India's Atomic Energy Programme – Past and Future

by **Dr. H.N. Sethna**

India had foreseen the potential for the peaceful utilization of atomic energy at a time when the pioneering activities in this field were geared essentially for military use. More than a year before the traumatic demonstration of the destructive force of atomic energy in Hiroshima, Dr. Homi Bhabha, the architect of the Indian nuclear programme, had declared 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". This statement captures the essence of India's efforts over the last three decades for the peaceful utilization of atomic energy, namely, the development of scientific and technological ability within the country to design and execute projects right from the laboratory stage to the industrial scale largely on the basis of its own efforts.

India had consciously avoided softer options and chosen the slower and harder path of a programme aimed at self-reliance which, in the long run, has paid substantial dividends. Today India is among the seven or eight countries in the world, and the only developing country, to have the complete fuel cycle, right from uranium exploration, mining, extraction and conversion, through fuel fabrication, heavy water production and reactors, to reprocessing and waste management. India has also reached a stage where its indigenously developed know-how can support all the required activities encompassing feasibility studies, site selection, detailed project design, construction, commissioning and operation of any plant in the entire fuel cycle chain. It has taken almost three decades of effort to reach this stage of development. The innumerable hurdles to be overcome along the way have given our scientists and engineers confidence that other difficulties, which may have to be faced in the future, can be surmounted.

THE EARLY PROGRAMME

India has had a rich tradition of fundamental research activities in various fields and has produced outstanding individual scientists like Sir C V Raman, S.N. Bose, K.S. Krishnan, Sir J.C. Ray and H.N. Saha. Organized research in nuclear science, however, began only in 1945, with the establishment of the Tata Institute of Fundamental Research in Bombay The Atomic Energy Act was passed in Parliament soon after the country gained independence in 1948, and set forth India's objective for the development and utilization of atomic energy solely for peaceful purposes It was, however, only in 1954 that the Government established a Department of Atomic Energy charged with the sole responsibility for all nuclear activities in the country. Until that time the work of the Atomic Energy Commission had been restricted to the survey of radioactive minerals, setting up plants for processing monazite and limited research activity in the area of electronics, methods of chemical analysis of minerals and the recovery of valuable elements from available minerals.

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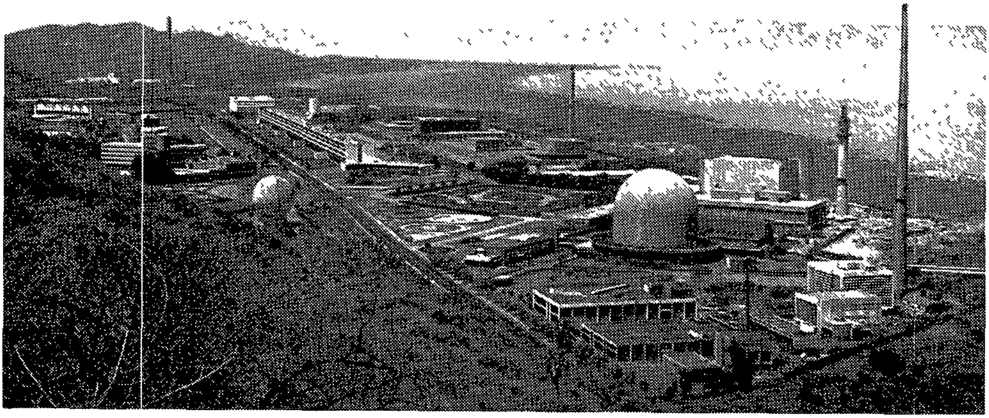


Figure 1. A view of the Bhabha Atomic Research Centre (BARC) at Trombay, near Bombay.

In 1954, a multi-disciplinary centre for research and development was set up in Trombay, near Bombay, which is now known as the Bhabha Atomic Research Centre (BARC). The fundamental criterion in the setting up of this national centre was that the institution should grow as the various groups developed indigenous know-how and became able to expand in a useful and co-ordinated manner. The beginnings were modest This Centre was initially manned by a small band of around 130 scientists and technicians. The Bhabha Atomic Research Centre has grown over the years to become the foremost institution of science and technology in the country with a staff of around 10000 of whom 3000 are scientists. A majority of these scientists and engineers are graduates of the Training School set up at the Centre in 1957.

A common dilemma of developing countries has been that technology imported from industrialized countries is often difficult to adapt to local socio-economic conditions. Such technology transfers can sometimes even hamper scientific innovations and entrepreneurial initiative for indigenous development leading to repeated technology imports. Many developing countries do not have a cadre of scientific and technical personnel who are capable of advising their national authorities on a strategy for the introduction of a sophisticated technology, such as nuclear energy, which would be suitable to local conditions. Most developing countries do not have adequate financial resources for establishing their own R & D efforts. The few developing countries that have the financial resources are, by and large, short of manpower and without adequate educational infrastructure. Another constraint which all developing countries have had to face is the absence of a diversified industrial base. In the developed countries, the frontier applications of nuclear technology were essentially an extension of already advanced conventional technology. On the other hand, even in India the era of nuclear power is concurrent with the beginnings of large-scale steel production, installation of fertilizer plants and other conventional industry set up with imported know-how. We had realized that the superimposition of advanced technology obtained from abroad does not imply progress in the real sense — it only creates illusions of progress. We recognized at an early stage of development that, due to these and various other factors, the most important task for the introduction of nuclear technology in India was to establish a cadre of scientists and engineers and generate interaction among various scientific disciplines and, at an appropriate stage, translate this interaction into concrete projects.

It was in this spirit that the first major project of the Centre was undertaken, namely, the building of a pool-type reactor. This reactor, named **APSARA**, became critical by 1956, within two years of the decision to construct it. It was the only reactor at that time in Asia, outside the Soviet Union We did not ask for such a reactor from the advanced countries but went about the work on our own. Except for the fuel elements, which were imported from the United Kingdom, the reactor and all its equipment were designed and built by our own people within the country. It was not an easy task. For instance, in the mid-1950s we had no experience in India on welding thick aluminium plates to the quality requirements for the reactor. Our engineers engaged on this job had to establish welding procedures and then train the welders themselves. Some of the early applications of argon arc welding involving aluminium and stainless steel were made on this and other projects at the Centre. The entire instrumentation and control system for the reactor was designed and built locally. The team of scientists engaged in this work drew upon their previous experience in designing instrumentation for cosmic ray experiments. This early experience has been mentioned in some details, since it demonstrates that with the multi-disciplinary interaction involved in the setting up of this first reactor, our learning process started well before the reactor became critical and available for experimental work and isotope production.

About the same time, in 1956, we decided to build **CIRUS**, a 40 MW natural uranium heavy-water moderated research reactor, with Canadian collaboration Our scientists were associated with the Canadians at all stages of this co-operative project. We simultaneously embarked on the task of setting up plants at the Centre, fully based on our own technology, for producing nuclear-grade uranium metal and fuel elements for this NRX-type reactor. We completed this task in time to provide half the initial fuel charge for this reactor, which became critical in mid-1960. The **CIRUS** reactor continues to be in operation to this day using fuel produced at the Trombay plant and heavy water from the facility we set up at Nangal in Northern India.

In the decade 1956—66, we embarked on a wide variety of technological activities such as uranium extraction and purification, fuel fabrication, reactor control and instrumentation, research reactor construction, radioisotope separation, radiation medicine and vacuum technology. Practically all these areas of technology were frontier areas even in the context of developments at that time around the world. All these facilities had small beginnings and expanded with the growth of expertise generated in our establishments.

In 1961 we commenced work for setting up a reprocessing plant at the Centre completely on our own and without any foreign collaboration. The plant was successfully commissioned in 1964, making India the fifth country in the world with reprocessing facilities. Incidentally, the cost of this plant was less than half the estimated cost of a similar capacity plant under construction at that time in another country. Our subsequent

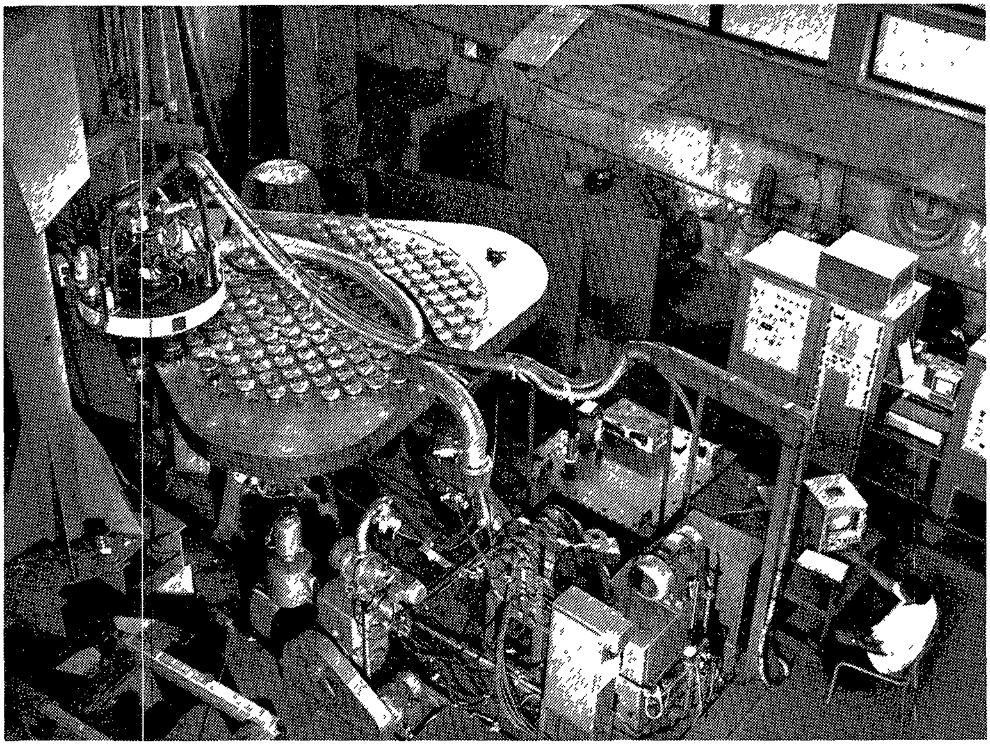


Figure 2. Tube to tube-sheet welding for the R-5 research reactor calandria at the BARC workshop.

experience in the construction of a power reactor reprocessing plant has confirmed our ability to set up and operate small capacity reprocessing plants at costs lower than indicative reprocessing costs elsewhere in the world.

THE APPLICATION OF COMMERCIAL NUCLEAR POWER

The decade 1966–76 saw the introduction of nuclear power in India. When early studies on the feasibility of nuclear power were carried out in the late 1950s and early 1960s, it was concluded that threshold conditions for introducing nuclear power on an economic basis existed in India in the western, northern and southern regions of the country These regions were chosen because of their distance from coal fields, which are largely concentrated in the eastern and central parts of the country. The transportation of coal over long distances to thermal stations continues to strain our transportation system and interruption of supplies have often caused load shedding. In some power systems, especially in the southern region where the bulk of electricity was traditionally provided by hydroelectric power plants, excessive load shedding had become a common phenomenon due to successive failures of the monsoons. Power production from oil and gas were never seriously considered in India, since a substantial portion of our requirements have to be imported. With increases in oil prices power production using oil became unfeasible. It was, therefore, recognized that power production in India would have to continue to rely on coal and hydro and, increasingly over the years, on nuclear power.

In formulating the strategy for nuclear power development in India, we had to take into account that, while our uranium reserves are rather modest (53 000 tonnes of which 30,000 are reasonably assured) we have one of the largest reserves of thorium in the world. We therefore conceived a three-stage nuclear fuel cycle strategy, with the installation of natural uranium reactors in the first phase, followed by fast breeder reactors in the second phase, using plutonium from the first generation reactors with either uranium-238 or thorium in the blanket, followed eventually by reactors based on the self-sustaining thorium-uranium-233 cycle.

India is one of the few countries at present continuing with the development of natural-uranium-fuelled reactors. The major reason has been our preference for a reactor system that can be operated using indigenous resources. This system also has the advantage of an efficient burnup, producing significant quantities of plutonium for use in fast reactors.

India's first nuclear power station at Tarapur, near Bombay, consisted, however, of two boiling-water reactors (BWR), each of about 200 MWe capacity, which went into operation in 1969. The decision to go in for a BWR system for our first nuclear power plant was prompted by the desire to demonstrate the economic viability of nuclear power in the country without delay by using a proven system. This station was a turnkey project awarded to General Electric of the USA on the basis of a global tender. The involvement of Indian personnel was, however, substantially more than the usual turnkey project Our scientists and engineers were responsible for all the preliminary work such as site selection, tender preparation and evaluation and also participated, to the extent possible, in the review of detailed designs, construction, inspection and testing of equipment and commissioning activities. Since 1975, the enriched uranium fuel elements for this station have been fabricated in India at the Nuclear Fuel Complex in Hyderabad from uranium hexafluoride imported from the USA We had not gone in for the development of indigenous enrichment capability primarily since a commercial scale enrichment plant would not be economically feasible for only one power plant for which, in any case, we had entered into an agreement for life-time fuel supplies.

About the same time as a commitment was made on the Tarapur plant, we also decided to install a heavy-water power station at Kota in the State of Rajasthan consisting of two 220 MWe reactors In this case, the project was a collaborative venture with Canada. India retained the responsibility for construction and installation activities while Canada undertook to supply the design and major equipment. We took the risks involved not only on the prices and schedule that such a procedure entailed but also in the capital investment on a system which was in its initial stages of development. While major equipment for the first unit of this station was imported, part manufacture of some of the major components was undertaken in India. We also fabricated many items of auxiliary equipment and half the initial fuel charge for the first unit. The efforts to rely on indigenous resources were intensified for the second unit of this station and major components such as the calandria, end shields, steam generators and fuelling machines were manufactured in the country. The first unit of the Rajasthan station has been in operation since 1975 and the second unit is in an advanced stage of commissioning.

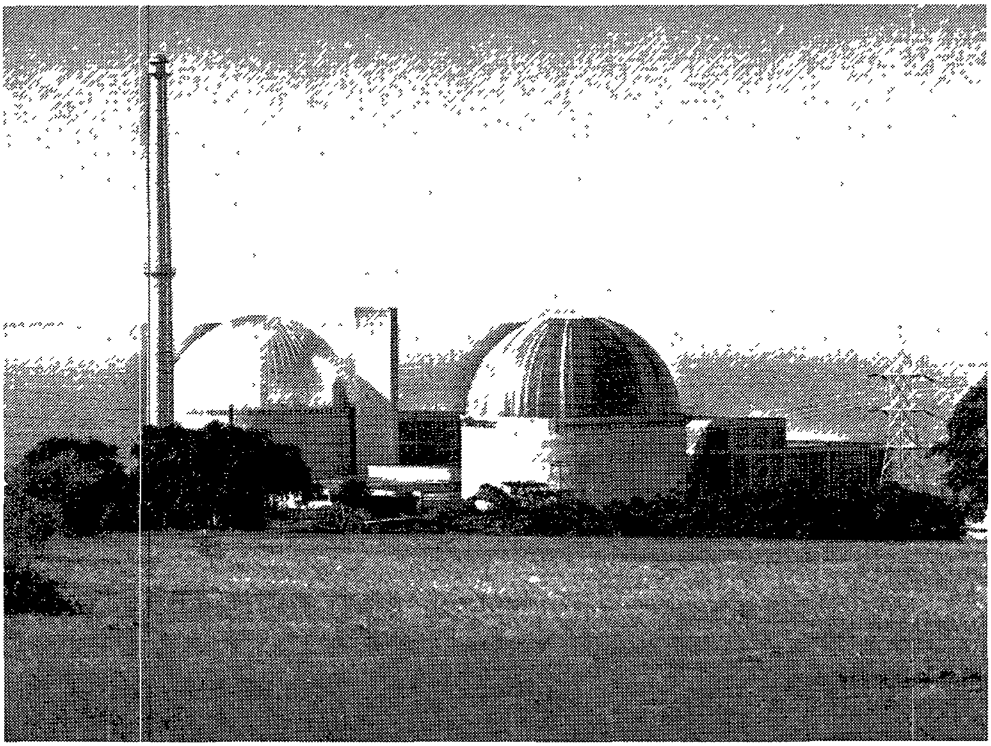


Figure 3. The Rajasthan nuclear power station at Kota.

Our third atomic power station, consisting of two heavy-water reactor units of 235 MWe each, the first of which is expected to attain criticality next year, is being built near Madras in Southern India. The full responsibility for the execution of this project rests with our own engineers and scientists. Several design modifications and improvements have been introduced at this plant for reasons of economy and to take into account local conditions. The fourth power station under construction at Narora in the State of Uttar Pradesh in Northern India also consists of two 235 MWe heavy-water reactors. These reactors have several new design features and concepts, including earthquake resistant design of the buildings and reactor components. Among the new features of the Narora reactors are an integral calandria-end-shield assembly, two independent fast-acting shut down systems for safety and reliability and a simplified water-filled calandria vault. We are standardizing the Narora designs and propose to repeat this design for two additional projects before we move on to construction of 500 MWe reactors of our own design. For certain components, such as reactor coolant pumps and steam generators, we have decided to standardize not only for the current size of reactors under construction, namely, 235 MWe, but also for the next size of 500 MWe. We propose to achieve this by using twice the number of components for the larger reactors and defer the scaling-up effort required by our industry to a later stage.

As a result of intensified efforts at using our own resources, we have progressively reduced the import component of our nuclear power projects. The import component of the first

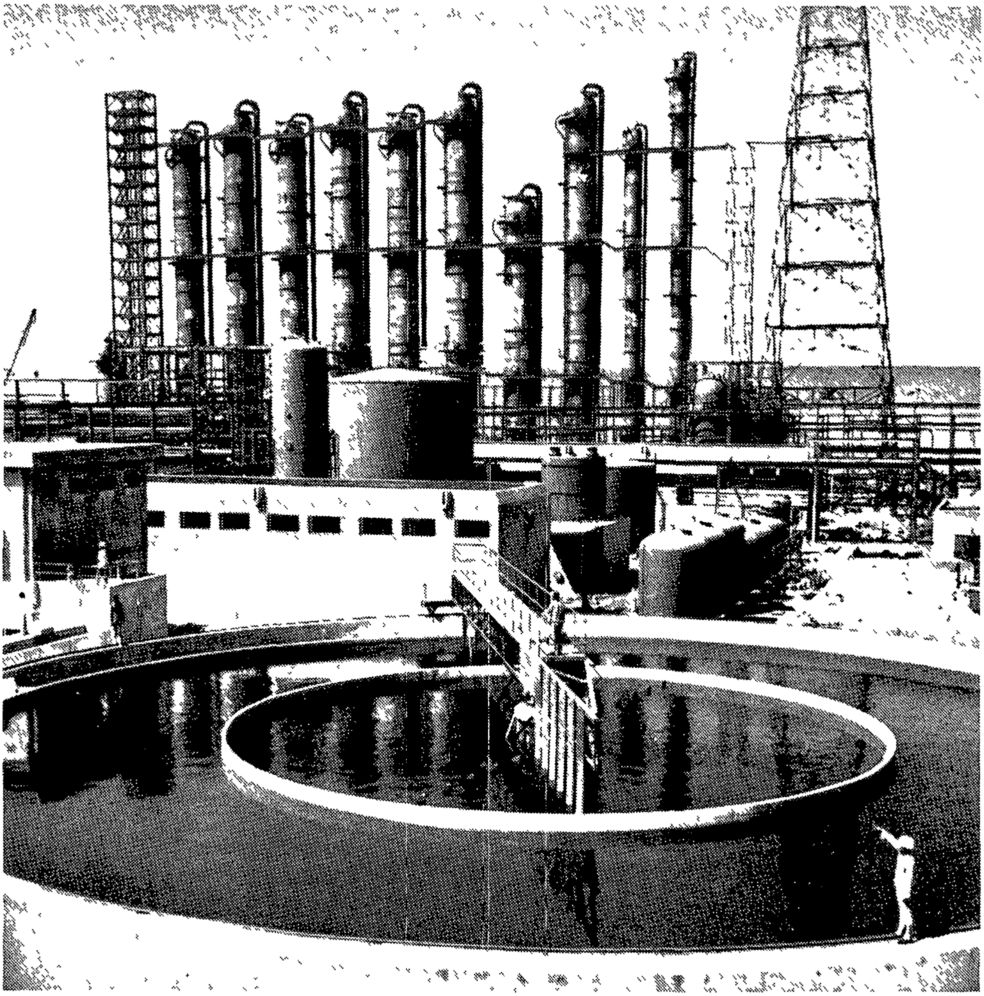
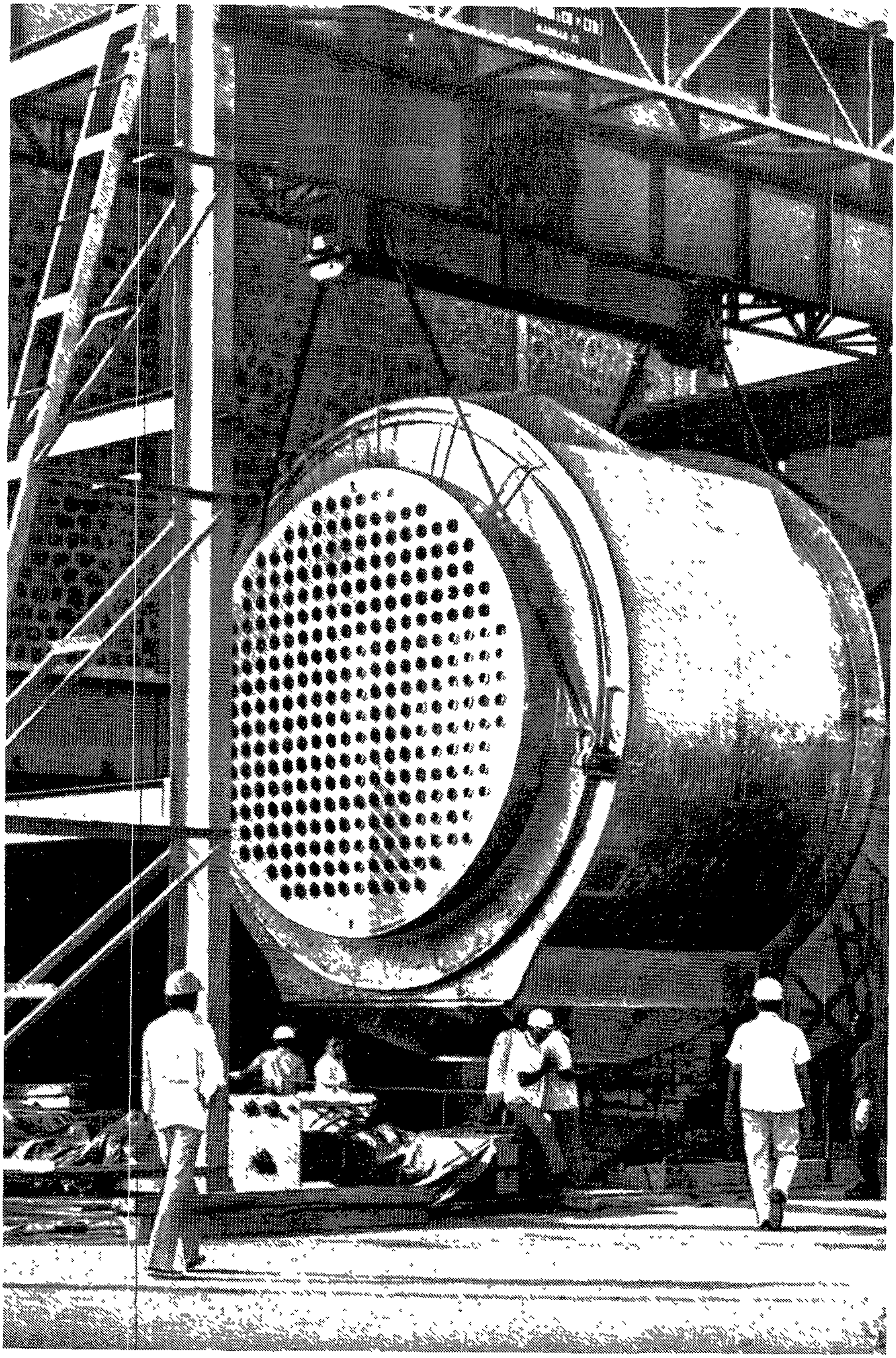


Figure 4. Heavy-water plant, using Indian-developed technology, nearing completion at Kota.

unit of the Rajasthan station was 45%, and this was reduced in the case of the second unit to 30% The import component declined further to 12% for the Madras power station and it is only around 9% for the Narora plant. Even this marginal import will be eliminated once the new manufacturing plants being set up in the country start operation. The establishment of design and manufacturing capability also helped us to reduce indirect costs of engineering, field management and commissioning, which usually form a substantial part of a turnkey project. For instance, we were able to reduce the cost of engineering as a percentage of cost per kilowatt installed from around 15% for the first unit of the Rajasthan station to less than 6% for the Narora plant. This is in spite of the fact that extensive design modifications were carried out for seismic conditions and various new concepts introduced in the later plant.

Figure 5. A calandria, of Indian manufacture, being installed at the Madras nuclear power station. ▶



THE IMPACT OF INDIA'S NUCLEAR PROGRAMME

To achieve our present level of self-sufficiency, the Department of Atomic Energy undertook tasks which perhaps have not been attempted by a similar organization anywhere else in the world. This reflects both our inherent weakness and our strength. We had to locate domestic manufacturers and persuade them to put in the effort to make precision components, both heavy and light, for the first time in the country. The Department of Atomic Energy itself had to evolve procedures for manufacture, quality control, inspecting techniques, etc. Often we had a difficult time in locating a single manufacturer with all the facilities for completing a job and we were forced to farm out such work to different manufacturers. This brought in its wake special problems of co-ordination between different shops, sequencing operations, corrective actions for deviations, etc., and finally we had to take up the work of the assembly of components In some cases, as for example, certain coolant channel components, we could not find any manufacturer willing to put in the effort and the money for such high-precision items, we could have taken the easier route of importing these components but having decided to tackle the problem and solving it ourselves we undertook this work within the organization

Nuclear power in India has not only been demonstrated as an economically competitive and safe source of energy but it has also played the invaluable role of a catalyst for the scientific, technical and industrial development of the country as a whole. Pioneering work in the field of process and equipment design for various chemical operations or metallurgical activities were carried out by the Department of Atomic Energy. The success of our national effort has made our industry, both in the private and public sectors, conscious of its potentialities for excellence. There was a significantly higher level of quality consciousness and improvements in the shop practices of almost all manufacturers who have been associated with our programme Though the resultant upgrading of the technological base was initially a difficult and expensive task, it has often given our industry the confidence and ability to secure expert orders against international tenders even for conventional equipment for sugar plants, cement plants, power plants, etc.

Work in the fields of nuclear fuels and materials has also generated internal demands for advanced materials of construction and for the means of producing them. For instance, the techniques developed for the extrusion of Zircaloy has found application in the extrusion of alloy steel tubes for use in our petroleum industry. The experience gained in the operation of highly instrumented plants in the nuclear industry permit local design of various chemical plants. Our expertise in vacuum melting and casting of uranium could be useful for the production of metals and alloys of controlled composition and to the progress of powder metallurgy. Even in the conventional field of civil construction, the experience gained on our nuclear projects has resulted in the mastering of new techniques. One example is in the field of pre-stressed concrete. The reactor buildings at the Madras station are built completely in pre-stressed concrete for a designed internal pressure containment of over one atmosphere. There is a large number of similar examples of the beneficial spinoff from the atomic energy programme to industrial development in the country.

THE FUTURE

Our reactors in operation and under construction presently account for only about 1300 MWe of installed capacity. The "high" estimate for our projected installed capacity at the turn of this century is a relatively modest 10 000 MWe, of which 3000 MWe is expected to be provided by fast breeder reactors. This will not be an easy task. Although we can build nuclear power plants at lower investment costs than are achieved in other parts of the world, the initial investment required and the gestation periods involved are still greater than those for coal-fired power stations. The availability of adequate investment capital could, therefore, pose a constraint in the immediate future. In the longer run, investment in nuclear power is expected to increase as mining and transport of coal in the next few decades becomes progressively more capital-intensive. We will also have to continue our efforts to upgrade domestic industry to meet the additional requirements of our programme.

The "no growth" philosophy and curbing of consumption in the energy sector, which is being advocated for good reasons in some advanced countries, has no relevance in our socio-economic conditions. Although our per capita consumption of electricity is very low, the bulk of electrical energy is consumed either in industry or in agriculture. Domestic use of electrical energy is hardly 10%. A significant part of the energy input in India is from the so-called non-commercial sources, such as fire-wood, which leads to deforestation on a large scale. Both economic and environmental factors would, therefore, dictate an increase in electrical energy consumption. It is perhaps for these reasons that we have not faced problems of public acceptance of nuclear power in India. This has not in any way made us complacent about the important question of nuclear safety. Our health physicists and radiation protection groups have established stringent standards and norms and we are actively participating in international co-operative efforts to strengthen and streamline methods further for safety evaluation and surveillance.

India's programme for the peaceful utilization of atomic energy has, to a certain extent, been affected by restrictive trade practices and unilateral embargoes on nuclear supplies by certain countries. These are unfortunate developments since they are essentially based on political mistrust and discrimination. In the case of India, such measures will cause temporary delays and perhaps cost over-runs for projects in the near future. In the long run, these developments will only strengthen and accelerate India's programme for complete self-sufficiency in the nuclear field.