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INDIA'S NUCLEAR POWER PROGRAMME AND CONSTRAINTS ENCOUNTERED IN ITS IMPLEMENTATION

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Abstract

Nuclear power development in India is based on the natural uranium fuelled pressurised heavy water reactors. However in order to acquire early experience in operation and maintenance of nuclear power stations, India's first atomic power station comprised of two units of boiling water reactors. Subsequent nuclear power stations currently in operation or under construction employ natural uranium heavy water reactors and each of the stations is a two reactor installation. While the first two nuclear power stations employ reactors of 200 MW capacity, the subsequent stations employ reactors with an output of 235 MW. 500 MW heavy water reactors are visualised for the period beyond 1985.

The first nuclear power station was essentially fully imported; the second nuclear power station which employs heavy water reactors already has a significant contribution of equipment manufactured in India. For the third nuclear power station and the subsequent one, practically all equipment is being manufactured indigenously. The nuclear power station at Narora is in a seismic region and hence the design is substantially more advanced than the ones at the earlier sites and also employs concepts which will be used in the 500 MW reactors.

Efforts are being made in the country to integrate power

generation systems into larger regional grids and eventually into a national grid; however, the distributed nature of power generation at present and other infrastructural limitations still favour small and medium size plants only. The paper brings out the efforts put in over the last ten years in establishing capability for design and manufacture of all equipment and systems required for nuclear power plants. A major constraint in expanding the nuclear power capacity is naturally related to the competing demands on available national resources. The paper also discusses other constraints than purely technological and financial and describes how efforts are being made to overcome these constraints.

1. Historically electric power generation in India has been based on hydro electric generation. Indeed India has some of the very early hydro electric power stations in Kashmir in the Northern part and in Mysore in the Southern part of the country. Thermal power generation largely based on coal was primarily confined to Eastern regions of the country around Calcutta, near the coal fields and in the other industrial centres such as Bombay. After the country became independent, hydro electric power development received substantial attention as part of multipurpose river valley projects aimed at flood control and water and soil conservation. Commencing from the early 60's, installation of relatively large sized coal fired thermal units received considerable attention even in regions of the country remote from the coal fields. In some of the power systems, especially in the South where bulk of the generation was from hydro electric power plants, due to failure of the monsoon in successive years, extensive load shedding became necessary. The need to provide adequate thermal back-up to such power systems was then recognised. Since most of the coal resources in India are concentrated in the Eastern and Central parts of the country, transportation of coal to load centres located in the Western, Northern and Southern parts of the country involves a distance of about 1000 Kms. or more. Power production based on oil or gas has not played any significant role in the country especially as oil has had to be imported to a large extent. (at present, 55% of our oil requirement is imported). With the increase in oil prices that has taken place from 1973 onwards, any large scale use of oil as a fuel for power production is uneconomic. Even with the location of some significant oil and gas resources such as the off-shore areas of Western India, oil and gas will not contribute in any significant measure to power generation. Production of electric power in India will, therefore, continue to rely on hydro and coal and in increasing measure on nuclear.

2. When the early studies on introduction of nuclear power into power systems in India were carried out in late 50's and early 60's, the conclusion was reached that threshold conditions for introduction

of nuclear power on an economic basis existed in Western India (around Bombay), Northern India (around Delhi) and Southern India (around Madras). Apart from the localised nature of Indian coal deposits referred to earlier, another factor which inhibits transportation of coal over long distances is the fact that most Indian coals have ash content varying from 30-40%. While generation of power from coal is being increased all over the country, as a matter of policy wherever feasible large coal-fired stations are being located at or near pit head. However, it has become necessary to construct coal based power stations at or near the load centres in view of the industrial development pattern that obtains. The conclusion reached in the mid 60's, namely that conditions for economic introduction of nuclear power in Western, Northern and Southern India exist essentially holds valid now also. The paper will discuss later the cost experience on the Indian nuclear power stations.

3. India has one of the largest resources of thorium and a somewhat modest resource of uranium. The strategy of nuclear power development has, therefore, considered installation of natural uranium reactors in the first phase, followed by fast breeder reactors in the second, using plutonium from the first generation reactors with either U-238 or thorium in the blanket, followed eventually by reactors based on the U-233 thorium cycle. The natural uranium resources initially identified in the country indicated that a natural uranium reactor programme of between 5000 to 8000 MWe could be sustained. Recent exploratory work has revealed the existence of substantial quantities of uranium resources in other parts of the country and there is reason to believe that a much larger thermal reactor programme than had been initially envisaged should now be possible. So far as targets for nuclear power are concerned, we have at present rather indicative figures; the actual capacities installed will depend on the operation of a number of constraints, which will be discussed in due course. The indicative targets are a nuclear capacity in the region of 6000 MW by the year 1990, of which approximately 1000 MW may be in fast reactors, and about 20000 MW by the year 2000, of which fast reactors could account for between 5000 and 7000 MW. India is one of the few countries which is continuing with the development of natural uranium fuelled reactors. The principal justification for this approach is that the country requires a reactor system that can be fuelled from indigenous resources. The external balance of payment position of the country over the last many years has been such that any option which involves continuing import of fuels, whether it be oil or nuclear fuel, in large quantities, cannot be considered. In the heavy water reactor system, we have a system which is an efficient burner and which produces significant quantities of plutonium, a fissile material ideally suited for use in fast reactors. Moreover the reactor system using heavy water and natural uranium was eminently suited from the point of view of manufacture of components within the country. India's experience with heavy water reactors started in 1961 when two research

reactors of this type went into operation. Even well before the first heavy water power reactor went into operation the country had considerable experience in operating heavy water reactor systems.

4. India's first nuclear power station consisting of two boiling water reactors each of 210 MW capacity went into operation in 1969. This station was built on the basis of a turn key type contract, the contractor being selected on the basis of global bidding. When the tenders were invited for this station in 1962, our preference for the natural uranium system was stipulated but the door was left open for enriched uranium reactor systems also. The tenders revealed that the then available natural uranium system, based on graphite reactors was eneconomic. Tenders based on the heavy water reactor system were not received as at that time none of the tendering parties had enough experience on this reactor system. While the first nuclear power station was built on the basis of a turn key type contract, the Department of Atomic Energy was responsible for all the preliminary work such as site selection, tender preparation, tender evaluation and contract preparation. Subsequently engineers of the Department were associated in the review of detailed designs for the power station, inspection at equipment manufacturers' works, inspection at site and testing and commissioning activities. The involvement of the owner's engineers and scientists was substantially more than in a normal turn key contract. Over the last seven years of operation of the Tarapur Station many interesting and complex problems have been encountered and the station staff have been able to handle successfully all these contingencies. In another paper to this Conference, details of the operating experience of this station are discussed. It would be of interest to mention that commencing from 1975, all the reload fuels have been supplied from the Nuclear Fuel Complex of the Department of Atomic Energy and from middle of 1976 onwards, the fuel management services are being rendered by the Bhabha Atomic Research Centre.

5. About the same time as a commitment on the Tarapur Station was made (1964), a decision was taken to install a heavy water type power station in the Northern part of India, in Rajasthan. This decision was preceded by a joint Indo-Canadian study on the technical and economical feasibility of constructing in India a power plant similar to the one at Douglas Point. In this instance, the project was executed on a different basis as compared to the first one; Canada was responsible for the design and supply of major equipment, while India retained the responsibility for construction and installation activities. The owner i.e. the Department of Atomic Energy naturally took the risks involved on price and schedule that such a procedure entails. Right from the commencement of this project efforts were made to manufacture in India as many components as possible. While major equipment both nuclear and conventional had necessarily to be impor-

ted, part manufacture of some of the major components was taken up in India. Apart from the many auxiliary equipment which were supplied from Indian sources, half the initial fuel charge was manufactured in India. In addition, the instrumentation and control system was to a large extent, assembled in the country. The efforts at indigenisation of components were intensified for the second unit of the Rajasthan Station and major nuclear components such as the calandria, steam generators, end shields, and fuelling machines were manufactured in the country. The first unit of the Rajasthan Station became critical in August 72; however, due to problems encountered in the turbine, power supply to the grid commenced only in May 73. Due to the fact that the reactor was loaded entirely with natural uranium fuel, there was a restriction on reaching full power till an adequate degree of flux flattening was achieved. The unit operated at near full power in July 74. Operation of the unit during 1974-76 has been affected by repeated failures of turbine blading. From about May 76, the unit has been running fairly steadily at a reduced output, the reduction being due to removal of third stage high pressure blading. In the operational phase since then, the primary effort has been to improve heavy water integrity and achieve better recovery of the escapes from the system. During the period 1972-1976, many inadequacies in the design and equipment choice in auxiliary systems were noticed and extensive engineering was required to be done to improve these deficiencies. The experience we have had is that engineering organisations used to North American conditions generally do not adequately appreciate the service conditions under which systems and equipment have to operate in developing countries. While Canadian technicians participated in commissioning the first unit of the Rajasthan Station, the commissioning activities of the second unit are being handled entirely by Indian technicians. The experience gained in the operation of the first unit over the last four years has been taken note of in carrying out appropriate design changes for the second unit and for the subsequent heavy water reactor units that are being set up.

6. In 1967 a decision in principle was taken to initiate work on the third nuclear power station in India also consisting of two units of the heavy water reactor type. In this instance it was decided to take on complete responsibility for the project as an Indian venture. The Power Projects Engineering Division of the Department of Atomic Energy was then set up and was entrusted with the task of engineering, construction and commissioning of the project. The nuclear design activities have been retained as an in house function and established Indian consulting engineering organisations in the field of power plant engineering have been associated to render engineering services in the conventional areas of the plant. All the major nuclear and conventional equipment including the turbogenerator have been manufactured in India. Preliminary work on establishing a township prior to commencement of site activities was taken up in 1968-69 and ground was broken in the reactor site in 1970. Thr first unit of the Madras

Atomic Power Station is expected to go into operation towards the end of 1978 and the second one in middle of 1980.

7. Following the Madras Atomic Power Station, authorisation to proceed with another twin unit station using units of 235 MW at a site near Delhi was accorded in 1974. In this instance the site is located in a seismic zone and it has therefore been necessary to extensively redesign the systems to make them suitable for such a site. The design is substantially more advanced than of the earlier units and has taken note of the operating experience of the first unit. The Narora designs are being standardised and are expected to be used in some more power stations. However, sometime around mid eighties, it is expected that the first unit of 500 MW reactor of our own design will be ready and this will thereafter be standardised.

8. In comparison with the current practice in most of the countries of the world, India is continuing to build relatively small size units. The distributed nature of the power systems in the country has necessitated a cautious approach in the selection of unit size. Considerations of spinning reserve availability and disturbance to the grid in the event of forced outage of the nuclear unit, still favour adoption of reactor units in the size range of 200/250 MWe. While justification for going in for large unit sizes in other parts of the world has been the reduced installed cost, our experience has been that the investment cost of the relatively small size units with most of the components supplied from within the country has indeed been comparable to that of relatively larger units installed in other parts of the world. Table I gives the capital cost of the various heavy water power reactors installed todate. It will be seen from the table that for the Madras Atomic Power Station whose units are expected to go into operation in 1978-80, the cost per KW installed including the cost of heavy water works out to less than 700 U.S. dollars. The cost for a new project for completion in 1984-85 period would also be under 1000 dollars per KW. It may be noted that in these cost figures are also included fairly substantial costs towards township and necessary infra structure, costs not often encountered in developed countries. Although on the basis of international comparison, the costs of the Indian heavy water reactors are lower, intensive efforts are being made to contain costs further in order to make available electrical energy at as competitive a price as possible. The main thrust in containing costs are -

(a) Standardisation of designs so that repeat manufacture of components is possible and

(b) Compressing the construction and manufacturing time as much as possible, to reduce the effect of interest during construction.

9. A developing country establishing design and manufacturing capability in nuclear power plant equipment has a big scope for reduction in the indirect costs. When a nuclear power station is bought on a turn key basis, the cost of engineering, field management and commissioning can represent a significant part of the total cost as a large number of expatriate engineers and technicians would be required in the setting up of the project. Table II compares the percentage of the total cost accounted for by engineering, field management and commissioning for the Indian heavy water reactors. Substantial gains are made when the engineering is transferred from overseas to the recipient country and further when repeat engineering is performed. A major constraint in any developing country embarking on setting up its own engineering organisation for nuclear power plant work is the availability of technical manpower, both in quality and in depth. In our programme, when the Power Projects Engineering Division was set up, the Bhabha Atomic Research Centre already had a large number of engineers and scientists who had substantial experience in various aspects of nuclear technology. The training programme for graduate engineers and scientists which has been going on at the BARC for the last 20 years, has been an important source of technical manpower for the power projects. Mere availability of formally trained people and the existance of an R & D organisation are not adequate to generate personnel with the necessary degree of confidence in tackling problems of design, manufacture and installation. It is the fact that a number of challenging design and construction projects were taken up and completed even before we launched on the nuclear power projects that has been responsible for making available the requisite personnel, both in quality and in number.

10. A major constraint that has been faced in implementing the nuclear power projects is the difficulty in getting major nuclear components manufactured in shops within the country in the time schedule required for the project. When it was decided to manufacture such components in India, heavy fabrication industry was just in the process of being set up. Till then the fabrication experience was confined to manufacture of cement plants, sugar plants, and small and medium size boilers. Indian industry both in the private and public sector was persuaded to participate in the manufacture of the nuclear components. In some instances such as precision machining of reactor internal components, there was inadequate response from industry and therefore this activity had to be taken up in the Central Workshops of the Bhabha Atomic Research Centre. In the manufacture of major nuclear components such as end shields, calandria etc., considerable efforts were put in jointly by our engineers and the industry to develop tooling, train welders, install clean shops and set up competent inspection groups using optical and other sophisticated instruments. In a number of instances, extensive mock up work and trial fabrication and machining had to be resorted to before embarking on the actual work. The

task of establishing competent manufacturing capability for the entire range of nuclear components has been a difficult one and at times frustrating but in the end it has been a rewarding activity. Table III gives brief particulars about the time taken for the manufacture of two major components namely the calandria and the end shields and also the number of design concessions that have been agreed to in the process of manufacture. As will be seen from the Table, there has not only been improvement in the total time of manufacture but also a substantial reduction in the number of design concessions granted. Lately we have been involved in inducting some degree of competition in the supply of even the major components. At present we have been able to qualify two to three suppliers for many of the components.

11. Although India has been able to establish engineering and manufacturing capability for nuclear power plants, availability of investment capital represents a major constraint in the rate of increase of installed nuclear capacity. As has been pointed out earlier, investment costs on nuclear power plants built in India are lower than similar nuclear power plants built in other parts of the world; nevertheless the investment costs are higher than for coal fired stations. Moreover, the gestation period for a nuclear power plant built hitherto has been 8 to 10 years. Since there has been a suppressed demand for electrical power all over the country, in drawing up our power plans, it is necessary to give higher priority for installation of coal fired thermal power stations which can be brought on line in a shorter time than nuclear stations. Table IV gives the investment in the power sector for the 4th and 5th plan periods and the percentages of the power sector allocated to the nuclear power programme. It will be seen that while investment in the nuclear power programme in absolute terms has increased quite substantially, the allocation as a part of the power sector has actually reduced. It is expected however, that in the longer term investment on the nuclear power programme will be accelerated as mining and transportation of coal in the next few decades could become progressively more capital intensive than hitherto.

12. Certain constraints of a non-technical nature have to some extent affected the implementation of our nuclear power programme adversely. These constraints relate to embargoes placed by certain supplier countries on supply of materials and components even though they are destined for purely peaceful applications such as nuclear power stations. We do not share the view that the objectives of non-proliferation would be achieved by placing such arbitrary embargoes on the free flow of materials and equipment. The history of scientific and technical progress over the many centuries has clearly demonstrated the beneficial nature of free flow of ideas and devices from one part of the world to another. Only a few centuries ago, which is a short time in the history of mankind, scientific and technological ideas flowed westward from India, China, Persia and Arabia. A

similar free flow of ideas, techniques and equipment could only contribute to further progress of mankind.

13. The experience in the implementation of the Indian nuclear power programme described in this paper may be useful to some of the other developing countries who are in the process of initiating their own nuclear power programmes. It is true that each case is specific and the conditions obtaining in India may not necessarily apply to other countries. However, it is hoped that some useful lessons can be drawn from our experience.

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TABLE I

COSTS OF PRESSURISED HEAVY WATER REACTORS CONSTRUCTED IN INDIA

	Total cost Rupees per KW	Time period over which bulk of the expenditure is incurred
Rajasthan Atomic Power Station Unit-1	3334	1966-1972
Capital value of Heavy Water inventory	630	
(Outlay on township and social services included in the total cost)	170	
Rajasthan Atomic Power Station Unit-2	4285	1968-1977
Capital value of Heavy Water inventory	1200	
(Outlay on township and social services included in the total cost)	170	
Madras Atomic Power Station Units 1 & 2	4352	1972-1980
Capital value of Heavy Water inventory	1280	
(Outlay on township and social services included in the total cost)	124	
Narora Atomic Power Station Units 1 and 2	4466	1977-1983
Capital value of Heavy Water inventory	1460	
(Outlay on township and social services included in the total cost)	121	
New Project (2 units of 235 MW each)	6359	-
Capital value of Heavy Water inventory	1540	
(Outlay on township and social services included in the total cost)	186	

Notes :

1. The cost values are given in Indian Rupees per KW installed.
2. The investment costs are given in terms of total rupees (not constant value rupees) based on cash flow.
3. Interest during construction is not added to the capital cost given above; this is allowed for appropriately in the arriving at unit energy cost.
4. Heavy water is not capitalised in the cost of the station as it is leased from an inventory account at appropriate lease charges; the capital cost includes lease charges on heavy water prior to

commercial operation as well as allowance towards heavy water losses during commissioning.

5. The Narora Station cost has a certain provision for escalation and contingencies but this may be exceeded and the capital cost may go up to ₨ 5100 per KW due to the steep escalation of prices experienced in 1973-1975 period.

TABLE II

COSTS OF ENGINEERING, FIELD MANAGEMENT AND COMMISSIONING

	Engineering		Field Management		Commissioning	
	Cost in Millions of Rupees	as % of cost/KW	Cost in Millions of Rupees	as % of cost/KW	Cost in Millions of Rupees	as % of cost/KW
R.A.P.P. Unit-1	107	14.6	17	2.3	42	5.7
R.A.P.P. Unit-2	119	12.7	36	3.9	45	4.8
M.A.P.P. Units 1 & 2	92	4.5	63	3.1	26	1.3
N.A.P.P. Units 1 & 2	119	5.7	57	2.7	24	1.1
New Project Units 1 & 2	132	4.4	57	1.9	30	1.0

Notes :

1. For RAPP-1 and RAPP-2, a substantial part of the engineering was done overseas. For all other projects, engineering is done entirely in India.

2. The commissioning costs include costs of commissioning personnel, loss of heavy water during commissioning and consumables. For RAPP Unit-1, a significant portion of commissioning cost was towards expatriate salaries etc. For RAPP Unit-2 while no expatriates are used for commissioning the cost of commissioning is high due to the high price of D_2O operating in this instance.

3. The cost of engineering is higher for NAPP as extensive re-engineering is required for a seismic site and many improvements have been made over the earlier design.

4. For a New Project since the NAPP design will be repeated, the cost of engineering is lower than for NAPP.

TABLE III

FABRICATION EXPERIENCE IN MANUFACTURE OF NUCLEAR COMPONENTS

		RAPP-2	MAPP-1
Calandria	Fabrication time - months	38	38
	Number of design concessions	51	25
End Shields	Fabrication time - months	51	44
	Number of design concessions	49	31

TABLE IV

OUTLAYS ON POWER SECTOR AND ON NUCLEAR POWER

	IV Plan (1969 - 1974)	V Plan (1974 - 1979)
Outlay on Power Sector as percentage of total plan outlay	18.6 %	16.6 %
Outlay on Power Sector in millions of rupees	29,320	61,900
Outlay on Nuclear Power Programme as percentage of outlay on power sector.	5.5 %	4.3 %
Outlay on Nuclear Power Programme in millions of rupees.	1,619	2,688