RECYCLING PERSPECTIVES

Indian Experiences and Road Ahead

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INDIA is committed to the closed fuel cycle (Fig.1) and perceives spent fuel as a source of energy. Although the Pressurized Heavy Water Reactors (PHWRs) are the main stay of nuclear power generation in India, Light Water Reactors (LWRs) and other reactors are also being adopted for meeting the growing energy demands of the country. The recovered Plutonium from PHWR spent fuel reprocessing is to be utilized in sodium cooled Fast Breeder Reactors (FBRs) along with recovered Uranium as MOX fuel as part of a multi-recycling concept enabling maximum utilization of fuel for electricity generation (Fig.2) .This strategy not only enables recycling of fissile and fertile elements into the nuclear reactor, but also presents us with an opportunity to reduce the radiotoxicity of the final waste for disposal. Recent developmental activities have helped in the evolution of the partition strategy that not only helps to reduce the radiotoxicity of the high-level waste but also enable the separation of useful radionuclides for societal benefits. In line with the abundant natural reserves of Thorium in our country, a thorium utilization program is also being pursued which encompasses reprocessing of irradiated thorium to recover U^{233} for its use in future reactors.

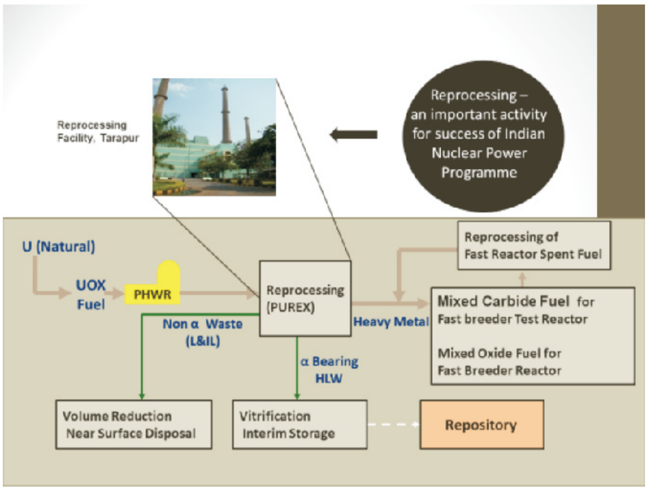

Fig.1: Indian Nuclear Fuel Cycle.

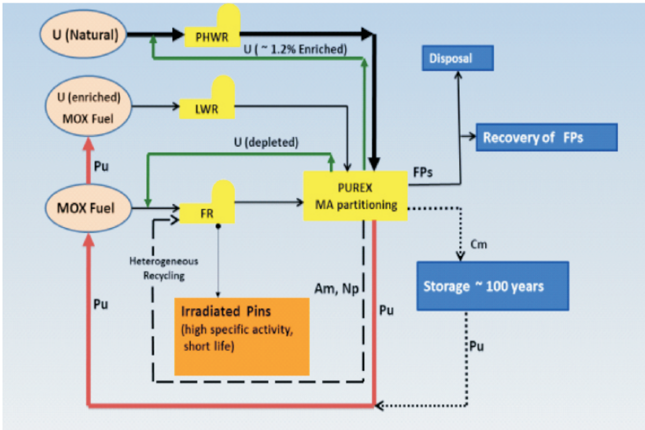

Fig.2: Evolving Nuclear Fuel Cycle.

Lessons Learnt

More than five decades of operational experience of back-end fuel cycle facilities have established a safe operating culture in India. Adopting good practices and incorporation of improved technologies have resulted in sustained higher through puts, increased separation efficiencies and higher decontamination factors resulting in acceptable product quality. This has also resulted in reduced man-rem consumption, improved safety, reduced environmental discharges and reduction in secondary wastes volumes for disposal. The challenging activities with regard to spent fuel handling, head-end operations, dissolution, solvent extraction cycles and final conversions are all carried out in conformity with internationally laid out safety regulations. Such indigenous, industrially matured technology is being now extended to set up an integrated nuclear recycle project with a name plate capacity of 600 T/year. This article will not only highlight the lessons learned during these five decades of operation but will also highlight the overall design perspectives of such plants for the future.

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The entire reprocessing operations can broadly be listed as a) head-end operations, b) solvent extraction cycles for obtaining pure product solutions and c) precipitation and calcination of product streams.

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Head-end Operations

These operations entail receipt of spent fuel from the reactor facility, followed by safe storage in the spent fuel storage pool at the reprocessing facility. Since these sufficiently cooled fuels are to be taken up for reprocessing operations, under-water storage is deemed convenient and is widely practiced. The reprocessing plants are situated advantageously relative to operational nuclear reactors to facilitate easy movement of spent fuel from reactor site to the plants. The casks that carry spent fuel during transport are appropriately designed to not only provide the necessary shielding at all times but are also designed to remain intact during off-normal situations including impact, fire etc.

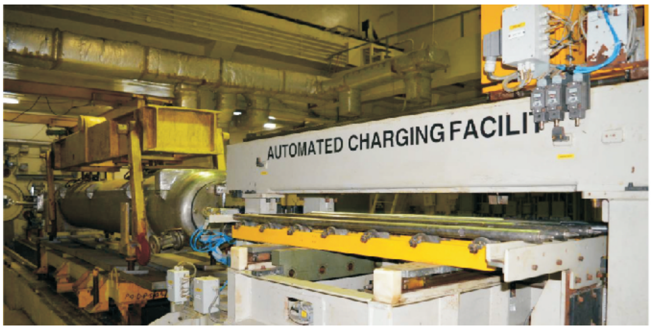

Fig.3: Automated fuel charging facility, Trombay.

Fig.4: Gang chopper.

While the research reactor reprocessing entails chemical decladding followed by dissolution of fuel, the PHWR spent fuel bundles are chopped into ~50 mm long pieces and dropped into a basket before being taken up for dissolution. The challenging aspects of head-end operation encompassing spent fuel charging and chopping have been successfully addressed by the deployment of an automatic fuel charger (Fig.3) and gang chopper (Fig.4). The hulls from PHWR reprocessing are further rinsed and assayed for activity before being stored, pending disposal.

Solvent Extraction Cycles

The dissolved solution containing uranium and plutonium along with all the fission products in nitrate form are subjected to solvent extraction cycles based on well-established PUREX process, resulting in relatively pure solutions with very low fission product contamination. The Co-decontamination and partitioning step ensures separation of Pu and U from all the other unwanted components of spent fuel and further separation of U and Pu product streams. The products thus separated, namely uranium and plutonium streams are further subjected to purification cycles to meet product specifications. Although the present plants employ uranus as the partitioning agent, focused R&D efforts are on to identify suitable and tailor-made agents for reprocessing of advanced reactors fuels including ^{229}Th-^{233}U systems.

The management of nuclear waste has been accorded high priority in the near term as it is well recognized that this can lead to a substantial impact on our nuclear energy programme.

Design and setting up of such operational facilities call for deployment of robust hot cell technology and appropriate remotisation of engineering system to operate safely and reliably in a high radiation environment. While the hot cells are primarily designed with appropriate shielding for processing such wastes, they also have to be equipped with remotely operated, O&M friendly material handling devices like EOT cranes, power manipulators, master slave manipulators, trolleys etc. Hot cells are also provided with shielding windows for viewing and suitably designed access areas for removal of used components and putting them into shielded casks for further management. Another most important aspect of hot cells is the design of appropriate penetration in hot cells serving as an interface between the inside active areas and the outside inactive areas of the plant.

In-cell transfer systems are designed with adequate stand by provisions and redundancies to ensure high system-availability. In this regard, air lifts, pumps and steam ejectors are used as maintenance-free transfer devices. An elaborate ventilation and off-gas system is put in place ensuring the required air changes in the various designated areas of the plant and also to ensure that the environmental discharges from such facilities are well below regulatory limits. Remote process sampling and automated sample transfer systems are very important aspect for efficient and safe operation of such radiochemical facilities. Fig.5 gives the inside view of such a hotcell showing an elaborate and complex piping system.

Reconversion Operations

The purified product solutions from solvent extraction cycles are further taken up for precipitation and calcination yielding their respective solid product in the oxide forms. While the uranyl nitrate is processed by the ADU route, the plutonium is processed by the oxalate precipitation route.

Utility & Services

The reprocessing operations are ably supported by vast utility and services that include ventilation and off-gas handling, common utilities like steam, water and compressed air. Radiological safety is ensured by radiation zoning of plant

Fig.5: Inside view of a hot cell.

Fig.6: Service distribution system.

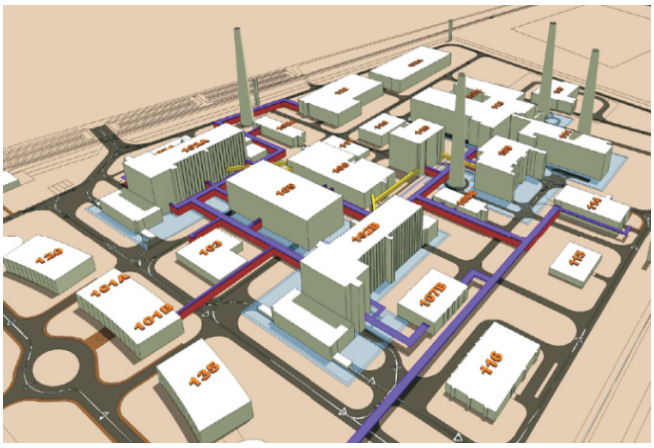

Fig.7: Integrated Nuclear Recycle Facility.

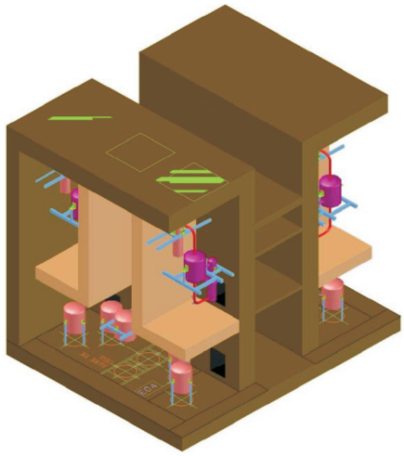

Fig.8: Sectional image of INRP.

areas and maintaining proper air flow pattern to these areas as per the radiation zoning. The industrial safety and security of such radiochemical facilities are accorded high importance and are therefore, ensured both by way of active as well as passive measures. A typical service distribution system is shown in Fig.6.

Instrumentation and control systems form a very important sub-system of reprocessing facilities, since all operations must be executed remotely inside radiological cells having concrete shielding structures of thickness ranging from 1-1.5 meters. Remote sensing of parameters like level, density, interphase, temperature, pressure etc. are done by various techniques and are made available to the control room. The present plants are all PLC-based SCADA systems, facilitating complete remote operation of such systems.

The electrical sub-systems of the reprocessing facilities essentially comprise of appropriate distribution systems along with the rated transformers. The DG sets sized in line with the safety requirements are set up and maintained as per regulations.

Safety Systems

All concerns with regard to safety of reprocessing facilities including criticality and red oil explosion are addressed right from the design stages to ensure that such situations are precluded during plant operations. While criticality is avoided by means of restricting mass, concentration, size and geometry, red oil formation is avoided by ensuring that the aqueous solutions going for evaporation are devoid of entrained organics.

The steam pressure and temperature along with vent sizing of evaporators are also some of the considerations for avoiding unsafe situations.

Waste Management

The management of nuclear waste has been accorded high priority in the near term as it is well recognized that this can lead to a substantial impact on our nuclear energy programme. In this regard, the partitioning program has been accorded high priority leading to setting up and operation of a first of its kind partitioning facilities at both Tarapur and Trombay. While the plant at Tarapur demonstrated the partitioning of minor actinides from HLW, the plant at Trombay has established fission product partitioning and the use of these radionuclides for societal benefits. Non-high level wastes are subsequently treated and managed appropriately with a focus on waste volume reduction and minimizing discharges to the environment.

The Concept of INRP

The concept of Integrated Nuclear Recycle Facility (Figs. 7 & 8) has stemmed from holding the concept of recycling as the main tenet for back-end processing. Recognizing the need for such activities, especially with regard to shared services and solution transfers, the next facility has been designed and is being set up at Tarapur for a name plate capacity of 600 T HM/year. The valuable experiences and lessons learnt have been incorporated in designing this project which is in advanced stages of construction.

Acknowledgements

The authors very humbly acknowledge not only the large and dedicated workforce of today who are contributing to this cause, but also the doyens of back-end who have led indigenous development of such a challenging technology in our country way back in 1964 when the first spent fuel rod was charged in the Trombay facility and all those who have contributed in improving and sustaining these activities.