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Back end of Indian nuclear fuel cycle-A road to sustainability

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ABSTRACT

Indian policy of '**closed fuel cycle**' implies reprocessing of the spent fuel thereby recycling the uranium and plutonium extracted from the spent fuel. Reprocessing leads to the generation of intermediate and high-level liquid wastes containing various radionuclides that need to be contained for periods ranging from few years to thousands of years. Low & intermediate level non-alpha solid and solidified wastes generated during reactor operation are disposed in near surface disposal facilities which are monitored regularly during and after operations. The normal gaseous and liquid wastes are discharged in air/water bodies after appropriate treatment and dilution and complying with regulatory norms of Indian Atomic Energy Regulatory Board, Mumbai.

The intermediate level wastes from reprocessing are first treated with basic objective of achieving volume reduction. Indigenously developed sorbents and solvents have been deployed. These have resulted in higher volume reductions with desirable decontamination factors as against their direct immobilization in bitumen and organic polymers. For high-level waste, a three-step strategy involving immobilization, interim retrievable storage and ultimate disposal in geological formations is followed. In the Indian context, the future policy for the management of high-level liquid waste is to separate (partition) minor actinides and burn them in fast reactors and/or accelerator driven subcritical systems. The high level waste also contains useful isotopes like 137Cs, 90Sr, etc. which can be deployed for societal benefits. The technologies have been developed to separate these minor actinides, fission products like 137Cs, 90Sr and are discussed in the paper.

For immobilization (vitrification) of the waste 'Sodium borosilicate glass' composition is deployed. Vitrification facilities on Industrial scale are in operation at Tarapur and Kalpakkam. To take care of the decay heat in the vitrified products, the waste is stored in intermediate storage for about thirty o forty years. The storage vault for interim storage has been designed, constructed and is operational at Tarapur and similar higher capacity facility is under construction at Kalpakam. A solvent extraction based plant for the recovery of 137Cs has been operated and radio cesium recovered has been converted into vitrified irradiation pencils. Vitrified high-level waste volumes currently generated and stored are not sufficient to call for setting up of a Geological Disposal Facility (GDF) immediately. Based on the projected growth in nuclear power profile for India (~54 GWe by year 2032), vitrified waste cumulatively produced and interimly stored for cooling till 2075, would only thereafter call for their economic transfer to GDF for the final disposal in a phased manner. In this paper, the technological and innovative details of the above aspects are presented.

1. Introduction

Management of radioactive wastes from the back end of the nuclear fuel cycle is vital for successful deployment of nuclear power. The 'back end' includes the safe management of spent nuclear fuel including reprocessing & reuse and disposal. If spent fuel is not reprocessed, the fuel cycle is referred to as an 'open' or 'once-through' fuel cycle; if spent fuel is reprocessed, and partly reused, it is referred to as a 'closed' nuclear fuel cycle (IAEA-TECDOC-1613, 2009).

In 'once-through' mode, the nuclear fuel passes through the reactor just once. After irradiation in the reactor, this fuel termed as 'spent fuel' is safely stored either as wet storage in pools or as dry storage in vaults or casks. This spent fuel after proper conditioning is planned to be put into a final repository. It may be mentioned

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that as of now, the final repositories for spent fuel is yet to be established any where in the world.

In 'closed fuel cycle' the spent fuel is considered as a resource material and is processed for the 'Recovery and Recycle' of fissile material. The spent fuel contains uranium ~96%, plutonium ~1% and balance high-level waste products ~3%. The uranium, with less than 1% fissile U-235 and the plutonium can be reused & recycled into reactors to extract extra energy leading to effective utilization of uranium. While Reprocessing of spent fuel leads to recovery and recycle of fissile materials, it also generates high-level liquid waste (HLLWs) containing various radionuclides that need to be contained for periods ranging from few years to thousands of years. As of today, France, Russia, Japan, India and China reprocess most of their spent fuel, where as USA, Canada, Finland and Sweden have currently opted for direct disposal. Most countries have not yet decided which strategy to adopt. They are currently storing spent fuel and keeping abreast of developments associated with both alternatives (Storage and Disposal of Spent Fuel and High Level Radioactive Waste).

Nuclear industry in India covers the entire range of activities right from the design, construction & operations of nuclear power/ research reactors and the supporting nuclear fuel cycle technologies. Supporting nuclear fuel cycle technologies cover exploration, mining and processing of nuclear minerals, production of heavy water, nuclear fuel fabrication, fuel reprocessing and management of radioactive wastes.

All these activities right from mining & milling of uranium ore, fuel fabrication, reactor operation and spent fuel reprocessing, generate various types of radioactive wastes. Besides ever-increasing use of radioisotopes in medicine, industry & agriculture and decontamination and decommissioning of some of the old facilities now in operation for more than five decades also generate radioactive wastes.

Implementation of a safe and sustainable technology to address optimized waste management is essential for the success and sustainability of our ambitious nuclear power programme. As a policy, all our future plans are to integrate reprocessing and waste management with a 'solid in and solid out' concept thereby avoiding the legacy of extended storage of high level liquid wastes beyond required cooling periods. These integrated plants (IPs) shall ideally have spent fuel as an input and uranium, plutonium and vitrified waste as output. Besides, waste management in India include all the aspects of handling, treatment, conditioning, transport, storage and finally disposal of these radioactive wastes. The underlying objective that governs the management of all such waste is protection of man and environment, now as well as in the future. As a waste management philosophy, utmost emphasis is given to waste minimization at all stages of design, operation and maintenance with effective confinement and safety. In India, the necessary codes and safety guidelines for achieving this objective are provided by the Atomic Energy Regulatory Board (AERB) in conformity with the principles of radiation protection as formulated by the International Commission on Radiation Protection (ICRP) (Raj et al., 2006).

Treatment practices and technologies currently adopted in India for different types of radioactive wastes are summarized (Fig. 1). Distinctive color codes for low level (LL), intermediate level (IL) & high level (HL) wastes in the figure reflect their nature, treatment practices and disposal adopted for these wastes.

An account of Indian practices for treatment and conditioning of low and intermediate wastes arising from the operations of research and power reactors are dealt in by K. Raj et. all in their paper on "Radioactive waste management practices in India" (Raj et al., 2006).

2. Management of low level & intermediate level liquid wastes (ILLWs)

Practices adopted for low level liquid wastes (LLLW) generated from power reactors is to concentrate and contain the radioactivity associated with these wastes as much as practicable, and also to dilute and disperse the very low-level activity to the environment well below the nationally accepted and internationally endorsed levels. All the intermediate liquid wastes (ILLWs) of reprocessing origin are processed to convert them into low level and high-level wastes. As such these ILLWs are not directly immobilized as was practiced internationally in the past. Legacy alkaline intermediate level liquid wastes of reprocessing origin stored over decades, have been addressed and successfully treated by indigenously developed sorbents/resins. Thus organic based immobilization matrices like bitumen and polymers proposed earlier for their direct immobilization were never implemented. Table 1 lists some of these Specific sorbents/resins and their performance for these ILLWs.

Based on these extensive studies, sorbents like recorsinol formaldehyde (RF) and iminodiacetic acid (IDA) are extensively deployed on industrial scale. These resins are highly selective and re-generable as well. Processing of over hundreds of cubic meters of alkaline bearing intermediate level waste with an overall volume reduction over 60 and decontamination factor (DF) of nearly 300 are routinely achieved in shielded column facility at Waste Immobilization Plant (WIP), Trombay (Fig. 2).

3. Management of high level liquid wastes (HLLWs)

In India, right from inception, we have been pursuing the policy of 'closed fuel' cycle thereby reprocessing of all types of spent fuels is inevitable and integral to our policy. While reprocessing of spent fuel is the most favored strategy for the sustainable development of Indian nuclear energy, the key issue for the reprocessing is the generation of high-level liquid wastes (HLLWs). These high level liquid wastes contain most of the fission products along with transuranic elements. Even though HLLWs constitute only ~3% of the volume of all radio active wastes, these hold 95% of the radioactivity with most of the fission products and some heavy elements with long-lived radioactivity. In view of the extremely long periods involved, these liquid wastes cannot be perpetually stored in liquid form. These have to be immobilized/solidified. Currently, sodium borosilicate based glass formulations are chosen as an immobilization matrix for high-level liquid waste worldwide. This process of immobilizing high-level waste into glass is known as "vitrification". Glass is the only man made material with established long-term integrity spanning over 5000 years. Industrial-scale production of glass incorporating radioactive waste has been demonstrated, and this production experience has been gained in a number of countries.

Positive evaluations of glass as a radioactive waste form and vitrification technologies have rested on the following (Glass as a Waste Form, 1996):

a) As a nonstoichiometric solid, glass can accept a wide range of waste stream compositions.
b) As an aperiodic solid, the structure of glasses is considered less susceptible to radiation damage effects than crystalline materials.
c) As a waste form, in combination with other barriers to radionuclide migration (e.g., the canister, backfill, geology), glass usually is considered to be a more than adequate barrier to radionuclide release.

Thus for the last 50 years borosilicate glass remained to be the

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