EVOLUTION OF RADIOACTIVE WASTE MANAGEMENT DESIGN FOR INDIAN PHWRS

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ABSTRACT

Radioactive Waste Management for Indian Pressurized Heavy Water Reactor (PHWR) based nuclear power plants is generally designed as an on-site facility with very little off- site treatment, if any. In early sixties, due to limited experience the segregation of waste at source was not attempted. Since then great strides have been made in the development of treatment and conditioning systems (TCS). Some of these processes earlier considered essential, no longer find favor as the waste obtained is relatively cleaner in terms of its chemical and radio-chemical nature. Solar evaporation has been successfully employed at one of the sites for volume reduction and containment of low level tritiated waste. With regard to solid waste, disposal of wet resins from reactor processes has been successfully tried in polymer matrix. The disposal of waste is governed by the discharge limits prescribed by Atomic Energy Regulatory Board and largely emulates ALARA principle.

The paper presents the evolution of overall waste management plant design, application of lessons learnt from extensive operating experience, strategy for handling "beyond design basis" waste.

INTRODUCTION

The on going Indian nuclear power program envisages significant contribution from small and medium sized pressurized heavy water reactors of 220 & 500 MWe rating. Of the 220 MWe Units, 7 are operating, 5 are in various stages of construction; and 6 to 10 are in planning stage. Introduction of 500 MWe reactors currently in design will vastly accelerate the pace. Energy from these units is expected to flow to grids by the turn of this century. Development and success of nuclear power program requires safe management of radioactive waste.

In the early stages of the nuclear power program, efforts were on in understanding the impact of releasing radioactive wastes into environment, and on developing processes for their effective isolation, containment and burial. Experience of over thirty years has established that the practices followed are safe though improvements in design with respect to techno-economic considerations are continuing.

The paper describes the evolution of design for disposal of liquid and solid waste for the current units. Objective of waste management program, characteristic features of PHWR relevant to waste generation and control, and regulatory requirements have also been covered.

DESIGN OBJECTIVES AND CONSIDERATIONS

The objective of waste management plants is processing of effluents and safe disposal of radioactive wastes, taking advantage of the geological and environmental conditions. Segregation, treatment, storage, disposal, operational controls, health and safety aspects are important design parameters. Flexibility in treatment and storage is needed to handle waste generated during major maintenance outages. The processing systems should meet the following objectives:

- Segregation of waste for ease of treatment.
- Reduction of waste volume for ease of handling.
- Containment and retention of radionuclides.
- Dilution & dispersal with plant cooling water.
- Hold up to allow for natural decay of short lived radionuclides.

CLASSIFICATION OF WASTES

Important parameters for waste classification are :

i. Type of contamination (alpha, beta and gamma).
ii. Level of contamination (high, intermediate and low)
iii. Chemical / physical nature.

Classification is necessary to optimize the treatment and conditioning processes . International Atomic Energy Agency (IAEA) has from time to time updated the classification. These are purely based on specific activity level which influences the need and extent of treatment. It also influences the requirement for shielding; another vital factor to be considered is handling of waste. However no universally accepted categorization exists and countries adopt their own classification.

In India, categorization has been generally done as per IAEA guidelines with due cognizance to the chemical nature which governs the subsequent treatment. Categorization and design basis quantities of wastes are given in the following paragraph.

SOURCES OF RADIOACTIVE WASTE

Generation of radioactive waste is inevitable in the operation of nuclear power plants. The type of fuel and moderator/coolant systems characterize the waste which can be in the form of liquid, solid or gas. The overall management aims at minimizing the gaseous and aqueous releases to the environment. The process of minimizing waste starts right from design stage by selecting reliable equipment requiring low maintenance; engineering nuclear systems for high integrity; improving fuel design to prevent fission products release to coolant; elimination of tramp uranium and selection of materials of construction which do not contribute to the generation of secondary radio-nuclides. Of course, the operation of the reactor within limiting conditions of operation and desired regime of water chemistry is essential to prevent fuel failure and generation of activation products.

Power reactor wastes usually contain 'beta' and 'gamma' activities, with 'alpha' remaining confined to the spent fuel.

Liquid Waste

In PHWR use of D_2O as primary coolant and moderator results in the generation of liquid waste which predominantly contains tritium. At the same time on-power fuelling minimizes the potential of contaminating PHT with fission products which are trapped in filters and IX units. The categorization and annual design basis quantities of waste for one unit of 500 MWe are given in Table I.

Solid Waste

Classification of solid waste for the purpose of disposal is done in the following manner. On the other hand, for selection of treatment process, the categorization is done as per Table II.

Category of Waste	Radioactive Dose Rate on the Surface
I	< 0.2 m Sv/hr.
II	2 m Sv/hr to 20 m Sv/hr
III	> 20 m Sv/hr.

DESIGN OF WASTE MANAGEMENT PLANT

India has at present two types of operating reactors :

i. BWR - 2 Units at Tarapur, Maharashtra.

ii. PHWR - 7 Units from Rajasthan, Kota, onwards.

Tarapur Waste Management Facility (TWMF)

For the 2 x 210 MWe Units at Tarapur commissioned in 1969, integral facility was provided for management of liquid waste. Provision for storage and disposal of solid waste was meager and needed augmentation to meet the safety requirements. Accordingly action plan was made to provide liquid waste treatment; storage and disposal facilities for low and intermediate level solid waste; and interim storage of process concentrate and their solidification. Additional facilities for baling, incineration, polymer and cement fixation have been provided. Subsequent to this, releases to the sea have reduced drastically from 89% in 1971 to 5% in 1988, of the permissible level.

Waste Management Plant (for PHWR's)

At the design stages of Rajasthan, Madras and Narora (RAPS, MAPS & NAPS) plants, limited data was available on volumes and nature of liquid rad waste generations. Hence projections of volume/activity levels were extrapolated from available data on similar plant operations in Canada etc. without any segregation. Presently with the operating experience of reactors additional data have been analyzed to project the quantities more accurately; duly accounting for possible reduction due to improvement in system designs. Following aspects were also considered.

- Normal and off-normal generations.
- Duration of reactor operation prior to maintenance.
- Reactor system design and age.

Nowadays the waste is not only segregated at source but is also stored in separate tanks in the main plant before it is transferred to treatment and conditioning system (TCS). Due attention is also given to include tritium activity levels for segregation of different categories of waste.

Discharge limits, for different categories of liquid wastes for a reference 500 MWe plant, are indicated in Table III.

SALIENT FEATURES OF STANDARDIZED DESIGN

Hold-up Capacity

Liquid wastes are treated in batches. Normally a day's storage should suffice. However, a week's storage is provided to meet various exigencies such as periods of zero plant discharge when regulatory limits are exceeded.

Drainage and Segregation

Collection and segregation of specific categories of wastes depends on identification of areas and designing the drainage system accordingly. Collection from many areas may result in more than one category of waste. Proper training and administrative control play an important role for waste management in such cases.

Liquid Effluent Sumps

The location of sumps has been decided to achieve gravity flow from various collection areas. These collections after sampling and analysis are transferred for further processing to the treatment plant.

Secondary Wastes

Emphasis has been laid on the selection of processes which generate low secondary wastes. Therefore the ion exchange system which may be used infrequently, has been proposed to be of non- regenerating type.

Off-normal Wastes

The design waste quantities have been worked out with a safety factor of 1.5 to 2.0. The waste generated under off-normal conditions will be handled on a campaign basis to meet the discharge limits. Some of the systems having a large inventory of clean light water but low potential of being contaminated are described below.

TABLE I
Liquid Waste for a 500 MWe Plant on Annual Basis

Waste Stream	Source	Qty. m^3/MWe
1. Potentially Active Waste (PAW)	Showers, Wash Room, Laundry	30
2. Active Non-Chemical Waste (ANCW)	Decontamination Waste rinses; lab. washes	20
3. Tritiated Waste (TTW)	Moderator Room Sump, D_2O Upgrading	3
4. Active Chemical Waste (ACW)	Equipment/Component Decontamination Waste	1

TABLE II
Type, Sources and Quantities for a 500 MWe Plant

Type of Waste	Source	Qty. m^3/Year
1. Combustible Waste	Mopping material, used clothes	70
2. Non Combustible	Plastic gloves	10
3. Non Compactable	Contaminated components	35
4. Filters	Primary Heat Transport (PHT) Aux. Cooling System	8
5. IX Resins	PHT, Moderator, Aux. Cooling Systems	15
6. HEPA Filters	Ventilation Systems	3
7. Misc.	Activated Carbon, Molecular sieves etc.	5

TABLE III
Estimated Activity Levels and Discharge Limits

	Waste Stream	Activity Levels (Bq/ml)	
		Gross B&G	Tritium
Activity Levels	1. PAW	4 E - 2	20
	2. ANCW	2	2 E + 3
	3. TTW	2	8 E + 4
	4. ACW	2 E + 3	2 E + 4
Discharge Limit	For a reference coastal plant at outfall	7 E - 3	2.5

- Potentially Active Process Water System: This is a closed loop intermediate cooling system for heavy water heat exchangers. In the event of heat exchanger tube leak, nearly 500 Te of light water inventory will be contaminated. Depending on isotopic purity, the water may be sent to upgrading plant or disposed off as tritiated waste.
- Spent Fuel Storage Bay / Receiving Bay Water (SFSB): The bay water can get contaminated if a fuel bundle leaks during storage. Additional waste generated in the form of spent filter and resins is accommodated in the existing conditioning system.
- Suppression Pool: The chances of contamination of 3200 m^3 of pool water are rather remote. Only possibility is during a major loss of coolant accident.
- Steam Generator (SG): SG tube leak could result in the contamination of secondary system.
- Coolant Tube Replacement is envisaged during the plant life. This has bearing on solid waste deposition.

Multi Unit Site

For a multi unit site with more than two units, a centralized facility for management of waste has been designed. The treatment and conditioning processes are sized for a single shift operation of two units and extended to two or three shift operations as more units become operational.

TREATMENT AND DISPOSAL OF LIQUID WASTE

Chemical Treatment with Co-precipitation

This method is used for active non-chemical waste having large volume and low activity. It involves coagulation, flocculation and sedimentation.

The chemicals employed in Indian plants are the Ferrocynides for Caesium and phosphates for Strontium. The addition of chemicals is followed by a flocculator and a clarifier. The clarified water is further treated if required. The sludges are thickened in thickeners/centrifuges and solidified in cement. A decontamination factor (DF) of about 10 is normally achieved.

Ion Exchange

Two types of ion exchangers have been in use:

- Naturally occurring clay: Vermiculite was used earlier for removal of Cs. Its use has been discontinued because of low capacity, non-regenerative nature and handling problems. A DF of 10 is possible.
- Synthetic Resins: They are regenerative type. A cation bed leads the mixed bed. The mixed bed does the polishing realizing high DF of the order of 100 to 1000.

Reverse Osmosis

This is quite a promising process and results in very low secondary waste. Considerable development & testing work has already been completed. For a single stage, DF of 10 to 100 is achieved. This process has not been applied so far as the waste produced is relatively clean.

Steam Evaporation

The non foaming type active chemical waste with no volatile activity is treated in thermosyphon type of evaporators. While high DF of the order of 10^3 to 10^4 are attainable, the process is being discontinued because of low volume of ACW. Instead, neutralization and fixation of precipitate in cement is planned.

Solar Evaporation

Disposal of tritiated waste at coastal and inland site with adequate availability of water is by dilution and dispersal. As release of tritium in a controlled manner at a low rate over large areas is an acceptable solution; solar evaporation is most suitable for tritium laden waste in tropical regions. This process is mainly governed by site climatic conditions. Evaporation is carried out by providing adequate area in the form of pans. Apart from ease of operability, solar evaporation helps to realize 'zero release concept'. A solar evaporation facility is being successfully used at RAPS, Kota, to concentrate low level liquid effluents (2).

The important design inputs are :

Net evaporation rate	: 1.26 m/year.
Amb. air temperatures	: 7.8°C to 46.5°C
Avg rainfall	: 815 mm (max 1270)
Relative humidity	: 30% Avg.; 60% during monsoon
Wind Speed	: 6 to 11 Km/hr.
Solar Radiations	: 713 Cal/cm^2/day in May.
Max. daily avg.	394 Cal/cm^2/day in December.

The plant provides 15000 m^2 evaporation surface with a capacity to evaporate 19000 m^3 per year.

The sludge from the bottom of pans is mechanically pushed to sump and further transferred by diaphragm pumps to storage tanks. Quatenary ammonium compounds are added to destroy algae and biogrowth. The sludge is fixed in cement prior to final disposal, in earthen trenches.

Tritium concentration in air around the pans and tanks has been well within the permissible limits. Annual discharges of tritium through the water route have significantly come down after the introduction of SEF.

Corrosion and contamination of concrete structure; and entry of birds and rodents into the pans need to be tackled at design stage.

TREATMENT AND DISPOSAL OF SOLID WASTE

A nuclear station produces various types of solid/ semi-solid wastes. Filters, ion exchangers and equipment/ component discarded during maintenance like impellers, valves and seals comprise of solid wastes. The secondary wastes like spent resins, chemical sludges, incineration ash etc. have also to be handled.

The wastes are collected and transported in suitable containers to the TCS building where they are segregated based on the surface dose levels and their nature into following categories:

- Category-I: The packages having surface dose of less than 2 m Sv/hr are segregated at source into combustible and non combustible packages. Bulk of the waste is incinerated to obtain high volume reduction. The resulting ash is fixed in cement. Hard compactable waste is reduced in volume by compactors. Non compactable, non combustible waste is given a coating of cement grout or molten bitumen and filled in primary containers. The drums are grouted with cement or coated with molten bitumen and disposed off in shallow land burial.
- Category-II: The wastes with surface dose 2 m Sv/hr to 20 m Sv/hr are mainly fixed in cement. Filters are containerized in standard drums, grouted with cement and sent for disposal.
- Category-III: The wastes with surface dose more than 20 m Sv/hr such as spent resins and filters of moderator, PHT and SFSB purification systems; highly contaminated discarded components are conditioned in cement/polymer in standard 200 liters MS drums for disposal.

Disposal of Solid Waste

Three types of containment have been used :

i. RCC trenches / concrete vaults.

ii. Tile holes.

iii. High integrity retrievable containers.

The disposal philosophy: Low and Medium Active Waste mainly Category-I, Category-II and part of Category-III are disposed in RCC trenches/concrete vaults.

High Active Solidified Waste with surface dose of more than 0.5 Sv/hr are contained in high integrity containers and retrievable facility. Wastes not requiring retrievability are disposed off in tile holes.

Decommissioning/Decontamination Waste

The waste arising from decommissioning of nuclear plant has not been considered for the design of facility. However provision for adequate space for burial of solid waste has been kept. The total radioactive waste from a twin unit station of 220 MWe PHWR type is estimated to be of the order of 4000 m^3.

Decontamination on a full scale of primary coolant system of a 220 MWe pressurized heavy water reactor in India has been recently carried out for the first time. A total quantity of 110 Kgs. of iron with radioactivity of 37 x 10^{10} Bq was removed with ion exchange units. Such radioactive wastes in the form of ion exchange resins are expected to be generated in future also. Waste management plants will handle them on campaign basis.

CONCLUDING REMARKS

Indian Nuclear Power program is backed up with a sound engineering facility for management of radio active waste. Operating experience of over thirty years in handling waste generated at our nuclear facilities including that from refurbishing of reprocessing plant has been full of challenges which have been successfully met by R&D efforts and design innovations. Solar evaporation was the result of such efforts to restrict tritium releases to water body. By and large, we have not only been able to meet but also keep the releases to a fraction of limits prescribed by regulatory body. We are not remaining content with the achievements but are continuing with our efforts to evolve newer designs of IX, reverse osmosis to further cut down the releases in line with ALARA principles.

It has not been possible to fully bring out all aspects of waste management, particularly the plant design features from their inception which have significant bearing on the waste generation & radiation exposure. However, it is heartening to say that our operating & maintenance personnel have requisite training and discipline to restrict the generation of waste and manage them without causing undue radiation exposure to themselves and public.

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