NUCLEAR FUEL FABRICATION IN INDIA*

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1.0 In India the per capita power consumption is very low compared to the advanced countries. The per capita consumption in India was 94 KWH in March 1972 as against 38 KWH in 1960-61. For the economic progress in the country, it is very essential that power generation has to be considerably increased. India's resources for such a large scale power generation are adversely distributed in specific locations in the country. For instance, the major coal reserves of the country are in the north eastern zone of Bengal-Bihar coal belt with very small reserves in the central region of the country. The major hydro power resources are in the not easily approachable hill ranges and in other available limited zones. The resources are much dependent on the vagaries of rain fall. The established oil reserves are also very much limited. The installed capacity and energy generated for the years 1960 - 1973 is as follows:

	1960-61	1972-73
Total installed capacity (Million Kw)	5.65	17.893*
Hydro (Million Kw)	1.92	6.786
Thermal " "	3.40	10.745
Diesel " "	0.33	0.362
Total energy generated (Billion Kw)	20.12	67.000

*This figure excludes 600 MWe nuclear power.

1.1 Taking into consideration the available resources, the Atomic Energy Commission (AEC) of Government of India has stressed that nuclear power programme has a very important role to play in meeting the power needs of the country.

1.2 The established reserves of uranium are of very limited nature and are not sufficient to sustain any significant installed nuclear power capacity for a long time based on natural uranium reactors. India is one of the foremost countries in its thorium reserves. The total reserves of thorium in India amount to over 500,000 tonnes in a readily extractable form, while the known reserves of uranium are less than a tenth of this. The aim of a long range atomic power programme in India has therefore to base nuclear power generation as soon as possible on thorium rather than uranium. Since all power reactors intended for breeding appear to require the use of enriched or pure fissile material a self sufficient programme must provide for production of such material. On various considerations the best way is to produce Pu as a by-product in atomic power station working on natural uranium. Heavy water moderated and cooled, natural uranium fuelled power reactors offer a very advantageous system for the first stage of the power generation programme leading to plutonium fuel based power reactor programme in the second stage and finally the thorium breeder system. AEC has now proposed a total nuclear power generating capacity of about 6,120 MWe by March 1989. Considering the meagre infra structure within the country, it has been realised that the nuclear fuel production in all its aspects has to be arranged as a governmental activity of Department of Atomic Energy (DAE). The foreign exchange affected by the indigeneous operations is also of very great importance to a developing country. An attempt is made in the following paras to highlight nuclear fuel fabrication programme being followed in India.

2.0 Tarapur Atomic Power Station was the first to be taken up for the Indian Atomic Power Programme and has been completed by International General Electric Company in the year 1969. The operations since the commissioning of TAPS (400 MWe for 2 units) in October 1969 have fully borne out the economic viability of atomic power in Western India. The first unit (200 MWe) of Rajasthan Atomic Power Station has attained its criticality on August 11, 1972 and is in operation since then. Construction work is progressing well on the second unit (RAPP-II 200 MWe) and is expected to be critical sometime in the year 1976. Two more stations of same type with some design modifications, MAPP-I and MAPP-II are planned at Madras 220 MWe each and are expected to be commissioned sometime in the years 1978 and 1980 respectively. It has also been decided by AEC to locate another Nuclear power station at Narora with a capacity of 220 MWe which is scheduled to go into operation in the year 1982. The location of various reactors is shown in Figure 1. While the Tarapur Atomic Power Station is based upon slightly enriched uranium oxide fuel clad in zircaloy, other stations are based upon natural uranium oxide fuel clad in zircaloy. Considering various types of fuel requirements, DAE has stressed setting up of fuel fabrication facilities.

3.0 The fabrication of fuel has been taken up on a firm basis with a commitment to supply initial core fuel elements for 40 MWt CIRUS research reactor at Trombay which is loaded with aluminium clad natural uranium metal fuel elements. Towards this, uranium metal production plant and fuel fabrication plant were set up in the year 1959. The initial investment in the fabrication plant now known as Atomic Fuels Division (AFD) is of the order of 5 million rupees (1959 price) with a foreign exchange component of about 3 million rupees. In the fabrication plant, the uranium metal is vacuum melted and cast, hot rolled in the alpha range, beta heat treated, machined and clad in finned aluminium tubes and finished fuel elements along with end attachments are supplied to CIRUS reactor. It may not be out of place to mention here that basic design of the fuel element has been supplied by Atomic Energy of Canada Ltd. and opportunities were provided for scientific staff to visit some of their fabrication operations. The whole technical know-how has to be entirely developed locally and the choice of equipment and its lay out, commissioning and putting into operation has been entirely handled by the Indian personnel. The replacement requirements of fuel and other components since year 1960 are being completely met. The behaviour of the fuel in the reactor has been satisfactory all these years. Having the facilities for the fabrication of uranium metal, the fuel for Zero Energy Reactor for Lattice Investigations and New Assemblies (ZERLINA) based on uranium metal rod clad in aluminium has been fabricated and supplied.

3.1 By that time it has become apparent that for power reactors uranium oxide fuel has considerable advantages over metallic fuel. In conformity with the decision to go ahead with uranium oxide fuelled Heavy Water Reactor, development work has been taken up with regard to the technology of oxide fuel fabrication. Towards this, Uranium Metal Plant (UMP) has standardized various parameters and produced acceptable grades of uranium/oxide powder for production of sintered pellets. After considerable study of the production parameters with regard to the pressing and sintering of ceramic grade uranium oxide powder, aluminium clad high density uranium oxide fuel has been produced for full core of ZERLINA Reactor. This has given sufficient insight and experience into the technology of production of high density uranium oxide pellets. By that time, a commitment was made to produce half initial core loading and stand-by fuel for RAPP-I reactor while the other half was being procured from Canada. With the assistance of AECL, specialised equipments for fabrication of fuel bundle assembly have been procured from Canada as a commercial purchase. Taking the time factor into consideration, facilities were improvised at the uranium metal fuel fabrication plant itself for the production of the above requirement. Even though considerable difficulties have been experienced in the early stages of fabrication, the full commitment of about 2500 fuel bundles with about 40 tonnes

......5

of contained UO_2 have been produced and delivered well in time. In addition to the quality control supervision of the department, AECL provided quality surveillance and the fuel produced has met fully the quality requirements.

3.2 In order to meet the requirements of fuel and other zircaloy components for nuclear power reactors, Nuclear Fuel Complex (NFC) has been designed and built at Hyderabad. The Complex essentially has the following constituent units; Zirconium Plant (ZP) comprising of Zirconium Oxide Plant, Zirconium Sponge Plant and Zirconium Fabrication Plant; Natural Uranium Oxide Plant (UOP); Ceramic Fuel Fabrication Plant (CFFP); Enriched Uranium Oxide Plant (EUOP); Enriched Fuel Fabrication Plant (EFFP) and Quality Control Laboratory for meeting the quality control requirements of all plants. All these units are now under regular operation. The location of various reactors and NFC is as shown in Figure 1 and the activities at the NFC in Figure 2.

Capacities of various plants at NFC are detailed below:

	ZP	UOP	CFFP	EUOP	EFFP
Annual Production capacity in tonnes	50	125	100	30	24

The complex employs a total of about 1700 personnel.

3.3 The provisions at Ceramic Fuel Fabrication Plant (CFFP) and Enriched Uranium Fabrication Plant (EFFP) are dealt with in detail in the following paras.

3.3.1 The capacity of CFFP is fixed at 100 tonnes per year based on initial inventory and sustained reload requirements of four 200 MWe CANDU type reactors with fuel burn ups of the order of 8000 MWd/TeU. RAPP-I unit has attained its criticality in August 1972 and is expected to go to full power sometime in 1974. Considering the schedule of installation of additional reactors, the capacity of CFFP is expected to be increased upto 400 tonnes per year by adding necessary equipment and increasing the working shifts.

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Based on the experience gained in the manufacture of initial half charge for RAPP-I unit, selection of the equipment, layout of the fabrication of facility was finalised. After process trials, work on regular production of RAPP type fuel bundles was taken up during June 1973 and in an year's time, about 1500 fuel bundles have been delivered for reactor use.

3.3.2 EFFP is designed to meet the reload requirements of Tarapur Atomic Power Station (TAPS). Enriched uranium hexafluoride imported from USA is converted to enriched uranium oxide powder at the Enriched Uranium Oxide Plant (EUOP). The layout of EFFP has been designed keeping in view the requirements of external inspection agency on the imported enriched uranium and provisions for vertical handling the four meter long assembly for alkali cleaning, autoclaving and for leak inspection. On commissioning all the items of equipments and with 8 metric tonnes of imported enriched uranium oxide powder and other zircaloy components, 30 TAPS assemblies have been fabricated and despatched to Tarapur Atomic Power Station by end of 1973. About 125 more TAPS assemblies are expected to be delivered by end of 1974 with the enriched UO_2 powder produced at EUOP. Reloading fuel for unit II contained mostly Indian fabricated fuel. NFC will meet fully the refuelling requirements for both the units of TAPS commencing from the next reload.

4.0 As mentioned earlier, thorium is of great significance to countries like India which possesses extensive monazite resources. In the nuclear power programme in India, the third generation reactors will be Th - U^{233} breeder system. Development work was taken up on thorium fuels as early as 1958 at Trombay. Requirements of sintered thorium and oxide pellets clad in aluminium have been met for conversion studies in CIRUS.

4.1 Under collaboration agreement with Sweden about 550 Kg. of high density sintered pellets of thoria were supplied to AB ATOMENERGI.

......7

4.2 Based on ORNL investigations of sodium cooled Fast Breeder Reactor Fuel with unclad metal core and blanket, a joint Indo-German Programme was formed to develop a thin clad thorium metal based fuel elements for fast breeder reactor.

4.2.1 The prime responsibility of DAE in this programme is to develop and produce high purity thorium metal powder and shapes such as strips, blocks, foils and tubes. Thorium metal powder is used for coating ThO_2-UO_2 or ThO_2-PuO_2 spheres in the development of dispersion type fuel elements. The powder is also used to make various thorium metal shapes by using powder metallurgical techniques of compaction and sintering followed by further fabrication into required shapes.

5.0 Plutonium fuel development work was initiated with the commissioning of Fuel Reprocessing Plant at Trombay in the year 1964 to process the irradiated fuel from CIRUS. Plutonium oxide sintered pellets of about 90% theoretical density have been produced and fabricated into stainless steel clad fuel pins for Plutonium Reactor for Neutronic Investigation in Multiplying Assemblies (PURNIMA). This reactor was designed, fabricated and commissioned in May 1972 and fuelled by about 24 Kg. of plutonium oxide.

6.0 Under an agreement with CEA France, a 40 MWt Fast Breeder Test Reactor basically similar to French FORTISSIMO is being constructed at Reactor Research Centre, Madras. The fuel is mixed oxide type with 30% PuO_2 and 70% UO_2 with U^{235} enrichment of about 85%, while blanket element will be having ThO_2 pellets. U^{233} produced in the blanket will be utilised to replenish the U^{235} depletion in the enriched uranium oxide.

6.1 Investigations are being carried out on uranium oxide-plutonium oxide fuels for developing a fabrication process for the fast reactor fuel.

6.2 Apart from the fuel and blanket assemblies, FBTR core will have nickel and steel assemblies.

......8

6.3 Presently the flow sheet is being standardized for fabrication of ThO_2 pellets. Development work is also on hand on various joining and assembly processes required for fabrication of different types of assemblies. As per the present plans, two fast breeder reactors of 500 MWe each will be commissioned in years 1986 and 1988 respectively.

7.0 DAE has decided to construct 100 MWt thermal research reactor at Trombay for a continued development of reactor materials and high performance fuel for thermal power reactors and also to provide better facilities for research in basic sciences. The reactor will be cooled and moderated with Heavy Water and will be fuelled with seven pin clusters of metallic natural uranium pins clad in aluminium. The reactor is expected to be commissioned by the end of 1979. Prototype fuel clusters have been made at AFD and are undergoing tests.

8.0 Development work is on hand for fabrication of Plutonium-Aluminium alloy booster rods for MAPP-II. These rods will be of plate type elements using zircaloy as cladding material.

9.0 In addition to the above, required number of cobalt slug and cobalt pellet absorber assemblies have been fabricated for RAPP-I reactor.

10.0 Department of Atomic Energy (DAE) has thus acquired a capability to process and manufacture different types of fuel and fertile elements indigenously to meet various research and power reactor programmes. The commissioning of large scale fuel fabrication plants well in time for the implementation of reactor construction programme is another milestone in our endeavour to achieve self sufficiency in the field of nuclear power technology.

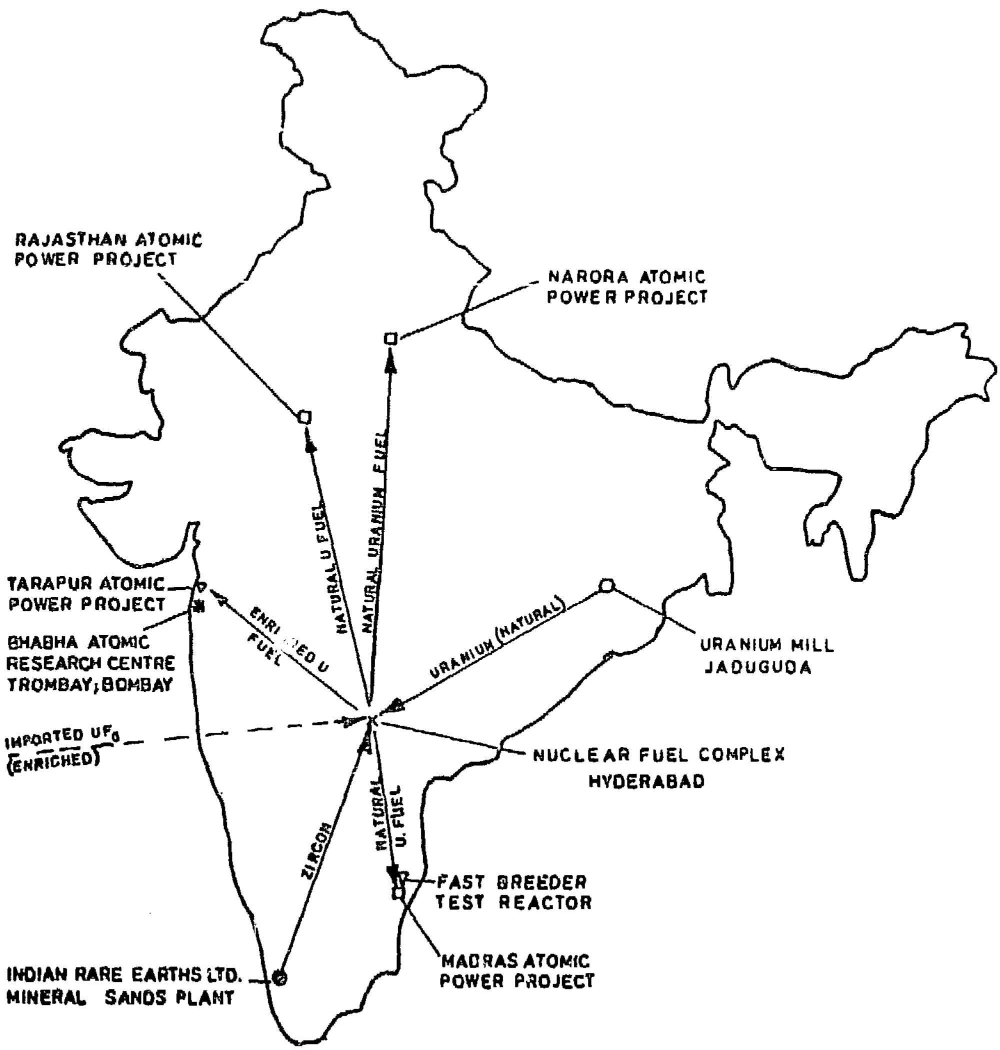

FIG. 1 NUCLEAR FUEL COMPLEX AND REACTOR LOCATIONS

FIG.2 ACTIVITIES OF NUCLEAR FUEL COMPLEX