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Science and the Problems of Development

H. J. Bhabha

This talk on science and the problems of development is based mainly on our experience in India during the last 20 years, but much of what we have to face here may be common to many underdeveloped countries, and some of them, I hope, will be able to profit from our experience, both successful and unsuccessful. It is interesting to note that practically all the ancient civilizations of the world—Persia, Egypt, India, and China—were in countries which are today underdeveloped. This is not surprising, since most of the countries of the world are still in this category. Western Europe is in fact a small area of the globe which outstripped the rest, essentially from the time of the Industrial Revolution, because of its development of modern science and the enhanced ability this gave it to utilize the forces of nature and to thus achieve a much higher material standard of life for its people. Western Europe was followed, and indeed to some extent overtaken, in industrial development by the United States, and more recently the category of the industrially developed countries has been joined by the Soviet Union, Japan, and a few others. A major part of the world, however, still remains underdeveloped by these standards. What the developed countries have and the underdeveloped lack is modern science and an economy based on modern technology. The problem of developing

Between 6 and 11 January, the Tata Institute in Bombay served as host to the International Council of Scientific Unions on the occasion of the latest of its biennial assemblies. Homi J. Bhabha, director of the Tata Institute and chairman of the Indian Atomic Energy Commission, addressed the assembly on the role which science can and should play in a developing country such as India. To those of us who knew Homi Bhabha and his dynamic nature, it was apparent that he was undertaking the task with even more than his normal vigor. During the address he spoke with a species of intensity that was unusual even for him.

At a reception later in the evening I asked if he would give me a copy of his manuscript for publication in *Science*. He expressed gratitude for the suggestion. His sudden death at the top of Mont Blanc two weeks later prevented him from reading the galley proof, but I am certain he would have wanted the address to appear in its current form.—FREDERICK SEITZ the underdeveloped countries is therefore the problem of establishing modern science in them and transforming their economy to one based on modern science and technology. An important question which we must consider is whether it is possible to transform the economy of a country to one based on modern technology developed elsewhere without at the same time establishing modern science in the country as a live and vital force. If the answer to this important question is in the negative—and I believe our experience will show that it is—then the problem of establishing science as a live and vital force in society is an inseparable part of the problem of transforming an industrially underdeveloped to a developed country.

Science has formed part of the activity of Indian universities for many decades and Government itself has had some scientific departments, like the Geological Survey of India and the India Meteorological Department, for quite some time. Indian scientists such as Raman, S. N. Bose, Saha and several others have made important contributions to the progress of science, which are now part of the fabric of modern science. But science as an organized national activity has been given an important place in the national life only since independence, thanks primarily to the vision and powerful support of our late prime minister, Jawaharlal Nehru, though some steps in this direction had already begun to be taken a little earlier, as, for example, by the establishment of the Council of Scientific and Industrial Research and the Tata Institute of Fundamental Research.

Debt to Nehru

I think it only appropriate that I should recall at this stage the immense debt that Indian science and scientists owe to Jawaharlal Nehru. Science was an essential, indeed basic, component of the India which he sought and worked so hard to build. "It is now patent," he said, "that without science and technology we cannot progress." So great was his zeal for science and for the scientific approach to life that he missed no opportunity of imparting his views to others. To quote: "You know that whenever the chance offers itself I say something about the importance of science and its off-shoot, technology. I think we should realize how modern life is an offspring of science and technology." And he fully realized that modern science and technology were as necessary for a highly developed agriculture as for industry. "After all," he said, "how has agriculture grown in many other countries greatly? It is because of the application of science and technology. If modern life depends so much on science and technology, then we must seize hold of them, understand them, and apply them." He saw the essential role of science in its historical perspective, not only in transforming the material environment, but in transforming man. To give only one more quotation: "Science has developed at an ever-increasing pace since the beginning of the century, so that the gap between the advanced and backward countries has widened more and more. It is only by adopting the most vigorous measures and by putting forward our utmost effort into the development of science that we can bridge the gap. It is an inherent obligation of a great country like India, with its traditions of scholarship and original thinking and its great cultural heritage, to participate fully in the march of science, which is probably mankind's greatest enterprise today."

If a scientific outlook is to be made a part of the mental makeup of every individual, then clearly his education has to be molded accordingly. Not only must science be taught at the secondary school stage, but his scientific education must commence much earlier with the help of scientific models and toys. But to be able to do this implies that scientific activity should already have been well developed in the country. Above all, scientific teaching and research at the universities must be strengthened and expanded. The universities are, however, autonomous organizations, jealous of outside interference, and the process must necessarily be slow and time consuming. It is probably for this reason that it has been considered expedient in many countries to set up national research laboratories and other scientific organizations for specific subjects.

Achievement of the aim of establishing science as an important national activity has been attempted in India through a number of governmental and quasi-governmental organizations working more or less independently, the most important among these being Atomic Energy, the Council of Scientific and Industrial Research, and Defense Science. The methods followed in all these have been different, and it is therefore instructive to take up the two largest of them—namely, Atomic Energy and the Council of Scientific and Industrial Research—as case studies, to see the advantages and disadvantages of the different methods they have pursued. These two organizations are approximately of the same size, Atomic Energy being somewhat larger in the total number of scientific and technical staff employed and in the total investment.

Council of Scientific and Industrial Research

The Council of Scientific and Industrial Research may be taken as the first planned attempt on the part of Government to establish a broad base of scientific and technical research in the country, particularly with a view to helping industry and industrial development. I would like to pay a tribute to the memory of my friend and colleague, the late S. S. Bhatnagar, thanks to whose enthusiasm, energy, and dynamic personality a large number of national laboratories were established within a period of some 7 years. His successors, Professor Thacker and Husain Zaheer, have carried forward his work with energy, and the Council of Scientific and Industrial Research now has some 25 laboratories under it, distributed throughout the country. In order that it should be free from the automatic application of all the government rules and regulations, the Council of Scientific and Industrial Research was established from the beginning in the form of a society with a governing body, nominated by the government, which included important ministers and officials, several of the leading Indian industrialists, and noted scientists. One of the main advantages of this setup has been that the Council of Scientific and Industrial Research has been freed from recruiting its staff through the Union Public Service Commission, whose methods are both time consuming and inappropriate for the selection of scientific and technical staff. The opportunity of framing an administrative structure and rules and procedures appropriate for a scientific organization, which this setup was intended to confer on the Council of Scientific and Industrial Research, has, however, been lost to a large extent by the omnibus adoption of government rules and regulations.

After independence, the prime minister himself became the president of the Council of Scientific and Industrial Research, and the minister of the ministry to which the council was attached became its vice-president. Besides the governing body of the council, which consisted initially of 15 members and today has 34, there was established a Board of Scientific and Industrial Research, to advise the governing body on scientific matters and, in particular, on the allocation of grants to various scientists in the universities and elsewhere for specific research schemes. As I have said, the governing body took early steps to establish a number of national laboratories and central research institutes. The first among them was the National Physical Laboratory, whose construction in New Delhi was started in 1947 and which was inaugurated in 1950; the National Chemical Laboratory, likewise inaugurated, at Pona, in 1950; the National Metallurgical Laboratory in the steel city of Jamshedpur in 1950; and so on.

All these laboratories were brought into existence in the same way. A planning officer was appointed for planning the work and the building of each laboratory. The plan was usually drawn up on the basis of the work of similar laboratories abroad, divided into divisions and sections, and an estimate of the staff required was made on this basis. An attempt to fill the posts was then made, through advertisement, and through invitation also in the case of the seniormost appointments. While this method of setting up a laboratory might give reasonably satisfactory results in a developed country in which science is already an important activity and in which a large number of scientists already exist in the universities and in other public and private laboratories and research institutes, it has serious disadvantages in a country in which organized science is still in its infancy and the number of available outstanding scientists is limited. Either it results in an outstanding scientist being taken away from a university or another research institute, or it results in a mediocre one, satisfying the so-called minimum qualifications, being appointed to a post requiring originality, initiative, and leadership. As we all know, the so-called minimum qualifications laid down for a post have little meaning in a research institute, and usually result in the floor becoming the ceiling.

A result of following this method has been that a number of good scientists have been drawn away from the universities into the national laboratories, leaving the universities weaker thereby. Thus, for example, the late K. S. Krishman, who was then professor of physics at the Allahabad University, was taken as the first director of the National Physical Laboratory, and, more recently, a successor has been obtained by taking a professor from the Banaras University. Similarly, the first two directors of the National Chemical Laboratory were eminent scientists who were brought to India from abroad, while, for the third, the head of the department of chemical technology of Bombay University was taken, and the appointment of his successor will deprive the same university department of yet another senior worker. These are not isolated instances, since the attempt to fill senior posts by mature scientists from outside must inevitably lead to their being taken away from the only institutions which have scientists in some measure, however inadequate, in an underdeveloped country—namely, the universities. 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 a weakening of the universities by the drawing away of some of their good people—their most valuable asset.

I must emphasize that these critical remarks are in no way aimed at individuals but at the system. The standard method of planning laboratories and filling posts is often forced on many by the administrative and financial requirements of Government. As Professor Blackett has said, "We must endow ability whenever it is found, and we must guard against subsidizing mediocrity." The standard method is certainly not conducive to achieving this aim. Government is spending large sums now on supporting scientific research and technical development, and it is in Government's interest to study and devise, *de novo*, the best administrative and financial procedures for scientific institutions and for getting the maximum return on the money spent. To apply existing administrative and financial procedures, devised for an entirely different purpose, to scientific institutions is largely to defeat the purpose which the government has in view and to let the tail wag the dog.

Atomic Energy

I turn now to Atomic Energy for a case study of a scientific organization which has been built up by an entirely different method, a method which might be described as "growing science." An Atomic Energy Commission was established in 1948 in the Ministry of Natural Resources and Scientific Research to survey the territories of the Indian Dominion for the location of useful minerals in connection with atomic energy, to promote research in the ministry's own laboratories and subsidize such research in existing institutions and universities, and to take such steps as might be necessary from time to time to protect the interests of the country in connection with atomic energy. Its decisions were implemented through the Ministry of Natural Resources and Scientific Research. Instead of planning a number of new laboratories, the commission decided to use the existing institutions to do the preliminary scientific work and to develop the scientific personnel that would be needed. Foremost among the institutions which were so used was the Tata Institute of Fundamental Research, and the history of atomic energy in India during its initial stages is so bound up with this institute that it merits special consideration.

Tata Institute. The Tata Institute of Fundamental Research was founded in 1945 as a joint endeavor on the part of the Sir Dorabji Tata Trust and the then Government of Bombay, on the initiative which I took in 1943, when I was a professor at the Indian Institute of Science at Bangalore. At that time there was no scientific institution in the country which had facilities for original work in subjects at the frontiers of knowledge in physics—in particular, nuclear physics, cosmic rays, and high-energy physics. I accordingly pointed out to J. R. D. Tata that "the lack of proper conditions and intelligent financial support hampers the development of science in India at the pace which the talent in the country would warrant," and suggested that the Tata Trust might take the initiative in setting up an institute for fundamental research. I also pointed out, in a letter dated 12 March 1944, that "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." The trustees of the Sir Dorabji Tata Trust decided to accept the proposal and financial responsibility for starting the institute in April 1944, more than a year before the explosion of the first atomic bomb on Hiroshima and before nuclear physics had become what might be called the "bandwagon" of science. This was also before it had been made public that atomic piles had been successfully operated and long before there was any talk of atomic power stations.

Bombay was chosen as the location for the institute, as the then government of Bombay was interested in expanding and improving the level of research work in physics, so it became a joint founder of the institute. This is perhaps the appropriate place to mention an important difference between the Tata Institute of Fundamental Research and all except a couple of the national laboratories of the Council of Scientific and Industrial Research—namely, that this institue has been a constituent recognized institution of Bombay University from the very beginning and has had close relations with many other universities in India, so that students of many of them have done work for the Ph.D. at the institute.

No organizational chart of the future development of the institute was submitted either when it was founded or later, and the philosophy has always been to support ability whenever it is found in the fields of work covered by the institute. Indeed, the philosophy underlying the founding of the institute was the same as that underlying the Max Planck Institutes in Germany: "The Kaiser Wilhelm Society shall not first build an institute for research and then seek out the suitable man but shall first pick up an outstanding man, and then build an institute for him." The institute received financial support from the government of India from its second year, through the Council of Scientific and Industrial Research and the Ministry of Natural Resources and Scientific Research. While the recurring grants from the Tata Trust and the government of Maharashtra continue, and indeed have been increased, the main financial support for the institute comes today from the government of India through the Department of Atomic Energy, the government of India having undertaken the permanent responsibility of supporting the institute in 1955. The recurring budget of the institute during the first year was only 80,000 rupees ($16,000); this was increased steadily at about 30 percent per annum during the first 10 years, and since then has increased at about 15 percent per annum, till the current year's budget is 15 million rupees ($3 million), making this the largest national laboratory in the country with the sole exception of the Atomic Energy Establishment at Trombay. Since not a single senior post has been filled by obtaining a professor or senior scientist from a university or from other research institutes in India, the growth of the institute gives an indication of the rate at which it is possible to develop scientific research in the country through growing one's own people and through absorbing those returning from studies in universities abroad. The institute has made a special point of growing scientists and has now reached the stage when it is able to feed good scientists into the universities, a policy which will be followed to an increasing extent in the coming years.

In addition to supplying people at professional level, the experiment is being tried of sending small and integrated groups of two to four research workers into the universities together with the equipment necessary for their work. The university has to undertake to provide them space and treat them as members of its own staff, and it may require each one of them to give not more than two courses of lectures per year. The group is of course selected by mutual agreement, to be engaged in a line of work which the university wishes to develop. At the end of the 2-year period the university will be free to absorb the group permanently, and, reciprocally, the members of the group will have the option of being so absorbed or of returning to the institute. It is expected that these groups will form the nuclei for building up larger schools of research in the universities.

The institute started work in 1945 in 6000 square feet (540 square meters) of hired space in an existing building. By 1948 its work had grown to such an extent that it was moved to 35,000 square feet of hired space in the building of the Old Bombay Yacht Club, and it was only in January 1962 that the new buildings of the institue were inaugurated by the late prime minister, some 16½ years after the institute was founded. This is another noteworthy respect in which the growth of the institute differs from the growth of the Council of Scientific and Industrial Research laboratories. Work has inevitably been built up first, and the permanent building has come afterward, and this pattern has been followed also in the development of the whole atomic energy program. Large and excellent as some of the buildings at Trombay are, some of them are just being completed, while the scientific staff which will occupy them has already been built up and the work is in full swing in hired space, much of which is extremely inadequate.

Before I leave the institute it may be of interest to give two more examples of building projects and development around people. As early as June 1944, Sir A. V. Hill had written to me suggesting that biophysics was a neglected subject in India and that it should be taken under the wing of the institute. While I agreed with his suggestion, I did not think that it would be wise to embark on this line till someone had been found who was mature enough to be able to work on his own and build up a group. When, however, in 1962 my attention was drawn by the late Leo Szilard to a very promising Indian molecular biologist, it was decided to start work in microbiology—work which has since then been growing very satisfactorily.

Another example is provided by the Radioastronomy Group. Four Indian radio astronomers had jointly written identical letters to the chairman of the University Grants Commission, to the director general of the Council of Scientific and Industrial Research, and to me as the chairman of the Atomic Energy Commission, offering to return to India as a group and establish radio astronomy here, if facilities and support could be given to them. When it had been ascertained that the members of the group had considerable original work to their credit and were of sufficient maturity to be able to work on their own in India, it was decided to take up radio astronomy at the institute. Thirty-two parabolic dishes presented by the Commonwealth Scientific and Industrial Research Organization of Australia, which had been lying unpacked for several years at the National Physical Laboratory, were handed over to the institute through the willing cooperation of Husain Zaheer, and these have been installed not far from Bombay for solar radio-astronomical work. In the meantime a project has been developed based on the use of a large cylindrical radio telescope for studying quasars and other radio sources and locating them accurately by lunar occulation. The telescope, which will have four to five times the collecting area of the Jodrell Bank instrument, will be designed and built entirely by Indian scientists and engineers and is expected to be in operation within 2 years. A site for it has been selected after a very extended study, as the axis of the telescope, which is 1700 feet (500 meters) long, has to be parallel to the axis of the earth. Work on the site at Ooty has already started. It is proposed to make this radio telescope one of the centers for inter-university work.

To return to atomic energy, groups were established at the institute to design and build all the electronics instrumentation without which atomic energy work is impossible. Thus, the Physics Division and the Electronics Division of the Atomic Energy Establishment at Trombay were both initially housed and built up in the institute. The electronics group of the Atomic Energy Establishment has today a staff of over 1300 people and is the strongest research and development group in electronics in the whole country. There was a time when no less than 175 members of the staff of the Trombay establishment were looked after by the institute, and the institute has given some 46 members of its scientific staff to man the various divisions of the Atomic Energy Establishment, many of them in senior capacities.

Trombay. I now turn to the Atomic Energy Establishment at Trombay, which is today by far the largest scientific center in the country, with a total staff of some 8000 persons, of whom nearly 1800 are professional scientists and engineers and another 3000 technical staff, many of whom, such as scientific and technical assistants, are science graduates. This establishment has grown like the institute, depending on the ability of the various groups to expand fruitfully. At no stage was an organizational chart drawn up, projecting the future pattern of the establishment. Only the broad lines of work were laid down, and major projects considered and approved. Thus, within a broad overall policy, the maximum freedom was given to members of the staff to display initiative in picking fruitful lines of work and in developing new ideas. The emphasis has been throughout on developing know-how indigenously and on growing people able to tackle the tasks which lie ahead. The generation of self-confidence and the ability to engineer and execute industrial projects without foreign technical assistance have been major objectives.

It was decided early in 1955 to build a reactor of the swimming-pool type. The basic design was frozen in July of that year, and the entire reactor, including the building for it, was designed and built entirely by our own scientists and engineers in just over a year, only the fuel elements which contain enriched uranium being supplied by the United Kingdom Atomic Energy Authority. The reactor became critical for the first time on 4 August 1956 and was the first reactor in Asia, apart from any the U.S.S.R. may have had in its Asian territories. This reactor was designed and built by us at a time when most European countries, except of course the United Kingdom and France, were buying their first reactor from the United States. The successful completion of this reactor gave our staff a great deal of confidence, and it was an invaluable facility around which the research and development of the project was built during the following few years. The control system for this reactor was built by the Electronics Division in some old wartime hutments on the site of the Tata Institute of Fundamental Research and gave trouble-free operation for 4 years till the reactor was shut down in 1960 for overhaul, maintenance, and repairs. At that time advantage was taken of the shutdown to install an improved control system, and a comparison of the control-rod drives and shutdown mechanisms installed in 1961 with those originally installed will show the advance that had been made by the Reactor Control Division in its engineering capabilities. The important fact remains, however, that the original control system, even if more cumbersome and less elegant, gave trouble-free service for 4 years, and the confidence gained in "doing it oneself" fully justified the course that had been followed. It may also be remarked in passing that this reactor, built by our own people, was in operation 2 years before the first reactor in China, which was designed and built by the Soviet Union.

Having decided to build a reactor of the swimming-pool type to begin with, we were looking around for a suitable design of reactor for carrying out engineering experiments on the design of future power reactors when we received an offer from the Canadian Government to build a reactor of the NRX type at Trombay. As this reactor suited our needs, the generous offer of the Canadian Government was accepted, after some questions had been settled. The CIR reactor at Trombay is an almost identical copy of the NRX at Chalk River, but differs from it in one important particular: the primary cooling-water circuit is a closed loop from which heat is removed by a secondary sea water circuit. The CIR being a Canadian gift under the Colombo Plan, all parts of it came from Canada, and the erection, through a Canadian responsibility, was carried out jointly with our staff. Although the total number of engineers and skilled artisans engaged on the construction of the CIR rose at one stage to as many as 1200, the maximum number of Canadian personnel at any given time at Trombay never exceeded 30. Indian welders had to be trained in the special welding techniques required, and all welds were radiographed. Similarly, Indian engineers participated in the erection of the reactor under overall Canadian supervision. I must say here, in appreciation of the Canadian concept of this cooperation, that when the project was decided upon they asked us to send some 40 scientists and engineers immediately to Chalk River to be trained in the operation and maintenance of the reactor, and it was most of these, as well as others, who were able to participate, on their return, in the construction of the reactor.

The CIR has fuel elements made of natural uranium clad in aluminum alloy, and it was decided to tackle the problem of making fuel elements in India from the very beginning. Accordingly, it was decided to set up a plant for making atomically pure uranium metal from uranium concentrate obtained from Indian monazite and other sources, and another plant for fabricating this uranium metal into finished fuel elements. In case any trouble arose during the initial operation of CIR, it was decided that half the first charge would be supplied by Canada and the other half made at

Trombay, so that trouble arising from the fuel elements could be isolated from trouble arising from other sources. It was well that this procedure was followed, because quite a number of difficulties were met in working up CIR to full power, and it could be established that this difficulty did not arise from the Indian fuel elements, which from the beginning performed as well as the Canadian-supplied ones.

The decision to build a uranium metal plant was taken in May 1956, construction was started in December 1957, and the first ingot of atomically pure uranium was produced in January 1959, the plant having been designed entirely by Indian scientists and engineers and built in about a year. Similarly, the fuel fabrication facility was also designed and built entirely by our own staff, and it produced the first fuel element in June 1959. The production of fuel elements is generally considered a rather difficult and tricky operation, and the successful production of nuclear-grade uranium metal and metallic fuel elements from it at a time when there were only about half a dozen countries in the world producing their own fuel elements added further to the confidence of our staff in their ability to undertake difficult tasks.

The economics of the operation are also noteworthy. The capital investment in the uranium metal plant and the fuel fabrication facility together came to approximately 8 million rupees ($1.6 million), of which the foreign-exchange component on industrial equipment, which had to be imported, was 3.2 million rupees (about $640,000). It costs us approximately 130,000 rupees ($26,000) to convert uranium metal into a ton of finished fuel element. Thus, even if the price of uranium concentrate is assumed to be $10 per pound, which is double the present market price, our fuel elements would cost 260,000 rupees ($52,000) per ton, or a single charge of 10 tons would cost 2.6 million rupees ($520,000). This 10 tons, if imported, would cost $750,000. Thus, apart from the fact that we obtain our fuel elements at two-thirds of the price at which we could buy them, the foreign-exchange saving on one fuel charge alone, which, when CIR is in full operation, is enough to keep it going for less than a year, more than compensates the total foreign-exchange expenditure in setting up this plant.

What is even more important, we now have first-hand technical knowledge for the erection of such plants on a much bigger scale. Construction will be started this year on plants to make zircaloy from zircon, atomically pure uranium oxide from uranium concentrate, and fuel elements for our two atomic power stations of 400 megawatts each which are being built in Rajasthan and Madras. These three plants have already been designed by our own staff and will be built within 2 years. It is estimated that they will cost about 75 million rupees ($15 million). They will have enough capacity to fuel not only these two power stations but those that will be built up to 1975, and, by expansion, later ones as well. However, the value of the fuel elements required by the Rajasthan and Madras stations alone will be 30 million rupees ($6 million) per annum, and a recurring foreign-exchange drain for the import of fuel elements will be saved for the life of these two power stations as a result of building these three plants.

It was originally envisaged at the beginning of the Third Plan that we would have to start building an industrial-scale plutonium plant, to be completed by the end of the Fourth Plan, for treating the used fuel from the nuclear power stations that would be in operation by then. In order to gain first-hand experience of the technology of building a plutonium plant—which, as is well known, involves many special techniques, including the handling of very large amounts of radioactive materials by remote control in the initial stages, and multiple precautions to avoid accidental criticality in the later stages—it was decided to build a pilot plant at Trombay costing about 35 million rupees, to treat some 20 to 30 tons of used fuel per annum. The chemical data for the process, in addition to what has already been published, were collected in our own laboratories, and the plant was designed, engineered, and built by our own staff and successfully underwent trial runs in 1964. It has been in operation since last year. As it happens, the capacity of this plant (for the same cost) is many times larger than that originally planned, so it has become possible to postpone the construction of the large plutonium plant. Secondly, the large plant was estimated to cost 140 million rupees, but, on the basis of what we have learned from the construction of the plant at Trombay, we now estimate that it would be possible to build an industrial plant of the same capacity for 100 million rupees, thus effecting a saving which is greater than the entire cost of the plant at Trombay. This shows the importance of undertaking research and development oneself, and shows that research and development, if properly carried out, effect economies amounting to more than their cost.

Electronics Division. I have already mentioned the work of the Electronics Division. It is now proposed to set up an electronics plant at Hyderabad for the manufacture not only of nuclear electronic instrumentation—including that which is required for routine production and use of isotopes in hospitals and industrial establishments and laboratories and for the control systems of reactors—but of a variety of electronic components and equipment which the Trombay establishment has been able to develop and which are required by the electronics industry generally, but are not yet produced in this country. Among these may be mentioned high-quality carbon resistors, Zener diodes, thermoelectric junctions, oscilloscopes, and a variety of other components and equipment.

An interesting example is also worth noting. While carbon resistors are being made by a couple of commercial firms in this country, with foreign collaboration, these are of commercial grade and have not passed the stringent tests required for atomic or defense equipment. On the other hand, the carbon resistors developed entirely by our own efforts at Trombay have met these stringent defense specifications and will now be produced in quantity to meet the requirements of the country as a whole. If a more complex variety of an object can be developed purely by indigenous scientific and technical effort, there is clearly no reason why production of a simpler variety should require foreign collaboration. The fact that foreign know-how had to be obtained for making commercial-grade resistors clearly emphasizes the fact that the policy followed in setting up industrial enterprises has been misguided, and that much more self-reliance should and could have been aimed at.

Technical Physics Division. There are many other examples of what might be called "technological fallout" from our atomic energy program which will benefit the industry generally. The Technical Physics Division has developed many different pieces of equipment needed for atomic work, which can be bought off the shelf in industrially advanced countries. The result is that we have been able to develop and make equipment, needed in this country, which has nothing to do with atomic energy directly. For example, a result of developing the vacuum technology of oil-diffusion pumps is that we have been able to make equipment for freeze-drying blood plasma on the one hand and for freeze-drying food and pharmaceutical material on the other. There are a very large number of other examples of this type.

Training Program. Additions to our scientific and engineering staff have been at the rate of between 150 and 250 per annum. To meet this requirement, the Atomic Energy Establishment, in cooperation with the Tata Institute of Fundamental Research, has run a Training School in which about 150 persons have been admitted per annum, through inviting applications from young men passing out of the universities every year and selecting the best of them. Those selected are then given a year's lecture course and training in certain general as well as specialized scientific subjects. At the end of the year most of them are absorbed into the establishment, the grading being on the basis of tests given throughout the period of their study and an examination at the end of the year. To give an idea of the figures, last year about 3400 applied, with first- and second-class degrees from the universities; 251 were selected on the basis of an interview; 130 actually joined the school; and 125 completed the course and were appointed at the end of the year. On admission, these young men become part of small scientific groups working on specific problems, and at the end of 2 or 3 years they become very useful scientists. The best among them are likely to become the future leaders.

We have found this method of recruitment very satisfactory, and although it has placed a heavy load on our senior staff by making the spectrum of our scientific staff much heavier at the junior levels than it should be, it has provided a powerful source of able young scientists, on the basis of which the program can be expanded continuously in the future. It will be seen, also, that this method of building up our staff does not drain away senior persons from the universities but, on the contrary, gives training, employment, and opportunities to young graduates of the universities.

To summarize, of the two ways of establishing science as a national activity in an underdeveloped country—the standard method on the one hand, and the alternative method of what I have called "growing science" on the other—the second seems to lead to better results in the end, with greater potential for continuous growth. While it may seem much slower and harder at the beginning, it has the capacity for continuous growth and for developing the people it needs, and its faster growth rate in later years more than compensates for the slow beginning. Moreover, it may lead to concrete results sooner than the other method in developing countries, in which there is not a large pool of mature scientists to draw from.

Industrial Development

I now turn to the problems of industrial development and the question whether a self-generating industry can be established without simultaneous establishment of a powerful scientific base. Indian industrial development has so far proceeded almost exclusively on the basis of setting up plants and industries with foreign collaboration. Our own experience makes it quite plain, however, that this method can never lead to a self-generating industry without simultaneous establishment of a powerful scientific research and development effort to support it. A few examples will make this plain.

The steel industry has existed in India since the First World War, and one of the two steel plants was among the largest in the British Commonwealth in the early 1920's. Yet, when these steel plants had to be expanded, it was necessary to draw upon foreign consultants and engineering firms to plan and carry out the expansion. When the government decided to establish a steel plant in the public sector at Rourkela, a German consortium had to be asked to undertake the job. For the next steel plant, at Bhilai, the same course was followed, this time with Russian technical collaboration. The third public-sector steel plant, at Durgapur, had similarly to be set up with the help of a British consortium, and essentially the same method is being followed in the case of the fourth public-sector steel plant, at Bokaro. Thus, the construction and operation of a number of steel plants has not automatically generated the ability to design and build new steel plants. Unless powerful scientific and engineering groups are established during the construction and operation of existing steel plants as a matter of deliberate policy, the dependence on foreign technical assistance will continue, and the steel industry will not reach a stage of technical self-reliance. A similar situation exists in almost every other industry.

On the other hand, where a strong scientific and technological base has already been laid, foreign collaboration can certainly lead to a quicker takeoff. An example from the atomic energy field will make this clear. As I have already indicated, we have designed and built our own research reactors since 1955. However, when economic studies showed that, in many areas of the country remote from the coalfields, atomic power stations could be competitive with conventional stations, we invited tenders, on a world basis, for the supply and erection of the nuclear power station at Tarapur, with only broad stipulations regarding certain of the technical requirements. The reason for this course is that no country has ventured to build a large power station of 400-megawatt capacity without building first a 5- to 50-megawatt prototype. The prototype takes as long to design and build as the large power station, so that, if we had chosen to build our atomic power stations without external technical assistance, it would have taken us some 4 years to develop and build a prototype and another 4 years to build the full-scale station. By resorting to foreign collaboration, the first 4 years of this development have been eliminated.

The second atomic power station of 400-megawatt capacity, in Rajasthan, is based on a Canadian design in which natural uranium is used as fuel, and heavy water, as moderator and coolant. As a result of CIR, this is a type of reactor which we have already had considerable experience. This time the Department of Atomic Energy has undertaken the prime responsibility for constructing the station, but with the assistance of Atomic Energy of Canada, Limited, and a Canadian engineering firm as consultants. The third atomic power station, at Madras, which will be of the same size and of the same basic design, will be built entirely by Indian scientists and engineers without any foreign consultancy. This clearly demonstrates that the result of having built up a very strong research and development organization with associated engineering skills is that we have been enabled, through foreign collaboration, to "buy" some 4 to 5 years of time and to make ourselves self-reliant even in the design and construction of large atomic power stations.

The relative roles of indigenous science and technology and foreign collaboration can be highlighted through an analogy. Indigenous science and technology play the part of an engine in an aircraft, while foreign collaboration can play the part of a booster. A booster can give a plane an assisted takeoff, but the plane will be incapable of independent flight unless it is powered by engines of its own. If Indian industry is to take off and be capable of independent flight, it must be powered by science and technology based in this country.

Disappointment at the small return that has come from our investment in science and technology is sometimes expressed. It should be realized, first, that scientific and technological development on a broad basis involves the development of a large number of scientists and technologists and the maturing of many of them. This is a process which must inevitably take 15 to 20 years. It is only today that our investment in science and technology has reached the stage of bringing returns. The recent stoppage of foreign aid has shown our tremendous dependence on a vast variety of foreign-made materials and pieces of equipment, many of which could and should have been produced in our country long before this. We found that a very large number of these items can be produced as a result of the know-how which already exists in scientific organizations here, and steps are being taken to produce these without foreign assistance. The results will show themselves within the next few years, and I have no doubt that the confidence which Indian technologists will gain thereby will spread to Indian industrialists and administrators, many of whom, not having any basis for technical judgments of their own, are inclined to play it safe by relying on foreign consultancy.

Many examples can be given of foreign collaboration resulting in badly engineered plants or technical mistakes, and when such technical mistakes are corrected the foreign consultant benefits from the experience. Whereas, if an Indian scientific or engineering organization had been employed, the experience gained even from initial failures would have been a gain to the country. The Soviet Union did not hesitate to follow this path. One should also remember that, in buying foreign know-how, one is paying for an element which covers the cost of research and development done by the foreign consultant, and it is clear that a more permanent benefit to the country would result if this money were made available for supporting research and development in India.

There is one final point I would like to touch on, and that is the role of administration in science. It is thought by many that we are reasonably advanced in administration but backward in science and technology. This statement is misleading. We have fortunately inherited extremely competent administrative services capable of dealing with all the types of administration which had to be dealt with before independence, in what was intended to be a static and underdeveloped economy. Consequently, experience of the type of administration needed for industry and for science and technology has been lacking.

The type of administration required for the growth of science and technology is quite different from the type of administration required for the operation of industrial enterprises, and both of these are again quite different from the type of administration required for such matters as the preservation of law and order, administration of justice, finance, and so on. It is my personal view, which is shared by many eminent foreign scientists, that the general absence of the proper administrative setup for science is a bigger obstacle to the rapid growth of science and technology than the paucity of scientists and technologists, because a majority of the scientists and technologists we have are made less effective through the lack of the right type of administrative support. The administration of scientific research and development is an even more subtle matter than the administration of industrial enterprises, and I am convinced that it cannot be done on the basis of borrowed knowledge. It must necessarily be done, as in the technologically advanced countries, by scientists and technologists themselves.