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Emerging Nuclear Fuel Fabrication Activities in India

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Abstract

Presently the installed capacity of electricity generation in India is 160 GWe. The integrated energy policy aims at an installed capacity of 778 GWe by 2031-32 to achieve per capita electricity consumption of 2700 kWh/year as against the 700 kWh/year. The share of nuclear power in India is around 3% presently. The increase in installed capacity is possible by increasing the share of nuclear power. India has opted for a unique three-stage power programme based on closed nuclear fuel cycle, which provides a multiplier effect through breeding. Consequent to the 123 agreement and clearance from Nuclear Supplier's Group (NSG) for international cooperation in the field of nuclear energy, the reactor technology options are wide open. Some of the technologies which are being pursued are: Pressurized Heavy Water Reactors (PHWRs) fueled with domestic Natural Uranium (NU), PHWRs fueled with imported Natural Uranium/Slightly Enriched Uranium (SEU), Light Water Reactors (LWRs) procured from abroad using imported Lightly Enriched Uranium (LEU) fuel, PHWRs with Reprocessed Uranium (RU) obtained from reprocessing spent fuel of LWRs, indigenous Pressurized Water Reactors (PWRs) and Fast Breeder Reactors (FBRs) using MOX/metallic fuel. The increase in the share of nuclear power through above technologies require setting up of fuel fabrication facilities such as: new PHWR Fuel Fabrication with indigenous sources, joint collaboration with foreign countries for fabricating fuel for imported LWRs, setting up PHWR fuel fabrication facilities with SEU/RU under international safeguards, setting up of enrichment and fuel fabrication facilities for indigenous PWRs and a series of fast reactor fuel fabrication facilities for fabricating fuel for FBRs. In addition to fuel fabrication facilities, facilities for manufacturing zirconium alloy and stainless steel structurals, tubes and components are also required to be set up. The paper gives in detail the emerging nuclear fuel fabrication activities in India.

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1. Introduction

The total installed generating capacity in India is from various sources like Thermal, Hydro, Renewable etc. (Fig. 1). Like in many countries, in India too, the major share is from Thermal Power, which accounts for 64.6%, while the same from Hydro and Renewable Energy Sources is 24.7% and 7.7% respectively.

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The share of nuclear power in India is around 3% presently. In order to match the world-average per capita consumption of energy, there is an urgent need to substantially increase the generating capacity in India. The increase in installed capacity is possible by increasing the share of nuclear power.

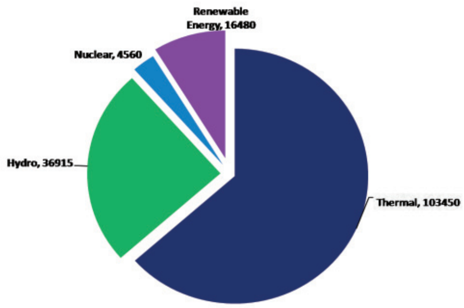

Fig. 1. Installed Generating Capacity from various Sources in India (2009–10)

The Nuclear Power Programme in India is based on three stages viz., installation of Thermal reactors utilizing natural/slightly enriched uranium in the first stage, which apart from power generation, will yield sufficient Plutonium for fuelling Fast Breeder Reactors in the second stage. Judicious introduction of Thorium in the Breeders will yield U^{233} that can be utilized as fuel in the third stage nuclear power plants. Thus the whole programme, envisioned by Homi J. Bhabha, is based on closed fuel cycle concept that will provide multiplier effect.

With the opening up of the nuclear trade with India, several firms in the world are exploring the possibilities of setting up of nuclear power plants in India that are based on PWR and BWR technologies. Thus, there will be wide horizons that are to be explored for setting up of fuel fabrication facilities in India for ensuring uninterrupted lifetime fuel supplies to these reactors. In addition, facilities for manufacturing zirconium alloy core structurals for LWRs and stainless steel components for Fast Breeders are required to be set up in India.

The following sections of the paper details the Emerging Nuclear Fuel Fabrication Activities in India.

2. Present status

2.1. PHWR Fuel

Several technologies for nuclear fuel fabrication involving various disciplines in Science & Engineering were initially developed at Bhabha Atomic Research Centre (BARC), Mumbai. The Science behind these technologies were successfully taken to lab-scale operations for demonstration in the production of two main streams i.e., Zirconium stream for the production of Zirconium Oxide, Zirconium Sponge, Zirconium alloying and Zirconium alloy fabrication; Uranium stream for the production of Uranium Di-oxide Powder, Uranium Di-oxide Pellet and Fuel Bundles for PHWRs. In addition, several laboratory methods and Quality Control techniques were also designed and demonstrated.

Based on the lab-scale demonstrations, several Plants were set-up during early seventies at Nuclear Fuel Complex (NFC), Hyderabad for the large-scale production of PHWR fuel bundles for Rajasthan Atomic Power Station. Starting with an initial capacity to produce fuel bundles for RAPS-1&2, the same was augmented several times over the next three-and-a-half decades to reach a stage of fuel production capacity, which is sufficient to cater to the reload fuel requirement of 16x220 MWe PHWRs and 2x540 MWe PHWRs. In addition, facilities were also added for the manufacture of Zirconium alloy reactor structurals like Pressure Tubes, Calandria Tubes, Garter Springs, Reactivity Control Mechanisms etc., for PHWRs.

Parallely, Plants were designed and constructed at NFC for the production of Fuel Assemblies for the two Boiling Water Reactors (BWRs) at Tarapur. These include Plants for the conversion of

Enriched Uranium Hexafluoride into Uranium Pellets and finally converting them into finished 6x6 matrix fuel assemblies.

Over the years, NFC has fabricated different types of PHWR fuel bundles consisting of varied designs like 19-element wire wrap, 19-element split spacer, 22-element split spacer and 37-element split spacer types containing Natural Uranium. In addition, fuel bundles were also fabricated consisting of different fuel materials like Thoria, RU and SEU. The cumulative production of PHWR fuel bundles since inception of NFC is 450,000 numbers.

The inflow of raw materials and the supply chain of finished fuel bundles/assemblies to various Reactor sites are shown in Fig. 2. The Zirconium sand, which is one of the beach sand minerals, is supplied by Indian Rare Earths Limited (IREL), which, in the first step, is converted to nuclear grade Zirconium Oxide Powder by employing specialized chemical operations. The stringent standards required for containing the impurity levels, like Hafnium, is met by employing specially developed chemical processes. The Oxide is subsequently converted into Zirconium Sponge metal through metallurgical operations, which is further taken up for alloying with Chromium, Ferrous, Nickel and Tin to produce ingots of Zirconium alloys. These are converted into Zirconium alloy fuel tubes and fuel components by processing through hot & cold working operations like Extrusion, Pilgering, Annealing etc.

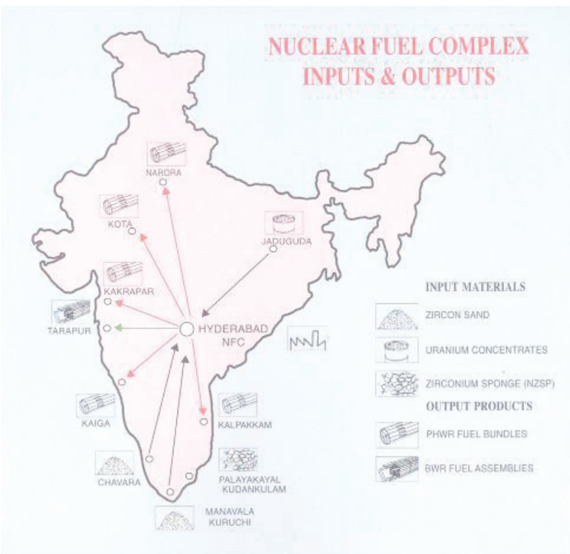

Fig. 2. Inflow of raw materials and the supply chain of finished fuel bundles/assemblies

In the Uranium stream, the yellow cake in the form of Magnesium Di-Urnate (MDU) received from Uranium Corporation of India Limited (UCIL) is first converted into nuclear grade Uranium Di-oxide Powder, which is subsequently taken up for Pelletization. The finished fuel bundles for PHWRs are manufactured by assembling Uranium Di-oxide Pellets with fuel tubes & components by employing sophisticated welding, machining and assembly processes. A schematic view of the above operations is depicted in Fig. 3.

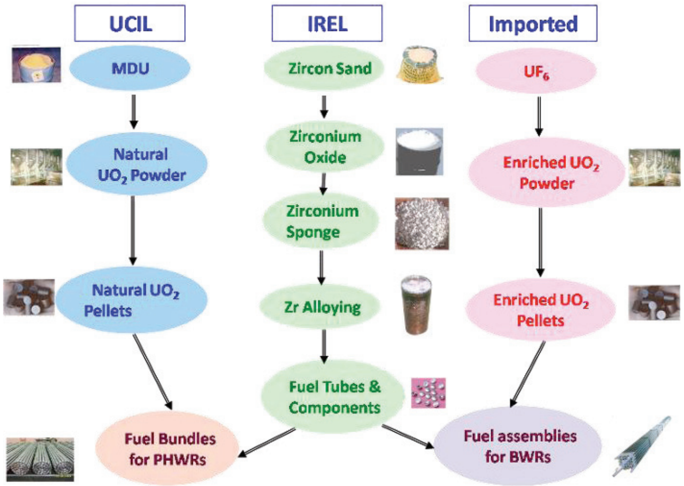

Fig. 3. Fuel Fabrication Activities at Nuclear Fuel Complex

2.2. BWR Fuel

Similar processes mentioned above are employed in the enriched fuel fabrication facilities for the conversion of imported UF_6 into fuel pellets. These are assembled with the fuel tubes & components for the manufacture of fuel assemblies for BWRs. Fuel elements with three different enrichments (2.66%, 2.1% and 1.6%) are assembled to produce 6x6 matrix fuel assemblies for the BWRs.

3. Core sub-assemblies for FBRs

A Fast Reactor Facility (FRF), set-up in early eighties, is engaged in the fabrication of Core Sub-Assemblies for FBRs. Several Core Sub-Assemblies like Fuel, Nickel, Blanket and Steel Reflector are being produced for the Fast Breeder Test Reactor (FBTR). Several developmental efforts have resulted in successful fabrication of components having intricate shape and critical dimensions.

Based on the experience gained, production facilities are being set-up for the manufacture of Core Sub-Assemblies for the forthcoming Prototype Fast Breeder Reactor (PFBR). These assemblies employ components made up of different materials, a view of which is given in Fig. 4

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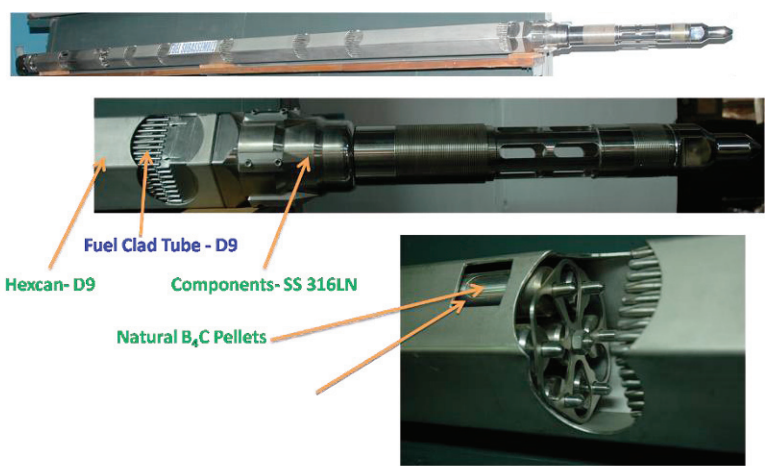

Fig. 4.Materials for PFBR Sub-Assemblies

4. Developmental and indigenization activities

Starting with 19-element wire wrap design adopted for PHWR fuel bundles during seventies, several innovations were carried out, which were successfully translated into production operations. Some of the important development works in PHWR fuel include resistance welding of appendages on to the fuel elements, graphite coating/baking of fuel tubes, development of process flow sheets for 37-element fuel bundles for 540 MWe PHWRs etc. In similar way, the process improvements introduced in BWR fuel fabrication include introduction of fully annealed thick wall fuel sheath, short & chamfered Pellets, pre-pressurization of fuel elements etc. All these efforts have resulted in improved fuel performance in the Reactors. Concerted technological efforts resulted in indigenization of several critical components required for BWR assemblies like spacers, top & bottom tie plates etc. (Fig. 5).

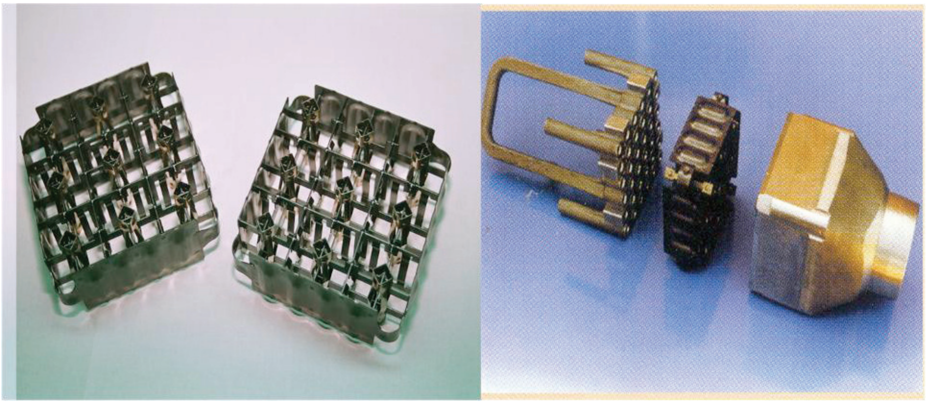

Fig. 5. Indigenization of BWR Fuel Assembly Components

The development of flow sheet for the production of Thorium Oxide has yielded valuable experience in large-scale production of Thoria Pellets, meeting the stringent quality requirements like microstructure, density, visual standards etc. (Fig. 6). Some of the critical components required for PFBR include manufacture of fuel tubes and hexagonal channels in D9 material. The noteworthy feature of the hexagonal channels manufactured at NFC is the 'seamless' variety, while such channels produced elsewhere in the world are through seam welded route. Fig. 7 depicts a view of critical components employed for PFBR.

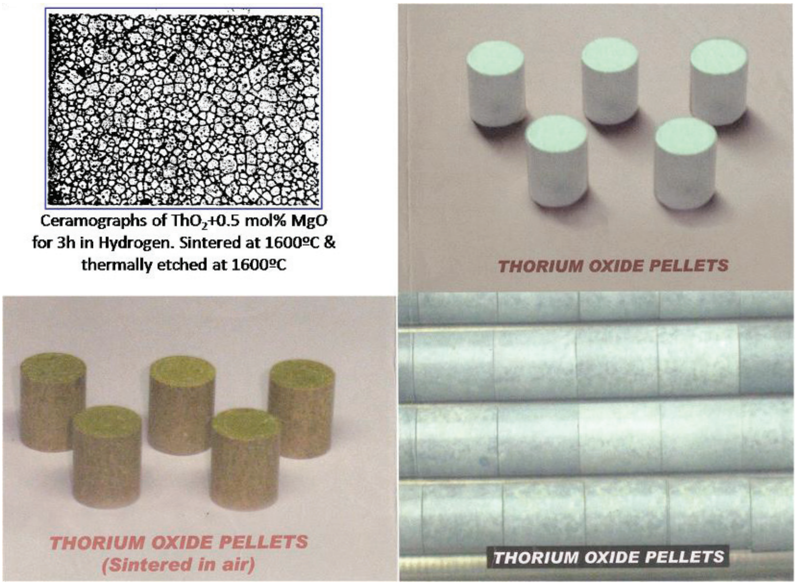

Fig. 6. Thorium Oxide Pellets

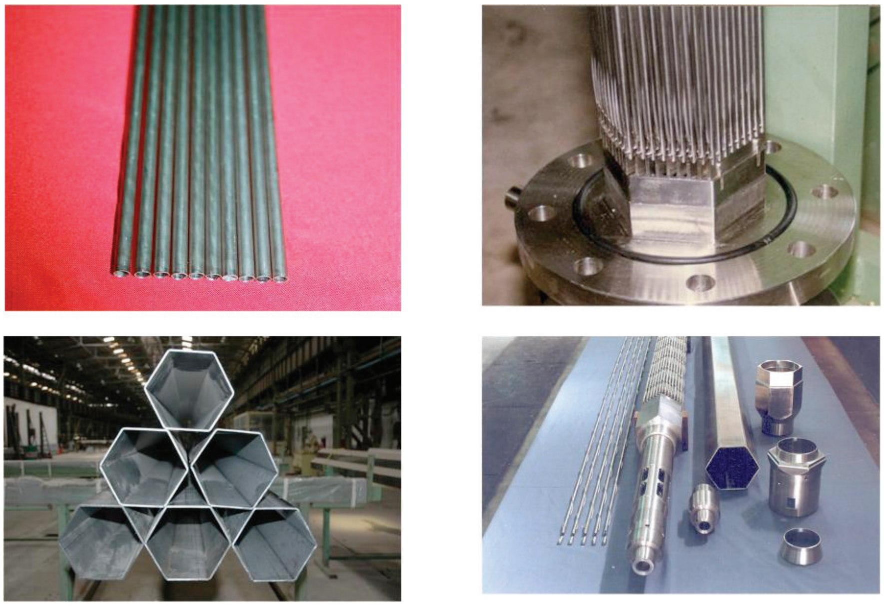

Fig. 7. Manufacture of Core Sub-Assemblies for FBRs

5. Indigenization of process equipment

Dr. Homi J. Bhabha, the architect of Indian Nuclear Power Programme, has said "If an item of equipment is imported from abroad, all one gets is a particular instrument. But if one builds it oneself, an all important lesson in expertise is learnt as well."

True to his vision, NFC embarked on a massive drive for building indigenous capability for the manufacture of process equipment required for the production of Fuels for Thermal Reactors and Core Sub-Assemblies for Breeders. Fig. 8 shows a view of the some of the critical equipment developed indigenously in the Fuel stream and Fig. 9 shows the equipment employed in Zirconium alloy fabrication Plants. While some of the equipment were conceptualized, designed and fabricated in-house, Indian industry played a matching role in developing some more equipment. The Fuel Plants at NFC are equipped with state-of-the-art systems involving robotized fuel assembly operations.

Fig. 8. Indigenization of Process Equipment in Uranium stream

Fig. 9. Indigenization of Process Equipment in Zirconium stream

Several advanced systems are installed in the Plants engaged in the manufacture of Core Sub-Assemblies for FBRs. These include high precision automatic welding machine, specially designed button forming equipment, fuel tubes crimping machine etc. In order to carry out assembling of 127 numbers of fuel pins containing MOX and RU Pellets, an automatic pin assembling machine (Fig. 10), that can be remotely operated, is contemplated.

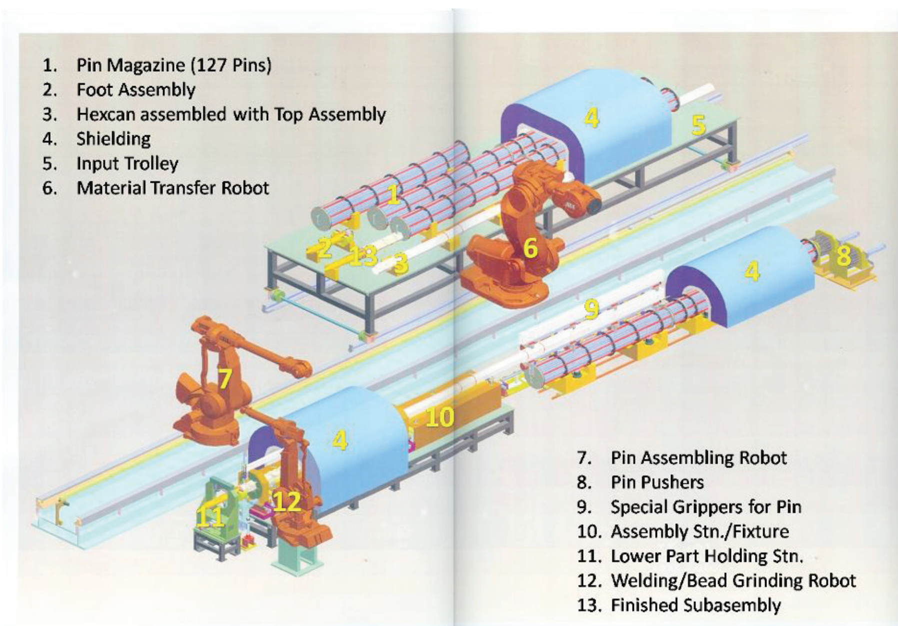

Fig. 10. Automatic Pin Assembling Machine

6. Future activities

In order to increase the share of Nuclear Power to the national grid, the Department of Atomic Energy (DAE) has envisaged programmes to generate 40 GW electricity through LWRs/PWRs. While these Reactors are expected to be installed in collaboration with different proven Reactor vendors in the world, it is very much essential to have fuel linkages for lifetime operation of these Reactors.

As a strategic decision, the fuel fabrication facilities will have to be set-up within the country in collaboration with foreign fuel manufacturers. Initially the supply of enriched fuel either in the form of Uranium Hexafluoride/Uranium Di-oxide Pellets by foreign fuel fabricators could be thought of, while the Zirconium alloy components required for the fuel assemblies can be manufactured within the Department. Subsequently, the conversion and enrichment facilities could be established within the country to ensure uninterrupted fuel supplies to LWRs/PWRs. The capacity of this enriched fuel fabrication facility would be in the range of about 1000 tpy. Towards this, several programmes are envisaged to be taken up for industrial scale glove-box operations for advanced fuel manufacturing, development of advanced materials for clad, PIE labs for quick feedback.

As a part of developmental works for Zirconium alloy clads, apart from new alloy development like Zr-Sn-Nb alloy and BCC alloys, optimization of existing alloys with respect to chemical composition, microstructure and texture is aimed at. This would improve the corrosion resistance, ductility and increased tolerance for Hydrogen. Similarly, as a part of development of advanced fuels, experimental studies are already initiated to produce Fuel Pellets with specific structure, large grain size with grain boundary condition by addition of TiO_2, Nb_2O_5, MgO etc. Also, technologies are underway to produce Pellets with controlled porosity by addition of special pore formers.

Towards the Fast Breeder programme in India, trial production is already in progress for the standardization of flow sheet for fabrication of double weld clad tube by cold pilgering process, production of Oxide Dispersion Strengthened (ODS) steels and 9Cr-1Mo tubes for use as clad materials.

Starting in early seventies for the fabrication of fuel for PHWRs, NFC apart from increasing the PHWR fuel production capacities, has added facilities for BWR fuel and core sub-assemblies for Fast Breeders. It is envisioned (Fig. 11) that, around 2030s, NFC would be engaged, in addition to the above, in the fabrication of fuels for VVERs, PWRs and ABWRs.

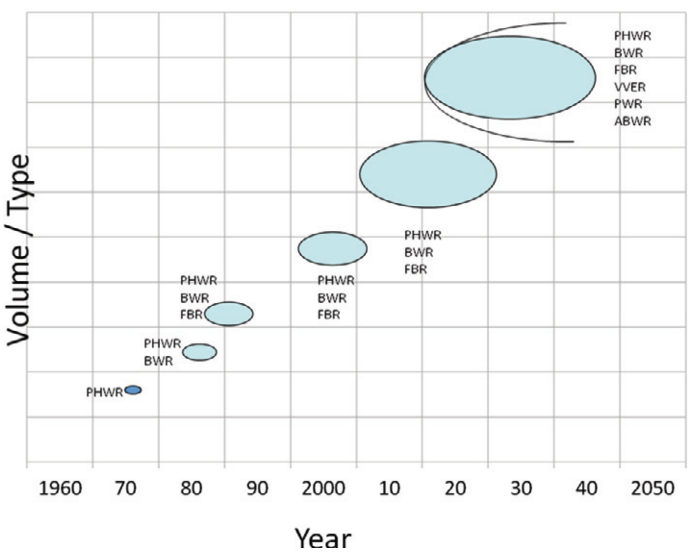

Fig. 11. Fuel & Core Sub-Assembly Activity – A Vision

7. Conclusion

For achieving an impressive growth rate in Indian GDP, it is essential to multiply power generation. India to have best utilization of Thorium through 3-stage Nuclear Power Programme (NPP). India is matured in closed fuel cycle technologies in the first stage of NPP. India to multiply nuclear power generation through LWRs and FBRs. Nuclear Fuel Complex (NFC), having mastered PHWR & BWR Fuel manufacturing technologies, all set to enter fuel manufacturing for LWRs.