

Economic and Technical Feasibility of Biological and Chemical Decontamination for Spent Ion-Exchange Resin Reduction in APR 1400 Nuclear Power Plants

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1. Introduction

The Liquid Waste Management System (LWMS) in the APR1400 nuclear power plant (NPP) primarily employs reverse osmosis (R/O) and ion-exchange technologies to ensure compliance with regulatory discharge standards. During the treatment of radioactive liquid waste, the ion-exchange process generates spent ion-exchange resin as a secondary waste product, classified as either low-level or intermediate-level radioactive waste. Given the widespread use of ion-exchange systems across nuclear facilities, large quantities of this resin are produced annually. To address this challenge, this study developed innovative biological and chemical decontamination methods aimed at significantly reducing the volume of spent resin generated in NPPs, followed by a comprehensive economic evaluation of the proposed approach.

2. Methods and Results

This section presents the experimental performance and system integration of the decontamination technology, demonstrating high removal efficiency and significant operational and economic benefits.

2.1 Experimental Method and Results

The core mechanism of the developed technology lies in the transformation of dominant radionuclide ions into stable inorganic crystalline phases (Fig. 1) through either chemical or biological pathways.



Fig. 1. Solid precipitates formed from radioactive liquid waste via the biological method.

Batch-scale experiments demonstrated that the biological approach achieved selective removal of cesium exceeding 80% within 24 hours, while the

chemical method attained a removal efficiency of over 95%. Furthermore, a broad spectrum of key radionuclides commonly found in nuclear liquid waste streams—including cobalt (Co), nickel (Ni), iron (Fe), chromium (Cr), manganese (Mn), and europium (Eu)—were effectively immobilized with removal efficiencies surpassing 99%.

2.2 Applicability and Economic Feasibility

The integration of a chemical or biological decontamination module into the APR1400 LWMS offers a transformative solution to eliminate recirculation and significantly reduce spent ion-exchange resin generation. Currently, the LWMS treats radioactive liquid waste sequentially through a charcoal bed, filter, reverse osmosis (R/O) unit, and ion-exchange column. However, incomplete removal of key radionuclides—⁵⁸Co, ¹³⁴Cs, and ¹³⁷Cs—necessitates frequent recirculation to meet discharge criteria. As illustrated in Fig. 2, the proposed system is installed between the R/O unit and the ion-exchanger and consists of two storage tanks (with level, temperature, and pH control), a columnar reaction mixer (equipped with reagent injectors), dehydration units, and associated pumps and piping.

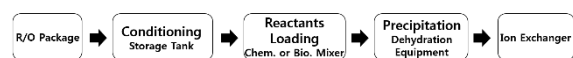


Fig. 2. Conceptual process for the chemical or biological decontamination.

The process targets long-lived radionuclides—⁵⁵Fe, ⁶⁰Co, ⁶³Ni, and ¹³⁷Cs—based on the waste acceptance criteria (WAC) of the nuclear waste disposal facility [2] and half-life thresholds (>1 year). A conservative decontamination efficiency of 90% was adopted, reflecting engineering margins. This level of performance reduces the post-R/O radionuclide load by a factor of 10, enabling direct discharge without recirculation and extending resin replacement cycles by up to 10 times.

Economic analysis (Table I), based on FSAR data from Shin Kori 3&4 [1] and MOTIE Notice No. 2017-195 [3], reveals substantial cost savings. Annual spent resin

volume decreased from 36 to 4 standard 200 L drums and from 3 to 2 high-integrity containers (HICs). With disposal costs of ₩15.8 million per 200 L drum and ₩87.2 million per HIC, the annual disposal cost dropped from ₩800 million to ₩200 million—a reduction of 71%. Over a 40-year operational period, total spent resin management costs are projected to decrease by 79.74% (material), 88.89% (polymerization), and 71.39% (disposal), demonstrating the long-term technical and economic viability of the integrated system.

Table I. Estimated annual costs for disposing of spent resin waste under two scenarios at Shin Kori 3&4.

Spent Resin Waste Streams	Option 1*		Option 2**		
	High Activity Spent Resin	Low Activity Spent Resin	High Activity Spent Resin	Low Activity Spent Resin	Waste from Chemical Process
Volume from FSAR (L·yr ⁻¹)	17,060	54,300	1,706	5,430	-
Projected Volume (L·yr ⁻¹)	2,075	6,600	207.5	660	605.90
Processing Capacity per Unit HIC/Drum	818L	187L	818L	187L	818L
No. of Containers /Drums	3	36	1	4	1
Disposal Cost per Containers/ Drums (₩)	87.18	15.80	87.18	15.80	87.18
Disposal Cost (₩)	261.54	568.80	87.18	63.20	87.18
Total Disposal Cost (₩)	830.34		237.56		

*Only LWMS [4]

**LWMS + chemical decontamination process

3. Conclusions

This study developed and evaluated innovative biological and chemical decontamination technologies for the treatment of radioactive liquid waste in the APR1400 nuclear power plant. The proposed method effectively transforms dominant radionuclide ions into stable inorganic crystalline phases, achieving over 95% cesium removal and >99% immobilization of key radionuclides such as Co, Ni, Fe, Cr, Mn, and Eu. When integrated into the existing LWMS between the R/O unit and the ion-exchanger, the system enables direct discharge without recirculation, extends ion-exchange resin replacement cycles by up to 10 times, and reduces annual spent resin generation by a factor of 10. Economic analysis based on data from Shin Kori 3&4 demonstrates a 71% reduction in annual disposal costs—from ₩800 million to ₩200 million—and significant long-term savings of up to 88.89% in polymerization and 79.74% in material costs over a 40-year period.

These results confirm the technical feasibility, operational efficiency, and substantial economic benefits of the integrated decontamination system, offering a sustainable solution for managing spent ion-exchange resin in nuclear power plants.

REFERENCES

- [1] Korea Hydro & Nuclear Power Co. Final Safety Analysis Report for Shin Kori 3&4 (2010).
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