the master's degree courses in widely diverse fields. Initially, the master's degree courses differed in standard and content from institution to institution and the courses were of one to two years' duration. A committee on post-graduate engineering education and research, with which I was associated, went into this question in 1959. The committee proposed certain basic or core courses for the master's degree, as well as a project report which demonstrated the design and analytical capability of the student. The experimental work brought the institutes closer to industry, while the core courses gave a depth of understanding for the fundamentals of engineering and the scientific method for the solution of original problems. The All-India Council for Technical Education accepted these recommendations and the Government of India provided the necessary budget for implementing the programmes. This was a significant effort at national level to promote advanced engineering education and research in the country.

I may add, that each student admitted to the master's degree course received a monthly scholarship; the doctoral students receiving a little higher amount. The scholarships acted as a great incentive to the best of our engineering students to study further within our own country instead of going abroad, thus advancing the cause of post-graduate technical education. In the early stages, to accelerate development in technological fields, however, teachers went abroad for higher learning and assistance was provided for specialisation in subjects for which proper facilities did not then exist with us.

An important institution is the Indian School of Mines, Dhanbad, established as far back as 1926. It has now developed into a specialised centre for under-graduate and post-graduate studies in mining, applied geology, petroleum, technology and geo-physics. It is at present our only centre for training petroleum engineers in exploration and reservoir engineering.

For higher level of professional leadership, Institutes of Management at Ahmedabad and Calcutta were first opened with an annual admission capacity of 120 students for the master's degree, some of whom also went in for doctoral degrees. Emphasis also was laid on research and consultancy services to industry, commercial firms and state and central government departments. Two more Institutes of Management have since been added at Lucknow and Bangalore.

National Institute for Training in Industrial Engineering was established in Bombay in 1963, as a specialised centre of management training in the application of work-study, industrial engineering, operational research and productivity principles and techniques. This institute also engages itself in industrial consultancy and research services.

A School of Planning and Architecture was established in Delhi. It acts as an advanced centre for post-graduate studies and provides research in town and country planning, housing and urban development. The School conducts a degree course in architecture and also offers post-graduate courses. In 1968, a National Institute for Foundry and Forge Technology was established at Ranchi. It provides specialised training facilities in foundry and forge technology for close collaboration between the Institute and the Heavy Engineering Corporation, Ranchi, where in-plant training facilities are offered.

III

The level to which the industrial production of a country can be raised, or at which it can be maintained, and the extent to which its economic life can be developed depend among other factors on the supply of skilled craftsmen and technicians. In the post-1947 period, extensive training programmes were organised under the Ministry of Industry, in order to assist the programme of industrialisation. There are at present 355 industrial training institutes spread all over India with an intake capacity of about 1,55,000 students. A scheme to train job-oriented workers, a vigorous practical training scheme has been instituted through the national apprenticeship schemes to train about 12,000 apprentices. A number of central ministries and departments like the Railways, Defence, Posts and Telegraphs have also instituted training programmes. Private industries too have been encouraged to start their own programme. Training courses were also organised by the all-India boards dealing with village and small industries, by small industries services institutes and the departments of industries in the states.

To meet the needs of industries for middle-level technicians, it was considered necessary to reorganise polytechnic education. The diploma holders were expected to gain knowledge of basic technology in the chosen fields and to apply technical knowledge for practical situations, providing leadership to craftsmen. The practical work in the polytechnics was suitably organised to give training in basic manipulative machine skills required for production jobs.

Since 1947, there has been a phenomenal increase in new technical institutions and in the number of students. It was recognised that the quality of the teacher was crucial for success. The country had to contend with a virtual explosion of knowledge and newer technological advances, and the creation of a strong and dynamic teaching faculty was therefore imperative. The central government became conscious of the problem of faculty development for which several measures were taken. One of them was the inclusion of teachers in the technical teachers' training programme which was started in 1959.

In those institutes, which had a well-developed and well-established programme of post-graduate courses, a certain number of places was reserved for serving teachers. Selected teachers were deputed to specialise in certain fields for the master's degree. A serving teacher, who had already acquired the master's degree and had some years of experience was encouraged to work for a doctoral degree, and opportunities were made available to the faculty members for continuous exposure to the latest developments and techniques.

Through the agency of the Indian Society of Technical Education, summer schools were started to enable college teachers to learn new methods of teaching in their respective subjects and to share their experiences with their counterparts in other institutions.

Institutes for training polytechnic teachers have been set up at Madras, Bhopal, Chandigarh and Calcutta for a wide range of in-service training programmes. These centres have been developed to introduce curriculum reform, preparation of instructional materials and new laboratory exercises in keeping with technical progress. Two more institutions, one at Bhubaneswar, and the other at Mysore have since been added.

The up-dating of the curriculum is an important phase of technical education. Study groups have been formed from time to time to examine the curriculum and instructional materials in subjects taught at the first degree level; this is a welcome development. Another step which was taken was to set into motion the evening colleges or institution service. This brought educational opportunities to citizens beyond the campus or to those serving in industries. Thus technical education has ceased to be viewed in isolation. We have been noticing increasing communication between public institutions, private enterprise and governmental agencies. Career development and skill up-dating have been aided more and more by joint activities such as conferences, seminars and workshops.

Higher technical education has been "democratised" and made accessible to all students of merit. Special concessions have been made available to scheduled castes and scheduled tribes students.

It may safely be asserted that in the decades ahead, the rate of economic growth will be increasingly dependent upon the rate of technological development, and since the rate of technological advancement depends on the availability of technical and skilled occupations, technical education becomes a prime factor in increasing the growth rate of national enterprise, and thus, the quality of life. The important question is how can tertiary education articulate and be made more relevant in the future, both to the needs of the individual and the needs of the society? Furthermore, we should be concerned with the relationship of institutions of higher education with each other; and with attitudes towards students, student-involvement and cooperation with the world outside.

Our technological institutions should respond more sympathetically and directly to industry, both in teaching and research. The attention given to sandwich courses—alternate periods in the industry and in the institutions—has a great deal to commend itself.

Industrial consultancy by faculty members is desirable. Apart from being a means of building an improved faculty, it provides a profitable and valuable connection between industry and institutes for a free exchange of ideas among educators and industrialists and to create mobility of staff between industry and institutes.

IV

I think it is important that the industrial firms in our country should establish or expand their own educational activities. England has developed a system of part-time technical education from which we could learn a good deal. Many firms release a percentage of employees for college work or for part-time technical schooling. Financial support from Parliament is now available for establishing or expanding plants, affording scope for improvement of work-based part-time trade and technical education. These measures may be insufficient to stimulate further education of a sufficiently high percentage of youth, but there is a wide-spread belief in England in the efficacy of part-time education, because, relating work to study is considered an effecttive means of motivation.

We must also direct our thinking to the combination of work and schooling, both for general and vocational education. New institutions could be created or new programmes could be established in existing institutions or vocational schools, preferably under educational authorities.

The engineer, who is ambitious, has for his continuing education to depend upon technical literature, professional society meetings, short conferences, which are very limited both in range and number for the size of our country and self-study. The impact of modern computers upon design of quantum theory, upon such areas as nuclear reactors and modern electronics, of plasma and atomic physics, upon new concepts of energy conversion and of new knowledge in various branches of science has determined much of the engineering of the future. Even graduates with advanced degrees find that in order to be creative leaders, they need from time to time, organised programmes for their own career development.

Unless our engineers maintain tap-roots, which can support intellectual nourishment from the constant flow of knowledge through research and development, they too, will eventually sicken or die as ineffective members of their technical profession. There is thus an imperative need for continuing education during the technologist's working life.

And lastly, I would like to add that we should not use our energies and funds to train those who neither possess the ability nor the desire to be scientists, on the ground that we need poor scientists as well as good scientists. We have to consider whether the present degree-holders are trained to perform any purposeful role in society.

In the past, science and technology had been compartmentalised in our governmental, university, industrial and institute operations programmes. With the growth of science, an increasing amount of cross-fertilisation and interaction not only between science, but between organisations and institutions should take place. There must be a close liaison and flow of personnel, support and joint operations so that the philosophy or principles of operation in one area may have an effect in other areas. This is being talked about in our country but no concrete steps have been taken to implement this idea. Our general confidence in scientists is a very recent development. A prominent part of our enquiry should be assigned to the nature of the support of society and to the further vital question of the social deployment of science. How much, should the conduct of science and its very goals be subjected to public control? How should the inner autonomy of science be protected in future? What should be the level and mode of social support as well as the social use of science? How can we try to recognise and deal with those substantive and operational differences between pure and applied sciences? What proportion of financial support should be adopted between pure and applied sciences in so far as we can overtly distinguish them?

The scientific knowledge, which has made possible modern industry, was acquired for the most part in the universities and institutions of the world by men, who were stimulated by curiosity. The popular conception that most successful scientists follow a career of stumbling upon important discoveries is not true. The discovery by Bell Telephone Laboratories of the semi-conductor phenomena, which made possible the transistor was certainly not an accident, but a result of an orientation which a creative environment can impart to a basic research enquiry. The long and distinguished tradition of the laboratory in the fields of communication and electronics provided an altogether fitting and probable birth place for this important discovery.

There are good reasons for establishing pure research departments by industry, the most important of which, is the coupling of basic research with applied research. I feel, a deliberate attempt has to be made to expose pure research scientists in educational institutions to industrial problems to bring about beneficial results. A common criticism is that most of our Ph. D. work is incapable of inspiring the younger research worker with a sense of social purpose or responsibility. Looking at the current trends, in the next few years, there will be a large output of Ph. Ds. who may be totally alienated from experimental work. The situation is rather disturbing. It calls for the institution of a deliberate policy of increasing concentration of support upon viable, often interdisciplinary projects, the sharing of expertise between institutions and industry, the institution of industrial fellowships and the deliberate selection of fields, whose importance and research transcend the purely scientific.

Some conscious efforts are necessary to promote activity in applied fields. The National Research Council, Canada, provides a good example for emulation. This is an agency which undertakes and promotes scientific and industrial research in Canada. It has also strong divisions of pure physics and applied physics, pure chemistry and applied chemistry and so on. Most of the investigations even in the division of bio-sciences have possible applications and influence in a number of widely differing fields, such as medical research, food-processing, dairying, refrigerated transport of food-stuffs and so forth. Both pure and applied research work are carried out simultaneoulsy in these laboratories, each receiving its impetus from the other, as well as industrial contract research and also testing for which no private or commercial facilities are available.

Technology is moving at a rapid pace. Our ability to meet the challenge of the future lies in maintaining an adequate feed-back from industry. A variety of methods of effecting greater interaction between the university and industry needs examination.

The key to the future is an appropriate and dynamic philosophy of higher education. The innovator is the new product of our research age. His education will undoubtedly require graduate work leading to master's or doctor's degree with good basic education. We must prepare innovators who could do creative design and development of a high order, especially from indigenous materials and sources. There is an imperative need to recognise creative work for the award of advanced professional degrees, and there is also a need to imbue graduate students with a sense of mission and at the same time with a sense of professional pride in contributions of creative design to our nation's progress. Our national capacities depend on the successful tripartite partnership between the government, industry and the academic environment. The great challenge ahead will be to make this partnership work better, to achieve greater permeability and greater feed-back among the three sectors. The principal strength of technical education lies in the coordinated totality in which all sectors of our society are structurally integrated, universalised and made continual; pragmatism must be shown in dovetailing, intensifying and diversifying our technological activity in relation to economic planning.

V. RAMALINGASWAMI

PERSPECTIVES IN BIOMEDICAL RESEARCH IN INDIA

In developing the theme of perspectives in biomedical research in India, I propose to deal in this paper more with the development of ideas and patterns relating to medical research in India than with its administrative or institutional frame-work. I shall confine myself to the health problems of India, their changing, evolving characteristics and what biomedical researches have done in the past, and more importantly, what they can do in the future. I also propose to take a rather broad view of biomedical research and include in it the study of man and his illnesses encompassing all levels of his organisation, from the submicroscopic structure of the molecules that constitute his body to the gross characteristics of his social organisation.

II

It is hardly possible to have an adequate conception of the future without an understanding of the past and the present. This is particularly true of biomedical research. Modern biomedical research in India dates back to over a century. Shortly after Ehrlich, Pasteur and Koch ushered in the "Golden Age of Medicine" in Western Europe around the middle of the last century, medical officers in India, working on their own initiative and with limited laboratory facilities, were making important contributions to the knowledge of tropical diseases. For example, Lewis discovered trypanosomes and filaria, Vandyke Carter discovered spirilla, leprosy and mycetoma, McNamara, cholera and Fayrer, snake venoms. Attempts at organised medical research date back to 1894, when the Indian Medical Congress submitted resolutions to the Government of India urging the establishment of a Medical Research Institute and central and provincial laboratories to study the ravages of enteric fever and cholera, a bacteriological laboratory was established in Agra in 1892; a plague laboratory was set up in Bombay in 1896, when Haffkine was provided temporary accommodation in a room in the Grant Medical College, Bombay, with a staff consisting of one clerk and three peons lent by the Bombay municipality. This laboratory was ultimately shifted to the old Government House, Parel, where it became the headquarters later of the Indian Plague Commission and formed the nucleus of the present Haffkine Institute. The Pasteur treatment of rabies was just introduced and "motivated to some extent by a desire to escape the great expense of sending soldiers bitten by rabid dogs to Paris", a set of Pasteur institutes was established, the first at Kasauli in 1900 which later was designated as Central Research Institute in 1906. Then came the King Institute in Guindy, and the Pasteur Institute at Coonoor in south India. In 1905 a research cadre of biomedical scientific workers, known as the Bacteriological Department, with thirteen officers (mostly from the Indian Medical Service) was established. Meanwhile, by 1897, Haffkine, who was deputed to work on the plague problem, had evolved a vaccine which was the first to be used on a large scale and, with modifications, remains an effective weapon for the prevention of plague even today. In the same year, at Secunderabad, Ronald Ross discovered the transmission of malaria by mosquitoes. A few years later, Donovan, working in the physiology department in Madras demonstrated the presence of the parasite known as Leishmania Donovani in the spleen of cases suffering from kala azar. Shortly afterwards, Rogers demonstrated the effectiveness of emetine in the treatment of amoebiasis.

These were truly impressive advances in the study of communicable diseases made in a relatively short period of time. By 1911, the need was felt for an organisational framework to plan, coordinate and fund medical research. There was also another consideration: "a sudden outbreak of an epidemic disease such as plague could not be dealt with adequately by a procedure which necessitated a delay of perhaps two years in obtaining the sanction of the Secretary of State for India in London for an additional research worker." Against this background was established the Indian Research Fund Association (IRFA) in 1911, the precursor of the present Indian Council of Medical Research (ICMR). The underlying idea was to utilise the facilities of the network of laboratories already established and assist the scientists working in those laboratories with the newly created funds which in expanding enjoyed complete freedom from routine administrative control. Quite rightly, the major objective of the IRFA was to promote research leading to the control of communicable diseases. Ironically enough, the IRFA was greatly concerned at that time at the decrease in the population of India, a development which was so drastically to be reversed in so short a time. During the thirty-eight years of its existence, the work of the IRFA was characterised by several features. It was plagued chronically by shortage of funds and there were years when no grant whatsoever was given to the association. Despite this, continued attention was paid to the study of major communicable diseases—malaria, kala azar, cholera, plague etc. which were rampant in the country.

The Indian Journal of Medical Research, started by the association in the year 1913, formed the main forum for contributions of articles based on researches done in India. This journal achieved over the years a place of recognition in the scientific publications of the world and has been in continuous publication, without interruption, since then; the present volume being the sixty-fourth annual volume of the journal. The two world wars interrupted the work of the association. The Inchcape Committee applied its cuts in 1923 on the IRFA. Economic depression in the early 1930, led to a drastic reduction in the government's grant-in-aid which continued until the end of the second world war. Despite these vicissitudes of support, however, the IRFA was able to accomplish a great deal. The Beri Beri Inquiry was started in Coonoor in South India in 1918 under Colonel Robert MaCarrison; it was closed down in 1923 and was reopened in 1925 under the comprehensive title of Deficiency Diseases Inquiry; this later became, in 1929, the Centre ofNutrition Research and still later the Nutrition Research Laboratories and as we know today, it finally evolved into the National Institute of Nutrition in Hyderabad. The Quinine and Malaria Inquiry under Major Sinton at Kasauli merged with the Central Malaria Bureau, leading to the establishment of a Central Malaria Organisation known as the Malaria Survey of India in 1927. The Malaria Survey of India evolved into the Malaria Institute of India in 1938. It started publishing in 1929 the *Records of the Malaria Survey of India*, which later became the *Journal of the Malaria Institute of India* and eventually *the Indian Journal of Malariology*.

The Institute itself has further evolved into the National Institute of Communicable Diseases. Shortly after the first world war, along with the Beri Beri Inquiry and Quinine and Malaria Inquiry, the Kala Azar Ancillary Inquiry under Major Knowles and Dr. Napier and researches in indigenous drugs under Colonel Ram Nath Chopra were initiated at the School of Tropical Medicine, Calcutta. The Kala Azar Ancillary Inquiry led to the appointment of a Kala Azar Commission by the government in 1924. The IRFA had an important role to play in the establishment of the All-India Institute of Hygiene and Public Health, close to the School of Tropical Medicine in Calcutta. The IRFA had succeeded in applying medical research to the most important health problems of India, initially to communicable diseases and subsequently to nutrition, maternal and child health and indigenous drugs. Many of the researches carried out under the IRFA had proved to be of substantial value in the launching of large-scale operations against communicable diseases.

III

After the attainment of independence, a radical new thinking was brought to bear on the problems of national health. To meet these challenges, it was considered appropriate that the IRFA should be redesignated as the Indian Council of Medical Research. This was done in 1949, and a full-time secretary was appointed for the first time. The first Secretary, later designated as Director and eventually as Director-General, was Dr. C.G. Pandit. He transformed this organisation to meet the new challenges and laid the solid foundations on which the ICMR rests today. He directed the affairs of the ICMR in its formative years continuously for sixteen years. Under his leadership, the ICMR adhered to the principle that it is the business of medical research to find practical solutions for important health problems, at the same time recognising that it is vital for progress that fundamental research is nurtured. The uncertainties of governmental grants largely disappeared: the research programme of the ICMR was cast within the framework of the five year plans. The urgent health problems facing the country were investigated through a deliberate planning process. New institutes wherever indicated were created, but this was done not too liberally and after a very careful in-depth analysis. Research in medical colleges was strengthened. Research units were established generally in medical colleges and institutions to provide a semipermanent support to ongoing researches around established investigators, facilities already available for research in institutions were strengthened. Regional institutions were encouraged to tackle regional problems. Conditions were created for attracting young and promising workers to a career in research; opportunities were created for training of research workers. Projects were supported on the basis of their scientific merits in terms of their relevance, timeliness and promise. Problems of national importance were isolated by the Council itself and the pool of talent available in the country was brought to bear on these problems through central organisation. The ICMR worked closely with the government so that there was a close coordination between the producers and consumers of research in the manner of a two-way reaction. The successive Director-Generals of the ICMR enlarged and improved upon this basic theme and the result, as we see it today, is a remarkable organisation with great flexibility and competence to mount a substantial research effort to meet the health needs of the country. I am convinced when a historical analysis is made, it will be found that the relatively small sums of money made available to the ICMR have been wisely invested, with much care and conservatism, and the nation has been well served by this organisation.

In addition to the ICMR, other agencies such as the Council of Scientific and Industrial Research, the Department of Atomic Energy, the Indian Council of Agricultural Research and the University Grants Commission also played significant roles in the promotion of biomedical research. There are also a number of laboratories supported by the central and state governments and voluntary agencies established mainly to manufacture vaccine which played a significant role in the promotion of medical research.

The most recent development is the establishment in 1956 of the All-India Institute of Medical Sciences as a centre for education and research in medical sciences. Through a special Act of Parliament, the Institute was established as an autonomous organisation to bring together facilities for teaching and research of a high order, to demonstrate excellence at under-graduate and post-graduate levels and to promote in its students a community of outlook and a high degree of culture. During the eighteen years of its existence, the Institute has developed a range of competence over a wide field, from sub-cellular ultra-structure to the study of health problems in rural societies, and is making efforts to mould educational patterns to suit the health conditions in the country. It is training teachers and researchers in clinical and basic sciences in significant numbers who in turn would be assets to medical colleges. The principle here is that top quality, by emulation and replication, can be relied upon eventually to supply top quantity. The establishment of the AIIMS was followed by the establishment along similar lines of the Post-graduate Institute of Medical Education and Research in Chandigarh and other institutions. The concept of a residential university, where faculty members and students live together on the campus for teaching and learning, of the whole-time principle for the faculty, and of the measure of autonomy by which growth and development of academic programme and policies are influenced largely by the scientific community itself, are features of these institutes. They provide an opportunity for fresh thinking on the whole pattern of organisation of medical education and research in the country.

IV

What has been the impact of all this growth and development of the medical research apparatus? Substantial gains to national health have been won in return for relatively small investments. Life expectancy increased from 32 to a little over 50 years in the past twenty years at the phenomenal rate of one year of increase every year, which is in sharp contrast to more than double the time that it has taken the western world to achieve a similar increase in longevity. Crude death rates have been declining from a high 47.2 during the years 1911-1921 to somewhere around 15 at the present time. Infant mortality rate had also declined since the turn of the century although it was still quite high around 140 per thousand live births in 1969. India adopted family planning as an official policy and as an integral part of socio-economic development. Stabilising the growth of population was at the centre of planned development. There are indications that the family planning programme is beginning to exert a significant impact. There have been substantial gains in the control of major communicable diseases such as malaria, small-pox and cholera.

Very substantial as our successes have been in the control of communicable diseases, no one would deny that there have been major set-backs as well. The present scene and the immediate prospects are a cause for concern, and dark clouds overhang the horizon. The spectacular initial successes in the control of malaria led to the euphoric concept of "eradication"; these successes were achieved mainly by interrupting or reducing the man vector contact through residual insecticide spraying of houses and reduction of vector population through anti-larvel measures. Malaria is still deeply entrenched in certain parts of the country, and in those parts which had gone into the consolidation and maintenance phases, reverses have taken place and the disease is returning. Besides managerial lapses, lacunae in our knowledge at both basic and operational levels contributed to this situation. Shortage of insecticides and the increase in biological resistance of vector and parasite were additional handicaps in the fight against malaria.

The technical know-how for the control of tuberculosis is available and it is noteworthy that work done in India played a very significant part in generating this new knowledge. The lack of necessity for institutional treatment and the development of effective regimens taking into account toxicity and cost of available drug combinations, constitute a major contribution to the solution of the foremost public health problem of India today. Highly effective, least toxic and relatively inexpensive regimens have been developed suitable to the people. Reliable diagnostic tools and effective preventive and curative methods are now available. Despite all these tactical advantages, the control of tuberculosis on a national scale, especially in the rural areas has not made much headway. In making the programme country-wide and extending evenly between villages and towns, it is important that it should be integrated in the community health structure. Tuberculosis has changed from being a clinical speciality to becoming a widely applied community health activity. Properly trained health auxiliaries can play a very vital role in the control of tuberculosis.

There has been little impact of modern medicine on the prevalence of leprosy in the country over the past ten to fifteen years. The National Filaria Control Programme has so far been confined to the urban areas only and a strategy to tackle the disease in the rural areas is yet to be evolved. Millions are affected by bancroftian and malayi filarial infections and millions are suffering from the incapacitating effects of guinea-worm infection. The solution to the problem of malnutrition is notoriously slow and the least spectacular as compared with communicable diseases. The long-range solution to malnutrition is inextricably linked with education of the people, agricultural development, development of animal husbandary, fisheries etc. Nevertheless, while aiming at the long-range solution, it is possible within limited resources to bring about significant improvements in the nutritional status of populations and to make a beginning towards the ultimate goal.

The regulation of human fertility in the best interest of the mother, child and society, and indeed in the best interest of the future of man, is the most crucial issue of our time. Time is of the essence. There are no doubt many gaps in our biological and sociological knowledge relating to human reproduction and fertility regulation. We need safer, more effective and more acceptable agents of contraception. But in vast areas of the developing world, including our own, we are not applying even a fraction of what we know. The existing knowledge and technology in the field of contraception, if applied with determination and leadership, are sufficient to bring birth rates tumbling down. What is known in the field of contraception cannot be fully applied because of deficiencies in our delivery strategies. The irony is that there are millions upon millions of fertile men and women who wish to limit the number of their children, but who for a variety of reasons are unable to have access to the available technology. There is general agreement that for sustaining a family planning programme effectively and on a continuing basis, one of the strategies needed is to hinge it on a comprehensive health-care system. It is only a small proportion of the rural population that actually comes in contact with modern medical and health services. A truly effective health service-based approach to family planning problem is urgent, requiring urgent pursuit of other approaches as well.

V

In most cases it is not so much a matter of research as a matter of application of the results of research already obtained. Whether it is utilising all the known methods of contraception fully, whether it is the distribution of massive dose of vitamin A to prevent blindness in children, whether it is the provision at regular intervals of a supplement of iron to pregnant and lactating mothers, or whether it is the control of protein calorie malnutrition, most of our programmes and targets flounder on the bed-rock of community outreach. This is, what I called some years ago, the "third approach" to public health. There have been until now two major approaches which did not involve the active participation of the community, *e.g.*, vector control for malaria and other communicable diseases. The institutional approach attempted provision of medical services to the obviously sick in hospitals. The most peripheral and yet the most vital outpost in the institutional structure is the health centre which is really the epicentre of health activities for community development. Health problems have a composite character; application of existing knowledge involves coordination with many agencies of community action. The health services have to be integrated into a health scheme of social and economic progress and of priorities. In addition to mass public health and the care of patients in the hospitals, there is this vast area of unfulfilled expectations, a large gap between what medicine can do and what it is doing, between the needs of individuals in the environment of their homes and farms and the great capabilities of modern medicine. To bridge this gap we need a "third approach" through the development of a third or outside faculty or a third delivery system and the use of a managerial type of physician. This approach tackles the village in its own setting, the villagers in their homes and farms so that medical and environmental care are given within the social matrix, and illnesses are dealt with at the points of their origin. The human and material resources of the community are thus liberated for the solution of their own problems.

As in health services, so in medical research, there is a vast area of unfulfilled expectations and the need for a "third approach." Hitherto the two approaches, fundamental research and clinical research have been the most extensively cultivated and prestigious. There is, however, a third type of research: community research which is the proverbial step-child. Here is a frontier of new medical research, a virgin territory with promise of progress and human welfare unmatched. What are the leading causes of ill-health in the community? What is the cost of mobile service versus a health centre? What drugs should be supplied as a matter of priority to a health centre? What is the economic burden of ill-health of various sorts-hook-worm anaemia, malnutrition, infectious disease? What are the feeding habits, the weaning foods, the social history and outlooks of people and how do they influence the health of the growing child and expectant and lactating mothers? How do cultural practices influence medical practice? What are the most effective methods for practising modern medicine in indigenous communities? Satisfactory answers to such questions are yet to be found. To bridge this gap in our knowledge is the task of future medical research.

There is an urgent need for operational research to bring about a harmonious integration of the different components of the health care delivery system. A multi-disciplinary approach is needed in which social and behavioural sciences should interact with biomedical sciences for a deeper understanding of the nature of the problems involved. There is need for pilot studies on the most economical combinations of various types of health services, the areas and populations to be covered, the nature of the training programmes, problems related to health intelligence and collection of accurate statistics, health education and, finally, the assessment of cost-benefit ratios. Improvement of the health care delivery system involves the evolution of a rational health-manpower policy. Radical changes in the objectives and processes of medical and para-medical education are needed. A new type of community oriented physician and health workers have to be developed. Research is needed to evolve entirely new patterns of community-based education with emphasis on preventive and promotive health.

There are fields in which community participation is not involved and mass action can be taken for the improvement of public health, *e.g.* vector control against a number of communicable diseases or the distribution of iodised salt for the control of goitre. These are purely managerial problems, demanding administrative efficiency and a sense of commitment on the part of those who are entrusted with the formulation and execution of policy. Endemic goitre has been completely prevented in Kangra valley where iodised salt has been supplied continuously, whereas in large parts of the Himalayan belt this supply is so inadequate that goitre control is running into difficulties. It is sad that while we have resolved the riddle of goitre, and while we produce enough iodised salt to control it, we are unable to ensure that it reaches the people who need it.

VI

Preoccupation with operational research and community-based research on pressing health problems should not lead to a relative neglect of basic research. Indeed for the final solution of the most pressing problems that we face today, we require an intensification of basic research. No amount of concentrated public health activity on isolated problems can lead to permanent and lasting solutions unless there is a core of well-trained workers in the country who are equipped to tackle any situation arising out of the newly applied measures from time to time. The price of freedom from disease is eternal vigilance. It is said that when, one day, Michael Faraday, the famous 19th century scientist, gave a learned lecture on electricity, Gladstone, the then Prime Minister of England, is believed to have made a sceptical comment, upon which Faraday retorted by saying, "Some day you can tax it." Existing methods are not adequate for the control of some of the major communicable diseases, and the resources required to tackle them on the basis of present knowledge are so large and the time needed to eradicate them is so long that it is essential to find better solutions. The advent of "New Biology" and the powerful new techniques in biomedical sciences introduced within the past decade or so offer a unique opportunity for the control of communicable diseases.

A great opportunity exists for an alliance to be formed between the scientists working in the laboratory and those studying disease at the clinical and community levels so as to develop imaginative approaches to solve the present problems. I would suggest a new synthesis of laboratory, clinical and epidemiological research in order to discover new methods for the prevention, diagnosis and treatment of major communicable diseases. I would advocate the institution of career development awards and other incentives for training a band of scientists and technicians who would be devoted to this area of communicable disease control. Task forces should be formed for studying the urgent problems. The yield of the existing laboratories could be greatly increased by a better coordination of their activities, through a net-work mechanism. Major goal-oriented scientific developments do not take place without a multi-disciplinary approach involving morphology, pathology, bio-chemistry, physiology, microbiology and so forth. In spite of the abundance of parasitic diseases contributing to so much morbidity and mortality, it is surprising that schools of parasitology are not flourishing in India. Indeed, the discipline of parasitology has been badly neglected. There is not a single chair of parasitology in any of the 105 medical colleges in the country. We need to train cadres of research workers for careers in tropical communicable diseases. The training of technicians is equally important. Research training will become a by-product of the search process itself. The World Health Organization is now working on mounting a major research programme on tropical communicable diseases along these lines in the continent of Africa. The need is equally great in India and South-East Asia.

We may take three diseases, which are rampant in the country—malaria, leprosy and filariasis. To illustrate the kind of new opportunities that await earnest research workers, let us take malaria first. What was once regarded as a success story of this century in the form of malaria eradication has now been reduced at best to the prospect of malaria control. Resistance of some of the most dangerous forms of the parasite to drugs and the resistance of the vectors to insecticides, especially to chlorinated hydrocarbons, have reduced the prospect of successful malaria control. An immunological approach leading to the development of an effective malaria vaccine seems to hold promise. Effective sporozite and merozoite vaccines have been tried out in non-human primates and merozoite vaccines show considerable promise and antigenic variation does not seem to be an insuperable problem. Although these advances are promising, much basic immunological research is still required in order to understand the basic immunology of malaria, its immuno-pathology and seriology as well as on the active production and field trials of malaria vaccines. The results obtained so far justify a cautious optimism regarding prospects for developing vaccine against human malaria.

The ideal anti-malarial drug which combines the virtues of prevention, suppression, cure and impossibility to create resistance, low toxicity, prolonged action and low cost is yet to be discovered. The chemotherapeutic approach could concentrate on field trials of available, newly developed anti-malarial compounds so as to promote the development of improved anti-malarial drugs. Research on the biology of the parasite, elucidation of the metabolic pathways and enzyme systems within the parasite, membrane biology of the erythrocyte and parasite, ultra-structural investigations of the parasite etc., these are some of the basic problems that require elucidation if we are to develop a scientific approach to the chemotherapy of malaria.

In the case of leprosy it is perhaps a trick of history that the first bacillus ever observed in diseased human tissues should even today be uncultivable in vitro. Mass in vitro cultivation of the lepra-bacillus is necessary for decisive progress in the control of leprosy. The introduction of the armadillo since 1972 has given a new model which will enable a rich harvest of bacilli to enable definition of the biochemistry of the bacillus, to develop immunological surveillance and to develop a vaccine for the prevention of leprosy. The isolation of a pure specific antigen from the leprosy bacillus would be of great value as a diagnostic and epidemiological tool, and as an immunological reagent for developing a vaccine. The frustrations that had bedevilled investigators in this area at last seem to be giving way and the gentle opening of the door of immunology may prove to be the most important development in medicine today. With regard to chemotherapy of leprosy, there is no evidence that the world-wide incidence of leprosy, have been lowered in recent decades in spite of the availability of effective treatment. The action of dapsone is slow, relapses are frequent, side-effects are possible and increasing number of strains are becoming resistant. Added to this is the diminishing interest on the part of the pharmaceutical industry. The need for a safe and faster acting drug is obvious. The possibility of finding anti-leprosy activity in substances of plant and fungal origin would have to be investigated.

With regard to filariasis, both the prevalence and geographic distribution have increased in recent years. The threat of urbanisation of filariasis with its serious consequences needs immediate study. There are many gaps in our knowledge of clinical and epidemiological features of filarial infections. Little is known about the morbidity and mortality caused by individual filarial infections. Four approaches are available to the control of filarial infections namely ,reduction of the parasite reservoir in the human host by chemotherapy, reduction of transmission by vector control, prevention of infection by sanitary methods including proper water management and reduction of risk of exposure to infection by public health education. Mass drug treatment and systematic vector control are the two major planks of the filaria control programme. During the past twenty years, no significant advances have been made in the chemotherapy of filariasis. Diethyl-carbamazine (D.E.C.) is still the drug of choice but it is effective only in the early stages of the disease and the length of treatment required and frequency of allergic reactions are some of the disadvantages of this compound. The role of immuno-pathological mechanisms in the clinical expression of the disease, research on drug development and detailed immunological and therapeutic studies are of great importance. More specific immuno-diagnostic tests, more effective and less toxic drugs are needed. Immunoprophylaxis should be a long-term goal.

VII

The point that I wish to make is that we need high technology to resolve the elementary needs of people. We need basic research oriented towards the immediate problems of the country, call it strategic research if you like. This is in fact the challenge to science as a whole. As the Prime Minister said in her address to the Indian Science Congress at Nagpur in 1974, it would be a fallacy to suppose that a lower level of science and technology would be adequate to deal with our problems. Scientific investigation and technological innovation of a primary nature is often required. She asked the interesting question: "how simple is simple?" and quoted Ghalib as saying "how difficult it is to make anything simple; even man finds it hard to be human."

We have still not been entirely successful in identifying men of outstanding merit and competence and in placing them in an environment where they could be maximally productive. How to challenge them and how to use them? As Vikram Sarabhai said in an address to the Indian Institute of Management, Ahmedabad, in April 1967, "structures, procedures and techniques are important, but these must be sustained by a cluster of attitudes, conveying care, trust and nurturance on the part of responsible persons."

The primary focus should be on essential questions without diversion into attractive side-lanes of interesting irrelevance. The research should be discriminating, intensive and continuous. A profound study of phenomena with precise objectives leading to practical measures of socio-economic uplift should receive major emphasis. A thin spreading of meagre resources over a wide front would produce no results.

Men working in our scientific laboratories must have close links with the national life in the crucible of reality. Science must be diffused by a conscious effort throughout society.

There are still deficiencies in our ability to involve medical colleges and the institutes of higher learning and the universities in biomedical research. A truly *symbiotic relationship* between these institutions and the organisations responsible for research needs to be built up. It is only in this manner that a base could be set up from which future advances can be made and education of future scientists beneficially influenced.

A rapidly increasing population, inadequate sanitation, microbial