Overview of Radioactive Waste Treatment in Domestic Nuclear Power Plants of Pressurized Water Reactor

Meng Hongshe

Abstract In accordance with the *Twelfth Five-Year Plan and* 2020 *Prospective Target*, China will see a coexistence of multiple reactors, different nuclear technologies, and standards in the development of nuclear power, and it is foreseeable that similar situation will also occur in radwaste treatment. This paper reviews the different radwaste treatment technologies in line with corresponding types of pressurized water reactor and proposes radwaste treatment options for newly built nuclear power plants of pressurized waster reactors by drawing experience from foreign peers.

Keywords Radioactive waste · Waste disposal

1 Introduction

All industrial facilities inevitably produce wastes in its production activities, in the form of dust, heat, chemical by-product, or others. As for a nuclear power plant (NPP), it will produce some gas, liquid, and solid wastes with radioactivity due to the existence of fission materials, corrosion product, and activated coolant. Radioactive wastes (radwastes) are materials that shall not be reused due to operation on site or contaminated by radionuclides, whose concentration or activity exceeds the clearance level that defined by government regulator. Radwastes from NPP are featured with radioactive inertia gas, iodine and aerosol gas, or active product, and low–intermediate radioactive liquid and solid wastes in fission products. To protect the environment from being contaminated and to prevent the work staff and residents around NPP from overdose exposure, these radwastes have to be treated before discharge or storage.

In accordance with the Twelfth Five-Year Plan and 2020 Prospective Target, China will see a coexistence of multiple reactors, different nuclear technologies, and

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standards in the development of nuclear power, and it is foreseeable that similar situation will also occur in radwaste treatment. This paper focuses on the treatment of low–intermediate radioactive gas, liquid, and solid wastes that contain active product and fission material in nuclear power plant of pressurized water reactor (PWR NPP) and propose options for radwaste treatment in domestic PWR NPP.

2 Description of Radwaste Treatment in Domestic PWR NPP

2.1 Radwaste Treatment for AP1000

Radwastes produced from AP1000 reactors are mainly radioactive liquid, liquid, gas, spent resin, and spent filter cartridge produced from primary loop in abnormal conditions, compressible and incompressible solid dry waste, etc. The outstanding character in its radwaste treatment is the application of SRTF (site radioactivity waste treatment facility), which is a center for disposing radwaste that is shared by four or more reactors in a NPP. SRTF sees its first application in China by the method of reducing volume, which includes dewatering and supercompaction, to dispose those radwastes produced by four or more reactors that cannot be processed by nuclear island waste liquid system, which are mainly solid radwastes and wastes produced from abnormal conditions.

2.1.1 Radioactive Liquid

Liquid radwaste system processes radioactive liquid produced from normal operation or anticipated operation occurrence by filtering and ion exchanging. By filtering, suspended solids shall be purged from liquid radwaste, along with the interception of spent resin to prevent them sliding into other equipment. The filter is a fine mesh mechanical filter, whose cartridge can be changed by remote operation. There are intermittent or continuous ion exchange method adopted for disposing liquid radwaste. As for continuous method, those to-be-treated liquid radwaste shall be purified by continuously flowing around columns that made from ion exchange resin. This method is usually accepted in NPP for its high efficiency.

Advance treatment of coolant liquid radwastes that produced from normal operation and anticipated operation occurrence is adopted by canceling conventional evaporation device and simplifying process and building arrangements. These coolant liquid radwastes together with other liquids that produced from special conditions are collected and temporarily stored in nuclear island and will be further treated by a set of mobile equipments that are shared by reactors or by SRTF after shifting by shielding transferring containers. In the latter case, devices such as filter, active carbon absorption bed, ion exchange bed, R/O filter, and R/O skid are deployed. The treated liquid radwaste then shall be sent back to nuclear island liquid radwaste system for further treatment or discharge after satisfying relevant standards, while R/O concentration solutions are sent to SRTF for drying. Mobile equipment shall be innovated along with the development of technology. At present, evaporation technology is functioning in SRTF of Sanmen NPP, but not in Haiyang NPP yet.

Liquid radwaste system consists of tanks, pumps, ion exchange bed, filter, etc.

2.1.2 Radioactive Gas

Active carbon delay beds absorb hydrogen-containing gas and fission gas produced from nuclear island. Fission gas is sent to ventilation tube after the absorption of active carbon and delayed decay. Main equipments involve gas cooler, steam separator, one active carbon protection bed, two active carbon delay bed, etc.

2.1.3 Radioactive Solid

Radioactive solid waste system only functions as collecting and interim storage without processing inside nuclear island. Solid wastes have to be sent to SRTF for volume reducing by transferring in shielded container and special vehicle. And SRTF is the first time being adopted in China, where various wastes that cannot be processed by nuclear island waste treatment system are volume-reduced by desiccating or supercompaction. SRTF is an independent facility that stays away from other buildings. Nuclear island wastes are verified and transferred in shielded container to appointed area in SRTF. SRTF is divided into waste processing area (including control access), laundry, and interim repository, and it processes wastes that are produced by itself including equipment exhaust gas, condensed solution, equipment cleaning water, and HEPA. These secondary liquid wastes shall either be sent back to chemical liquid waste treatment system or slot-discharged by evaluating their radioactivity, and the wastes thus occurred do not have to send back to nuclear island or other facilities. With its high density of processing, SRTF avoids overlapping equipment inside each single unit; therefore, costs concerning operation, management, and maintenance are greatly reduced.

2.2 Disposal of CPR1000 and EPR Radwaste

Radwastes from CPR1000 and EPR are mainly reusable radioactive liquid, disposed radioactive liquid, service liquid, gas that containing hydrogen and oxygen, spent resin, condensate solution, spent filter cartridge, and compressible and incompressible solid wastes.

2.2.1 Radioactive Liquid

Reusable liquid wastes refer to reactor coolants discharged from primary loop that are not contaminated by air and containing hydrogen and fission products. These coolants are reusable after systematic collecting and treatment. Disposed liquid wastes mean process drain, floor drain, and chemical liquid, which shall be collected, sorted, stored, filtered, demineralized or evaporated, and discharged with monitoring. Condensate solutions produced from evaporation shall be barreled after cementation.

Evaporation and condensation process refers to boiling radioactive liquid that contains volatile solvent (water) and nonvolatile material (fission product and inorganic salt) in evaporator. Part of the liquid shall be evaporated and exacted and be discharged, reused, or further treated according to its quality index after condensation and monitoring. Condensed residuals that are rich in radionuclide shall be stored or solidified.

Centrifuge technology witnesses its first application in Taishan EPR NPP, which has the benefit of without producing secondary waste.

2.2.2 Radioactive Gas

CPR1000 radioactive gas that contains hydrogen shall be discharged after a series of treatments, including condensation, storage (explosive-proof), decay, monitoring, and iodine removal by filtering and dilution. Gas that contains oxygen shall be discharged after heating and dehumidifying, iodine absorption, decay, and iodine removal by filtering.

EPR adopts active carbon delay bed and relied on active carbon's feature of transferring elements to reduce the decay activity of radioactive inertia gas.

2.2.3 Radioactive Solids

Radioactive solids can be divided into different categories by its characters, such as spent resin, concentrated solution, spent filter cartridge and other solids of strong radioactivity, compressible wastes (i.e., paper, plastics, clothes, gloves, working suit, and ventilation filter cartridge), and incompressible wastes (for instance, metal blocks used after repairing or changing, fittings, and metal tubes).

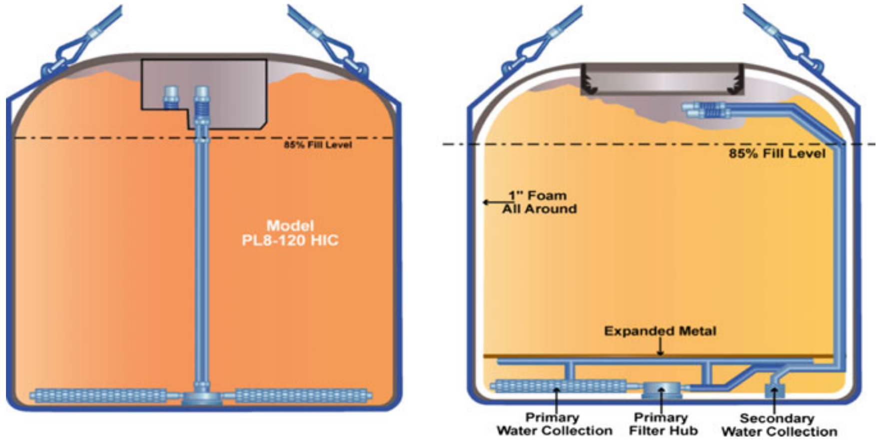
Spent resins and concentrated solutions have to be solidified, which can be divided into inside and outside categories (for detail, see Fig. 1 below).

Spent filter cartridge (dose rate higher than 2 msv/h) and other incompressible strong radioactive waste (such as metal blocks used after repairing or changing, fittings, and metal tubes) have to be treated by cementation.

Spent resin and spent filter cartridge can be directly stored in high-integrity container (HIC), which is a specially designed container with high strength, leak tightness, and chemical and thermal stability and can be loaded with radwastes that

Inside-container door type mixer | Inside-container double helix mixer | Outside-container mixer

Fig. 1 Solidification inside and outside of the container [1]



Filling with spent resin | Filling with spent filter cartridge

Fig. 2 High integrated container [2]

are not solidified. HIC is used to dispose radwastes such as spent resin and spent filter cartridge with dimension ranging from 0.23 to 8.5 m^3 and is equipped with many internal structures and lifting devices. It is made from interlinked polyethylene and can prevent corrosion in shallow ground to improve its safety, and what's more, its storage life is longer than that of steel containers. HIC vault is fixed by threaded bolts. HIC is suitable for storing radioactive dry waste, cement cladded radioactive parts, dewatered spent rein, active carbon, etc. Details are shown in Fig. 2.

Compressible wastes (paper, plastics, clothes, gloves, working suit, ventilation filter cartridge, etc.) have to be sorted out in sorting station and then precompacted and supercompacted in a 200-L metal container. During supercompaction, the container has to be perforated to release the air contained. After supercompaction,

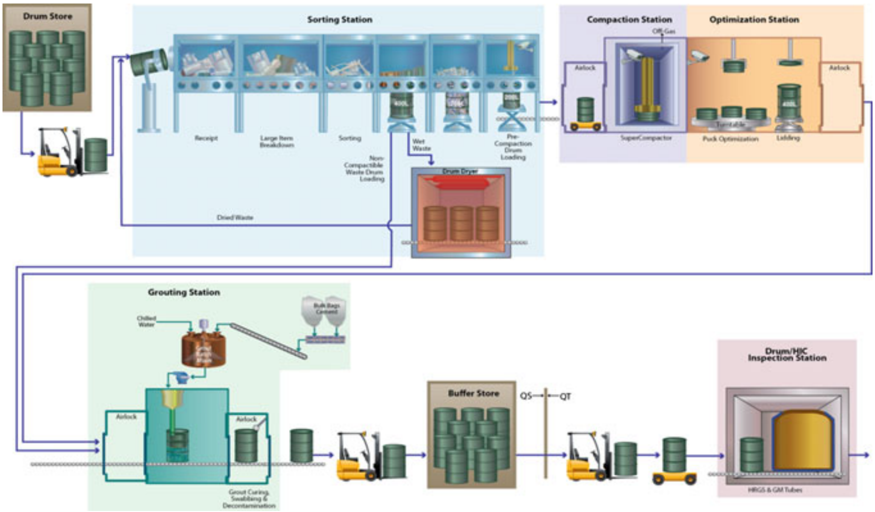


Fig. 3 Treatment of compressible waste [2]

pellets have to be measured by height, weight, and dose rate, which shall determine the allocation of pellets in 400-L metal containers for cementation (see Fig. 3).

3 Current Situation of Disposing Radwaste in Foreign NPPs

In the study, the treatment methods of liquid waste in foreign PWR NPPs used are ion exchange, membrane separation, evaporation, filtering, desiccation inside container, etc. In France, methods such as evaporation, ion exchange, filtering, and centrifuge are adopted; in Germany, evaporation, ion exchange, centrifuge, and desiccation inside container are adopted; in Japan, evaporation, ion exchange, filtering, and centrifuge are adopted.

Methods for treating gas in foreign PWR NPPs are compaction, storage (explosive-proof), decay, iodine absorption, iodine removal by filtering, dilution, active carbon delay bed absorption, heating and dehumidification etc.

There are many ways of disposing solid wastes in foreign PWR NPPs, which are cementation, HIC sealing, hot compaction and wet oxidation for spent resin, molten salt oxidation, microwaving, biodegradation, cementation, and burning. Plasma molten volume reducing technology uses thermal plasma fast pyrolyzes wastes and produces glassy inorganic. The gas it produced breaks down into atoms and simplest molecules, and most important of all, those toxic organics shall be reduced into nontoxic small molecules. In the case of NPP, radionuclides in low and intermediate solid wastes are fully cladded in glassy slags and its product is in a stable inorganic state. Plasma molten volume reducing technology has a high ratio of volume reduction with merits of stable product and free of secondary contamination, and it is widely accepted as one of the advanced technologies in the world.

4 Conclusion

To sum up, it is concluded that:

4.1 Disposal of Liquid Waste

Evaporation is mainly used in and out of China to treat liquid radwaste in PWR NPP; although filtering membrane is adopted, it is not matured yet for it brings the change of filter membrane and treatment of secondary waste.

4.2 Disposal of Gas

Active carbon absorption and decay shall be the mainstream technology. It adopts hydrogen oxygen recombiner, where nitrogen can be recycled and inertia gas shall be selectively absorbed by delay bed before discharge.

4.3 Disposal of Solids

Cementation is mainly used to dispose spent resin and concentrate, and it is divided into inside and outside mixing. Cementation of spent resin has problems such as uneven distribution and bulging.

Spent filter cartridge and waste pellets with high dose rates have to be cementated and sealed.

Metal containers shall gradually replace concrete containers.

HIC is loaded with solid waste and has long ensurence and good leakage tightness, which is suitable for dewatered resin and other wastes. However, material, manufacturing process, and product checking for HIC have to satisfy the relevant standards. For HIC package with high activity and surface dose rate, its lifting, transportation, storage, and ultimate disposal have to meet the national standards and regulations.

Thermal compaction and wet oxidation are also an option for treating spent rein. But the latter method risks explosion with the use of hydrogen peroxide, and the oxidants are hard to control, what's more large quantities of secondary liquid waste have to be treated.

Compressible wastes (paper, plastics, clothes, gloves, working suit, low-dose filter cartridge, etc.) can be treated by compaction, cementation, and buring. However, burning is only in research phase. Plasma molten volume reducing has been put into actual use, while it does not embark on China yet.

In conclusion, radwastes are of complicate composition, and each corresponding treatment method is accompanied with defects. While in selecting the treatment method, we shall not only consider waste volume reduction, but also the safety and stability of ultimate product. By comprehensive consideration can we adopt the optimized solution, in order to produce truly clean energy from NPP.

References

1. The pictures from IRH Engineering, Westinghouse Electric Germany GmbH, AREVA GmbH.
2. The pictures from Energy Solutions, LLC.