

Nuclear Power Plant Liquid Radioactive Waste Management and Overseas Practices (Dismantling/Decontamination)

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1. Introduction

The decommissioning of commercial nuclear power plants (NPPs) generates vast quantities of radioactive waste, among which liquid radioactive waste presents significant challenges due to its mobility and diverse chemical compositions. Effective management of this liquid radioactive waste is critical not only for environmental protection but also for ensuring worker safety under the ALARA (As Low As Reasonably Achievable) principle. While various laboratory-scale treatment technologies—such as ion exchange, membrane filtration, and chemical precipitation—have been developed, scaling these technologies from controlled laboratory environments to the complex operational conditions of an actual decommissioning site remains a significant challenge. To ensure "field applicability," it is essential to optimize these technologies to handle the high variability of waste streams encountered during the dismantling and decontamination of large structures. This study aims to present specific technological advancements and verification strategies for the stable implementation of liquid waste treatment systems at commercial NPP decommissioning sites, drawing on global best practices and site-specific requirements, such as those of Kori Unit 1.

2. Current Status and Verification of Key Technologies for Liquid Waste Treatment

Liquid Waste Treatment System: Mobile Reverse Osmosis (RO) Unit Within the decommissioning scope of Kori Unit 1, the evaporator is designated as a priority component for removal. Due to the requirement that the evaporator be dismantled prior to the final clearance of the controlled area, any liquid radioactive waste generated after its removal cannot be processed by the existing plant systems. Consequently, it is necessary to implement a new, independent treatment solution to manage post-dismantling liquid waste. To address this, a newly developed mobile Reverse Osmosis (RO) Membrane system will be deployed. To ensure that the treated effluent meets the strict regulatory discharge limits, the mobile system will be engineered with a configuration similar to the primary nuclear power plant liquid waste treatment facilities. The system will consist of three primary stages:

1. Pre-treatment Unit: To remove suspended solids and protect the membranes from fouling.
2. Reverse Osmosis (RO) Membranes: To achieve high-efficiency removal of dissolved radionuclides and ions.
3. Ion Exchange (IX) Equipment: To serve as a final polishing step, utilizing inorganic ion exchangers (e.g., tin antimonates or crystalline silicotitanates) which exhibit high selectivity for trace radionuclides even in the presence of competing ions. This stage ensures the removal of residual isotopes that may bypass the primary membrane process, a necessity supported by studies demonstrating the superior performance of inorganic materials in complex waste matrices.

3. Three major strategies to treat the liquid waste

1) Implementation of Mobile and Modular Evaporation Treatment Systems

Since existing fixed liquid waste treatment facilities are often prioritized for removal during the early stages of decommissioning, global trends—particularly in the United States—are shifting toward the adoption of "Mobile Evaporation Units," which modularize high-performance evaporation systems.

- Deployment of Containerized Evaporation Systems: By utilizing compact, high-efficiency evaporation units designed for trailer-mounting or containerization, flexible waste concentration and processing capacities can be secured on-site without relying on massive, permanent plant infrastructure.
- Operational Flexibility and Contamination Control: The rapid deployment of evaporation modules in close proximity to waste generation zones fundamentally minimizes the risk of leakage and secondary contamination that may occur during the transport of large volumes of liquid radioactive waste.

2) Multi-stage purification for regulatory compliance

To meet stringent discharge limits and environmental standards, overseas cases (e.g., Germany and Japan) emphasize a multi-layered purification architecture to ensure "zero-leakage" and high decontamination factors.

- Integrated RO-IX Process: Combining pre-filtration, Reverse Osmosis membranes for bulk ion removal, and high-selectivity Ion

Exchange resins for the final polishing of trace radionuclides (e.g., Cs-137, Co-60).

- Customized resin application: Developing and applying site-specific selective resins based on the isotopic characteristics of the waste stream to maximize the Decontamination Factor (DF).

3) Volume reduction and secondary waste minimization
A critical factor in decommissioning cost is the volume of secondary waste generated during the treatment process. Advanced strategies focus on maximizing the recovery of treated water and minimizing the final waste form.

- Concentration and solidification: Utilizing advanced evaporation and membrane concentration to reduce liquid waste to a minimal slurry or sludge, which is then stabilized through cementation or dry-powder(dry-mix) process.
- Reagent regeneration: Implementing electrolytic or chemical regeneration processes to recover decontamination agents and reduce the amount of spent resins and filters.

4. Conclusions

This study addresses the critical necessity and strategic implementation of independent liquid radioactive waste treatment systems for the decommissioning of commercial nuclear power plants, specifically focusing on the operational constraints of Kori Unit 1. The removal of primary plant infrastructure, such as the evaporator, necessitates a transition from permanent facility-based processing to flexible, field-applicable technologies to maintain safety and regulatory compliance under the ALARA principle.

The proposed technical framework integrates a three-stage purification process—consisting of pre-treatment, Reverse Osmosis, and Ion Exchange—to ensure the high-efficiency removal of dissolved radionuclides and trace isotopes. Furthermore, the adoption of mobile and modular evaporation units, as seen in global trends, provides a scalable solution that enhances on-site agility and significantly mitigates the risk of secondary contamination during waste transport. By combining these multi-layered purification architectures with advanced volume reduction techniques, such as dry-mix stabilization and reagent regeneration, the system maximizes the decontamination factor (DF) while minimizing the environmental and economic burdens of secondary waste.

In conclusion, the integration of mobile modularity, multi-stage purification, and waste minimization strategies provides a robust and stable roadmap for managing liquid waste during NPP decommissioning. This approach not only ensures strict adherence to regulatory discharge limits but also establishes a technical benchmark for the safe and efficient decommissioning of similar commercial nuclear facilities worldwide.

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