Indian programme on radioactive waste management

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Abstract. The primary objective of radioactive waste management is protection of human health, environment and future generation. This article describes, briefly, the Indian programme on management of different radioactive wastes arising in the entire nuclear fuel cycle adhering to this objective.

Keywords. Radioactive waste; vitrification; near surface disposal; deep geological disposal; partitioning and transmutation.

1. Introduction

Any industrial activity results in generation of some waste material. Nuclear industry is no exception and the presence of radiation emitting radioactive materials which may have adverse impact on living beings and which is likely to continue to the subsequent generation as well is what sets nuclear or radioactive wastes apart from other conventional hazardous wastes. Another unique feature of the radioactive waste is the decay of radioactivity with time. This fact is gainfully exploited by the nuclear waste managers.

Management of radioactive waste in Indian context includes all types of radioactive wastes generated from the entire nuclear fuel cycle right from mining of uranium, fuel fabrication through reactor operations and subsequent reprocessing of the spent fuel. Since the spent fuel is reprocessed with a view to recover and reuse the U and Pu produced there, the fuel cycle is termed as ‘closed’, unlike in other countries like USA, Canada, etc. where the spent fuel is stored as waste. Figure 1 depicts all the activities across the **closed fuel cycle** adopted in India along with their connectivity. Radioactive wastes are also generated from use of radionuclides in medicine, industry and research.

Effective management of radioactive wastes involves segregation, characterization, handling, treatment, conditioning and monitoring prior to final storage/disposal. Radioactive wastes arise in different forms viz; solid, liquid and gas with variety of physical and chemical/radiochemical characteristics. Depending on the level of radioactivity, radioactive wastes can be classified as Exempt waste, Low and Intermediate level waste and High Level Waste. Classification of radioactive waste, as recommended by International Atomic Energy Agency (IAEA) is shown in figure 2.

Exempt wastes have levels of radioactivity too low to warrant any concern from the regulators. These can be disposed of to the environment and are not likely to cause any adverse impact.

Figure 1. Nuclear fuel cycle.

Figure 2. Radioactive waste classification system (IAEA).

Low and intermediate level wastes are further categorized as short lived and long-lived wastes. Radiological hazards associated with short lived wastes (<30 years half-life) get significantly reduced over a few hundred years by radioactive decay. The **high level waste** contains both short and long lived radionuclides, warranting high degree of isolation from the biosphere and usually calls for final disposal into deep geological formation (repository). Due to release of large amount of energy in form of radiation, the high level waste usually generates heat. In India, a coherent, comprehensive and consistent set of principles and standards, in line with international standards, is followed and practiced for waste management systems.

The primary objective of radioactive waste management is protection of human health, environment and future generation. The overall philosophy for the safe management of radioactive waste relies on the concepts of (i) **delay and decay**, (ii) **dilute and disperse** and (iii) **concentrate and contain**. Wide range of treatment and conditioning processes are available today with mature industrial operations involving several interrelated steps and diverse technologies as discussed below.

2. Low and intermediate level waste

2.1 Liquid waste

Low and intermediate level (LIL) liquid wastes are generated in relatively large volumes with low levels of radio-activity (few microcurie/l to millicurie/l). If a particular stream of radioactive liquid waste contains short-lived isotopes, it may be stored for adequate time period to ensure that majority of the radionuclides die down, thus, following the 'delay and decay' principles. Similarly, if the level of radioactivity present in the liquid waste is small, it may be pragmatic to dilute it sufficiently to render the specific activity levels well below the stipulated limits set by the regulators and discharge it to a large water body following the 'dilute and discharge' principles. In all other cases, the waste may call for suitable treatment in order to make the waste amenable to discharge. For the treatment of LIL waste, several processes such as chemical precipitation, ion exchange, evaporation, reverse osmosis are employed either singly or in combination for the treatment of such wastes.

Depending on the nature of the waste, radionuclides present and level of contamination, the treatment scheme is chosen to **concentrate bulk of the activity** in a small volume and **discharge the supernatant** to large water bodies after further polishing and monitoring as per national and international standards. The discharges are only a small fraction of the allowed limits. The radioactive concentrate is **conditioned and immobilized** in highly durable matrices like cement, polymer, etc. fulfilling the objectives of 'concentrate and contain'.

2.2 Solid waste

Significant quantities of solid LIL wastes of diverse nature are generated in the different nuclear installations. They are essentially of two types: 'primary wastes' comprising components and equipment contaminated with radioactivity (e.g., metallic hardware), spent radiation sources, etc. and 'secondary wastes' resulting from different operational activities. Some solid radioactive wastes include protective rubber and plastic wear, miscellaneous metallic components, cellulosic and fibrous materials, spent organic ion-exchange resins, filter cartridges, etc. Solid waste management plants in India are equipped with facilities for segregation, repacking, processing and embedment for radiation sources. Treatment and conditioning of solid wastes are practiced

Figure 3. Modules of near surface disposal facility.

to reduce the waste volume so as to minimize the consumption of space in the disposal facilities and also the mobility of the radioactive materials contained. Low active combustible wastes are **incinerated** and compactable wastes are reduced in volume by mechanical **compaction**.

The final packaged conditioned waste is then disposed off in **near surface disposal facilities (NSDF)**, a few meters below the earth's surface. A multibarrier approach is followed in NSDF to ensure confinement and isolation of the wastes from biosphere. Various modules of the disposal facilities are designed to accept different levels of activities in terms of dose rates. While wastes which give out very low doses are disposed off in stone lined or brick-walled trenches, wastes having higher activity are disposed off in reinforced concrete trenches and tile holes. Backfill materials are employed in the design of NSDF for prevention of activity migration during off-normal scenario of water ingress into the NSDF. Special emphasis is laid on closure of such modules after it gets filled. These include appropriate closure such as clay for the stone lined trench and concrete cover for the other two. Provisions for monitoring and surveillance are also incorporated in the NSDF. Provision of bore holes helps in sampling the ground water for monitoring purposes. Regular environmental monitoring ensures that radioactivity in air, water and soil in and around the disposal facility remains within the safe limits prescribed by the regulatory body. Figure 3 shows different modules of a near surface disposal facility. India has extensive and varied experience in the operation of near surface disposal facilities in widely different geo-hydrological and climatological conditions. **As a national policy, NSDF is co-located at each site of nuclear installations in India.**

2.3 Gaseous wastes

Radioactive gases and particulates carrying adsorbed radionuclides are the two pollutants in the gaseous waste. These must be removed before the off-gases are released to the atmosphere through tall stacks. That is why always a comprehensive off-gas treatment and ventilation system, designed to handle normal and anticipated off-normal conditions, is installed in nuclear power plants and other fuel cycle facilities in order to keep the air in the working area and the environment free from radioactive contamination. Various designs of scrubbers are deployed wherein off-gases are intimately contacted with suitable liquid media so as to retain the activity in the liquid phase. Specific **adsorbers** are also used to remove volatile radionuclides like iodine, ruthenium, etc. The off-gases are finally routed through **high efficiency particulate air filters (HEPA)** which are designed for an efficiency of >99.9% for sub micron size particles.

Figure 4. Summary of the radioactive waste management practices.

Surveillance and monitoring of the off-gases ensure that the discharges are well below permissible limits. Treatment of the secondary solid wastes (filters and adsorbers) is accomplished as described above.

A brief summary of the various radioactive waste management practices followed in India has been presented in figure 4.

3. High level waste

High level radioactive liquid waste (HLW) containing most (~99%) of the radioactivity in the entire fuel cycle is produced during reprocessing of spent fuel. In addition, hull waste i.e., the hollow clad tubes, is generated as solid HLW after the spent fuel is dissolved for the purpose of reprocessing. Public acceptance of nuclear energy largely depends on safe management of radioactive waste, especially the HLW. Strategy for management of HLW takes into account the need for effective isolation from the biosphere and surveillance for extended periods of time spanning over future generations.

Thus the management of high level liquid waste in the Indian context encompasses the following three stages.

- (i) Immobilisation of high level liquid waste into vitrified borosilicate glasses.
- (ii) Engineered interim storage of the vitrified waste and other high level wastes with passive cooling and surveillance over a period of time, qualifying it for ultimate disposal.
- (iii) Ultimate storage/disposal of the vitrified waste and other high active solid waste in deep geological repository.

3.1 Vitrification process

India is one of the few countries to have mastered the technology of vitrification. Owing to the high radiation fields, various operations are carried out remotely in specially designed and state-of-the-art cubicles made of 1.5 metre thick concrete walls known as 'hot cells'. These hot cells are equipped with remote handling gadgets and systems. Some of the major remotisation gadgets include custom designed robots, remote welding units, remote inspection/surveillance devices and manipulators. Indigenous development of the remote handling equipment has been pursued in active collaboration with the Indian industries, academic and national institutions.

Development of glass matrix for HLW is interplay of its composition, specific glass additives and the processing temperatures. Maximum loading of waste into glass, though desirable, gets limited by solubility of the waste components and the decay heat. Glass forming additives should conform to chemical durability and acceptable processing temperatures. These processing temperatures are dictated by volatility of the specific radionuclide and compatibility of the melter material under corrosive environment of molten glass.

Presence of certain chemical species like sulphate, aluminium, thorium, fluorine, platinum group metals, etc. in high level waste poses additional challenge for glass formulation development on account of their limited solubility/non-compatibility in glass composition. The vitrified products are evaluated for various properties like melt temperature, waste loading, homogeneity, thermal stability, radiation stability and chemical durability using advanced analytical instruments. The solidified waste form must also meet the criterion for its interim and long term storage followed by its ultimate disposal in deep geological repository.

India has rich experience in operation of vitrification plants at Trombay and Tarapur. Figure 5 shows the design of induction heated metallic melter operating at Trombay and the Joule heated ceramic melter operating at Tarapur. A third plant consisting of ceramic melter is nearing completion at Kalpakkam.

Cold crucible induction melting (CCIM) is emerging as the futuristic technology for the vitrification of high level liquid waste at much higher temperatures. Besides being compact and advantageous as in-cell equipment, it offers flexibility to treat various wastes with better waste

Figure 5. Schematic of melters used for vitrification of HLW.

Figure 6. Glass melting in engineering scale cold crucible set-up.

loading and enhanced melter life. Figure 6 shows the melting of glass in inactive engineering scale cold crucible at Trombay.

The vitrified product is encapsulated in suitable containers and overpacks and stored for dissipation of radioactive decay heat and surveillance for a period of about 30 years. During this period of surveillance, sufficient data would be generated on the product behaviour. Besides, the radiation and thermal conditions of the product are expected to get stabilized to a level where transport of the product becomes viable. On the basis of safety and detailed techno-economic considerations, natural draught air cooling system has been designed for the storage vault. A solid storage and surveillance facility (SSSF) has been set-up at Tarapur for interim storage of vitrified high level waste. Figure 7 shows the canister and overpack and the interim storage facility at SSSF, Tarapur.

Figure 7. Canister with overpack and interim storage facility.

3.2 Deep geological disposal

Among the options considered for disposing of vitrified high level waste, international consensus has emerged that deep geological disposal is the most appropriate means for isolating such wastes permanently from man's environment. The basic requirement for geological formation to be suitable for the location of the radioactive waste disposal facility is remoteness from environment, absence of circulating ground water and ability to contain radionuclides for geological periods of time. India has wide spectrum of rock types especially those offering good potential as natural barrier for isolation and confinement of vitrified waste products. Granites, constituting about 20% of the total area of the country, could be the most promising candidate for deep geological repository. Even though the need for deep geological repository in India will arise only after a few decades, nonetheless, research and development work is in progress in the field of natural barrier characterization, numerical modelling, conceptual design and natural analogues of waste forms and repository processes.

A system of multiple barriers that gives greater assurance of isolation is followed for disposal of radioactive wastes. The overall safety against migration of radionuclides is achieved by a proper selection of waste form, suitable engineered barrier, back fill and the characteristics of the geo-environment of the site. Figure 8 shows the schematic of the multibarrier disposal concept.

Backfills and buffer constitute most important components of multibarrier scheme adopted in a geological disposal system in hard rocks. These are placed as layers between the waste over pack and the host rock mainly to restrict the groundwater flow towards the waste form and to retard the migration of radio-nuclides to the biosphere in the unlikely event of their release from the over pack. Swelling bentonitic clays have emerged as preferable choices as back fill material.

Model formulations, implementation and data are essential for safety assessment of disposal facilities under various scenarios. This is systematically assessed through predictive modelling of the gradual failure of the engineered barriers (i.e., the waste form, waste package, and backfill) and the subsequent transport to environment of radionuclides by circulating groundwater. Such safety assessments are based on a good physical understanding of the processes involved in the release and transport of radionuclides, and also those affecting the repository and the geological formation.

Figure 8. Schematic of the multi-barrier disposal concept.

3.3 Recycle and reuse

The need for resource utilization along with technological advancement has led to emerging scenarios of recycle options, which may also reduce the burden on future generation. Significant reduction in the potential radioactivity of the waste can be achieved through improved recovery and recycling of plutonium. For sustained development of nuclear power, the environmental impact of the long term radio-toxicity of HLW needs to be reduced. In the **partitioning and transmutation** technology, the long lived minor actinides (Np, Am, Cm) and fission products (^{129}I , ^{99}Tc , etc.) are isolated from the waste and transmuted by subjecting them to neutron bombardment whereby they either become non-radioactive or convert into elements with much shorter half-lives than the original. This transmutation may be achieved in **Integral Fast Reactors (IFR)** or **Accelerator Driven Sub-critical Systems (ADSS)**, leading to either elimination or reduction of radioactive inventories. This would be a long term strategy for the management of high level waste and would provide both environmental and resource advantage. Partitioning of HLW also permits the use of advanced ceramic waste forms such as Synroc as a special matrix for conditioning of selected waste streams in parallel with the established vitrification technologies. Synroc being polyphase and polycrystalline assemblage has an added advantage for immobilisation of high loadings of actinide wastes. India is pursuing a developmental programme to achieve the above objectives.

4. Conclusion

India has achieved self-reliance in the management of all types of radioactive waste arising during the operation of the nuclear fuel cycle facilities. Decades of safe and successful operation of our waste management facilities are testimony to the Indian waste management practices being on par with international standards. Apart from having made immense technological progress in this field, a valuable human resource base has been created consisting of scientific and technical man power well-versed in the design, construction, operation and maintenance aspects of these facilities. In line with global scenarios, technologies are constantly upgraded for minimization of discharges to the environment.

Further reading

Dey P K and Bansal N K (2006) *Nucl. Eng. Des.* 236: 723

Raj K, Prasad K K and Bansal N K (2006) *Nucl. Eng. Des.* 236: 914

Radioactive Waste Management at a glance (2012) Nuclear Recycle Group, Bhabha Atomic Research Centre, Trombay, Mumbai