Research Paper

https://doi.org/10.7733/jnfcwt.2018.16.1.65

Management of Spent Ion-Exchange Resins From Nuclear Power Plant by Blending Method

Nursaidatul Syafadillah Kamaruzaman, David S. Kessel, and Chang-Lak Kim*

KEPCO International Nuclear Graduate School, 658-91 Haemaji-ro, Seosaeng-myeon, Ulju-gun, Ulsan, Republic of Korea

(Received December 13, 2017 / Revised February 5, 2018 / Approved February 21, 2018)

With the significant increase in spent ion-exchange resin generation, to meet the requirements of Waste Acceptance Criteria (WAC) of the Wolsong disposal facility in Korea, blending is considered as a method for enhancing disposal options for intermediate level waste from nuclear reactors. A mass balance formula approach was used to enable blending process with an appropriate mixing ratio. As a result, it is estimated around 44.3% of high activity spent resins can be blended with the overall volume of low activity spent resins at a 1:7.18 conservative blending ratio. In contrast, the reduction of high activity spent resins is considered a positive solution in reducing the amount of spent resins stored. In an economic study, the blending process has been proven to lower the disposal cost by 10% compared to current APR1400 treatment. Prior to commencing use of this blending method in Korea, coordinated discussion, and safety and health assessment should be undertaken to investigate the feasibility of fitting this blending method to national policy as a means of waste predisposal processing and management in the future.

Keywords: Spent ion-exchange resins, Blending method, Mass balance approach, Mixing ratio, Waste acceptance criteria

*Corresponding Author.
Chang-Lak Kim, KEPCO International Nuclear Graduate School, E-mail: clkim@kings.ac.kr, Tel: +82-52-712-7333

ORCID

Nursaidatul Syafadillah Kamaruzaman http://orcid.org/0000-0002-9565-3930
David S. Kessel http://orcid.org/0000-0002-3601-9198
Chang-Lak Kim http://orcid.org/0000-0002-6931-9541

1. Introduction

In nuclear power plants employing light or heavy water as a coolant as well as in most waste treatment plants, ion-exchange materials are widely used for the purification of various water streams [1]. Since the spent ion-exchange resins retain radioactive nuclides as well as chemical impurities, they present a form of low level radioactive waste (LLW) and intermediate level radioactive waste (ILW) which requires particular handling and treatment for their storage and disposal. According to [2] and [3], ion exchange resins are used at commercial NPPs to capture radioactive contaminants dissolved in water during plant operations. After some time, the capability of ion-exchange resins to eliminate the contaminants from the water reduces and it must be removed to replace with new ion-exchange resins. In many cases in the nuclear industry, spent ion-exchange resins (spent resins) are considered as a problematic solid waste and require special treatment and precautions to meet the waste acceptance criteria for a disposal site.

Spent resins are a form of low and intermediate level radioactive waste that must be treated and conditioned for storage and disposal purposes. The methods used for conditioning and treatment can achieve several targets regarding management of spent resins, and the improvement of safety and economics linked with the further handling, storing and disposal are taken into account. Managing the spent resins that are generated from an NPP involves treatment of spent resins prior to the conditioning and may reduce the volume of waste. Therefore, the objectives for spent resins radioactive waste management are defined as shown in Fig. 1. The objectives are based on IAEA Technical document for Management of Spent Ion-Exchange Resins from Nuclear Power Plants [1].

The top-level objective, which is the management of spent resins, has five primary objectives. There are shown as volume reduction, immobilization, storage, disposal, and economic. The volume reduction objective requires pre-treatment method options, which are dewatering, drying, and blending and concentration averaging. Dewater and drying treatment is a traditional method that mainly used for conditioning of spent ion-exchange resins. Then, they are packed with or without absorbents into containers for storage or even for disposal [1]. The method generally preferred at present is to include immobilization in the conditioning. The blending and/or concentration averaging objective has two sub-objectives of reducing the amount of waste stored and lower the disposal class, with potential

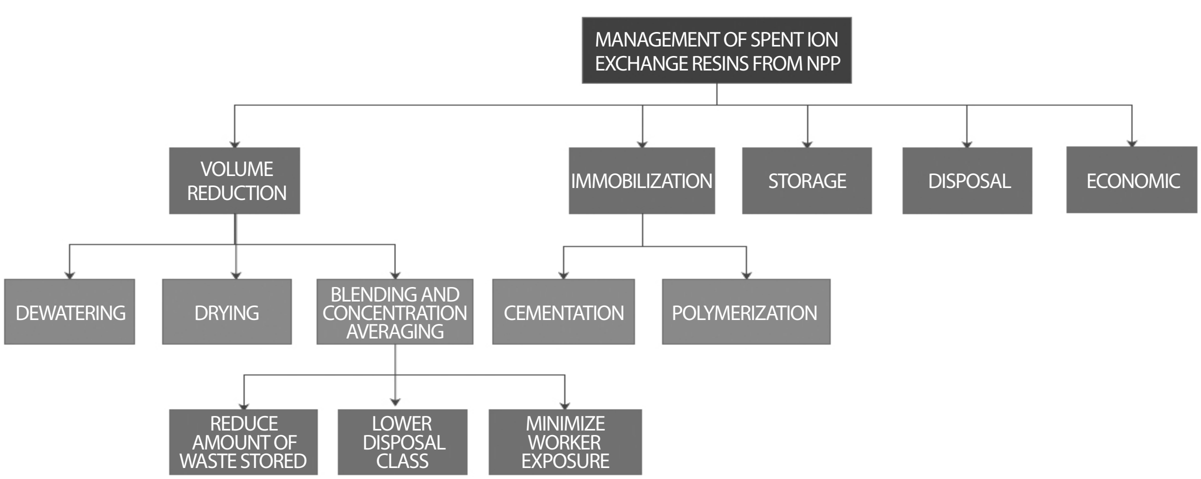

Fig. 1. Objectives hierarchy for managing spent resins from NPP.

impact in reducing worker exposure. Generally, spent resins are classified as low and high activity spent resins. Low activity spent resins will be treat prior to volume reduction. However, high activity spent resins are usually stored for a long period of time for the sufficient decay; then they are transferred to a disposable container such as a High Integrity Container (HIC) [4]. But in the blending method, it is proposed to treat both low and high activity spent resins with an appropriate method in order to assure safety during handling, storing and disposal.

Blending is defined as a process which combines materials with different radionuclide concentrations into a single tank or container to produce a mixture that is more amenable to storage, further treatment, and final disposal. Blending may include some forms of treatment and general waste packaging processes [5]. The blending method also requires adequate mixing for homogeneity of the mixture product to make sure final radionuclide concentration meets the WAC requirement for final disposal. However, blending is not a dilution process, which is mixing contaminated waste with clean or uncontaminated material solely to reduce waste classification. This process increases the total volume of contaminated waste to be managed, thus dilution is not allowed by the regulatory body. Meanwhile, blending of wastes to reduce the hazards in handling the wastes is desired and should be required [5]. After the treatment process, immobilization process is taken place to reduce the mobility of radioactive materials in the wastes and to ensure safe transport, storage, and disposal. The nature and extent of the two process steps can vary much depending on the technique applied. Thus, it is possible to combine both volume reduction and immobilization in one process as subsequent operational steps, as it is done in many bituminization methods. Cementation and polymerization are most commonly used for immobilization method of spent resins.

Table 1. Disposal of blended (projected) and unblended ion-exchange resin volume by waste [6]

Waste Class	Resin Volume, $ft^3 \cdot yr^{-1}$ (unblended)	Blended Resin, $ft^3 \cdot yr^{-1}$
A	75,000	83,000
B/C	12,000	4,000
Total	87,000	87,000

The Barnwell LLW disposal facility closed to states outside the Atlantic in June 2008. As a consequence, 90 of the 104 operating reactors have to store their own wastes as reported in [6]. This issue urged licensees and industry representatives exploring and considering a mixing of low level radioactive waste (LLW) as a way to mitigate the impact of Barnwell's closure. The blending of spent resins from NPP which can be blended into a relatively uniform mixture is once initiated by a waste processor in Tennessee. This blending approach would allow some materials that would otherwise have been disposed of as Class B or C waste to be mixed with Class A waste to create a Class A mixture [6] as it can be accepted in Class A disposal facility. As reported by P. Tran (2008), Class B and C resins account for approximately 12,000 ft^3 of LLW annually disposed, whereas Class A resins account for about 75,000 ft^3 annually disposed [7]. The article states that if resin blending was practiced, the volume of Class A resin would increase by approximately 8,000 $ft^3 \cdot yr^{-1}$ to a total of 83,000 $ft^3 \cdot yr^{-1}$. This would leave about 4,000 ft^3 waste classification and disposal of Class B/C resin to be stored as shown in Table 1 below.

For this study, the assumption is made that there will be a reduction in the disposal cost of LLW in the Wolsong repository compared with the disposal cost of ILW. Therefore concentration averaging and blending ILW may be highly beneficial from a cost perspective. In trying to combat the issue of ILW currently stored in NPP site, blending is proposed as an alternative treatment to convert the stored ILW Waste to LLW so as to meet the specific WAC requirement at Wolsong site, and then be shipped for disposal. This study aimed to develop the management of spent resins that are generated from the nuclear power plant through the blending method. The Final Safety Analysis Report (FSAR) for Shin Kori 3&4 is selected to provide the annual amount of radioactive waste generated. Then, the concept of blending method is developed by considering the Korean situation. In addition, blending is a target to give benefits in improving the existing radioactive waste management in Korea by reducing the spent resins stored in the plant.

Table 2. Treatment method for spent resins waste

Treatment	Package Drum
Cement Solidification	200 L Hanul C1 Concrete Hanul C2 Concrete
No treatment	200 L (shielded)
Drying	200 L Ferralium-HIC Polyethylene-HIC
Repacking	320 L Kori Circle Concrete

2. Spent Resins (SR) Waste in Korea

2.1 Status of spent resins treatment method

Since the operation of the Kori 1 NPP in 1977, KHNP has used various treatment methods for generated solid radioactive waste. In case of spent resins, there are three treatment methods available which are cement solidification, drying, and repacking. However, cement solidification and repacking into the 320 L drum are currently not used due to high leachability and has less volume reduction capacity [8]. Table 2 describes the treatment method for spent resins.

In APR1400, polymer solidification system is installed as a part of the waste treatment system. It consists of a mobile type polymer solidification system to solidify spent resins, and a stationary polymer solidification system to solidify dried R/O concentrate, as shown in Fig. 2 [4].

The polymer solidification method has been used over 40 years in the US, Japan, and Europe due to many advantages on compressive strength, durability, chemical resistance and water tightness. This method was chosen for the

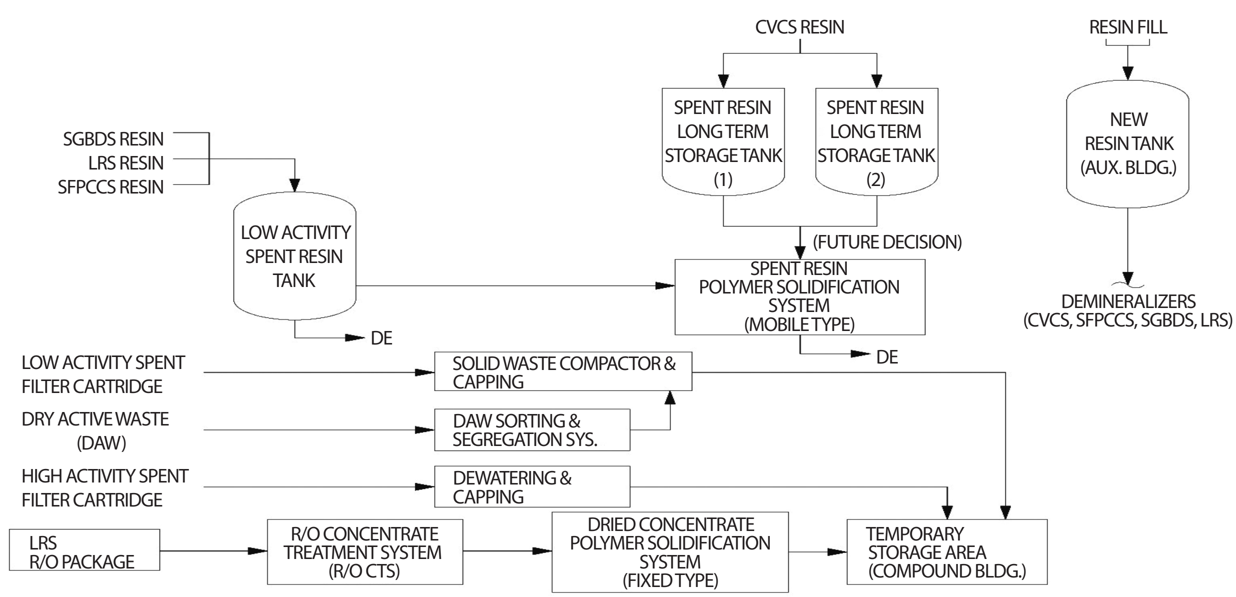

Fig. 2. Flow diagram of solid radioactive waste system in APR1400.

APR1400 by KHNP to treat generated waste which is homogenous such as concentrate, spent resin and sludge to be acceptable for disposal into the repository. Polymer, which is used to solidify in Shin-Kori 3 & 4, is supplied by AHAE Corporation in Korea and it is composed with 2 types of Radson 100 and Radson 200 as described in Table 3 [8].

2.2 Estimated spent resins inventory for Shin-Kori 3 & 4

The inventory of spent resins should be known before blending process takes place. It is the crucial part to be considered to perform blending. Therefore, the inventory such as volume or mass (as applicable), and radionuclides activity of spent resins are used to determine the activity concentration of the waste. In general, waste volumes may be calculated from the mass of the waste divided by a representative density. According to [9], for spent resins, the volume and mass of the waste are the dewatered volume and mass. Spent resins in APR 1400 generated from purification system of Chemical and Volume Control System (CVCS) and Spent Fuel Pool (SFP) system contains high activity and are classified as ILW, while low activity spent resin generated from Liquid Radioactive Waste System (LRS), Steam Generator Blowdown System (SGBDS), and Spent Fuel Pool and Cleanup System (SFPCCS) are classified as LLW. Table 4 shows estimated of spent resins inventory of Shin Kori unit 3&4 based on the FSAR estimation. From this report, the estimated volume of spent resins generated per year is approximately 71.36 m^3 maximum for both units [10].

Table 3. Specification of agent used in polymerization

Type	Radson 100	Radson 200
Use	Main agent	Additional agent
Component	Epoxy Resin	Polyamide Aliphatic amine Modified-poly amino amine

Table 4. Estimated spent resins inventory of Shin Kori 3&4 generated per year

Waste Class	Waste Stream	Percentage (%)	Volume ($m^3 \cdot yr^{-1}$)	Drums (EA)*
ILW	High activity spent resin	23.91	17.06	94.8
LLW	Low activity spent resin	76.09	54.30	301.7
	Total	100	71.36	396.5

*The number of drums was calculated considering the filling ratio of 0.90 to meet WAC

Table 5. Activity and concentration of major radionuclides in spent resins

Radio-nuclides	High activity SR (Bq)	Concentration ($Bq \cdot g^{-1}$)	Low Activity SR (Bq)	Concentration ($Bq \cdot g^{-1}$)	Half-life
^{54}Mn	3.20×10^{13}	1.47×10^{6}	2.10×10^{9}	3.02×10^{1}	312.3 days
^{55}Fe	3.30×10^{13}	1.51×10^{6}	1.60×10^{9}	2.30×10^{1}	2.73 years
^{58}Co	1.30×10^{12}	5.95×10^{4}	5.90×10^{9}	8.49×10^{1}	70.86 days
^{60}Co	1.60×10^{13}	7.33×10^{5}	7.00×10^{9}	1.01×10^{2}	5.27 years
^{65}Zn	9.20×10^{12}	4.21×10^{5}	6.70×10^{8}	9.64×10^{0}	244.26 days
^{137}Cs	2.00×10^{14}	9.16×10^{6}	1.30×10^{10}	1.87×10^{2}	30.17 years

Fig. 3. Operational concept for blending application.

The total volume of 71.36 $m^3 \cdot yr^{-1}$ is estimated after dewatering and solidification treatment by polymeric solidifying agents to fill the void of spent resins. The spent resins may contain significant quantities of radionuclides, which include corrosion, fission and activation products [11], [12]. The major radionuclides that may be present include ^{133}Ba, ^{137}Cs, ^{58}Co, ^{60}Co, ^{55}Fe, ^{54}Mn, ^{63}Ni, ^{99}Tc, and ^{65}Zn [2]. Therefore, the activities of major radionuclides were generated from the FSAR Shin-Kori 3&4 as shown in Table 5.

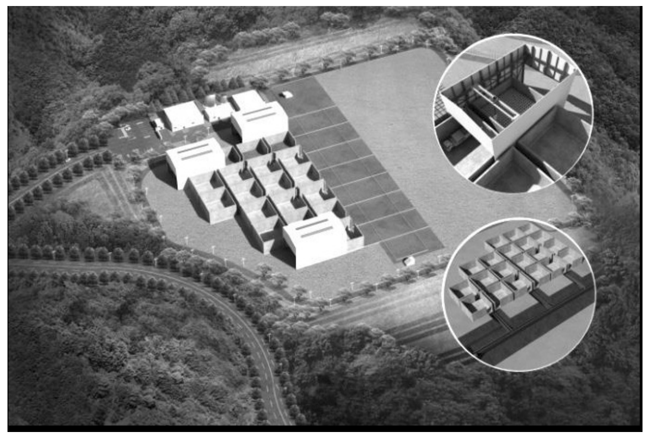

Fig. 4. Conceptual design of near-surface disposal facility in Wolsong Repository [13].

3. Methodology

3.1 General operational concept of blending

Remarkable amounts of spent resins are generated from the NPP operation and it is categorized as solid radioactive waste. Based on their classification, spent ion-exchange resins can be either low level waste or intermediate level waste. To reduce the amount of spent resins stored and lower the waste disposal class, blending method is applied. By this blending method, the final mixture of blendable spent resins is allowed to dispose in the LLW Disposal Facility if it meets with the WAC requirements and blending operational concept explain as in Fig. 3.

In Korea, a LLW disposal facility known as the near-surface disposal facility is the second phase of construction of the repository facility. The capacity of this facility is 125,000 drums in the area of 120,000 m^2, as shown in Fig. 4 [13]. There are 20 numbers of vaults, with the size of 20 × 20 × 9.55 m, and width of 0.6 m.

3.2 Requirement Analysis

Requirements are the keystone that needs to be considered to propose and implement a new process or technology. According to Buede, stakeholder's requirements provide operational statements by the stakeholders concerning to their needs [14]. In Korea, the stakeholders that relate to the radioactive waste management are a regulatory body (KINS), Disposal Facility (KORAD), and NPP owner (KHNP). Table 6 describes the requirement analysis for spent resins management by blending method.

3.3 Screening process of blending application

Spent resin is categorized as the single waste type with multiple waste streams. In the NPP, there are two waste streams of spent resins with different radiological character-

Table 6. Requirement analysis

Stakeholders	Requirements	Explanation
Regulatory Body	Waste Classification	Radionuclides Concentration Permission of waste blending method
	Safety Assessment	Demonstration of safety for public and environment results from blending process
Disposal Facility Owner	Waste Acceptance Criteria (WAC)	Clarification of down-blending to meet WAC for LILW disposal repository
	Waste Disposal	Perform site-specific intruder assessments and prove it by reasonable exposure scenarios Clarification of waste form and weight limit for handling
NPP Owner	Compliance with domestic regulations	Waste Acceptance Criteria Waste Classification Demonstration of safety for public and environment results from blending process
	Waste classification and identification	Estimation of spent resins total volume generate from NPP Identification of waste stream that can be blendable based on their physical and radiological characteristics.
	Waste Class reduction by blending	Suggest applicability of blending method by considering Korea current situation Suggest appropriate or optimal mixing ratio Identify the amount of stored spent resins to be used for blending process
	Cost saving by blending method	Estimation of cost saving through waste class reduction and approval of amount to apply blending method in Korea.
	Risk management	Risk management plan for blending approach Identification of the accidents from expectable scenarios

istics; which are one from the primary system, and the other one from the secondary system are combined in a single container. Generally, ion exchange resins from primary system are high activity resin and classified as ILW, meanwhile, ion exchange resins from the secondary system are low activity resin and classified as LLW [15]. In order to classify a mixture of multiple blendable waste streams, screening criteria may be used to simplify blending application, as shown in Fig. 5. In this study, low level and intermediate low level waste of spent resins are to be blended. Thus, the other radioactive solid wastes such as dry active waste and spent filters will be screened out and waste characterization is done to know either waste are blendable waste streams or discrete items. This process includes identifying the radiological and physical characteristics of the waste.

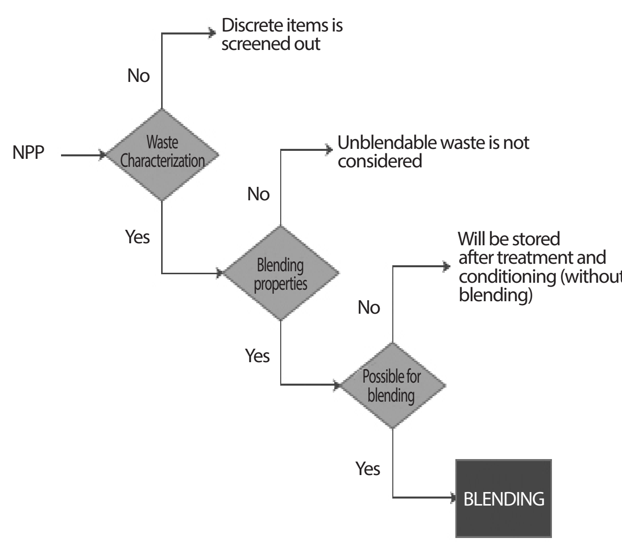

Fig. 5. Screening process for blending application.

Next, the determination of blending properties takes place. If waste can be physically mixed to create a homogenous final product or do not expect to contain durable items with significant activity, then the waste can be considered further for blending. If not, unblendable waste cannot perform blending and screened out. The last step of the screening process is the possibility and applicability for blending. It means that after blending, it is expected to give effects of:

- lower disposal class
- reduce the amount of spent resin stored
- reduce the final disposal cost

3.4 Blending method options description

Mixing or blending of particles is an important process in many industries, such as chemical, ceramic, plastic, and minerals [16]. The main objective of mixing is to achieve a highly homogenized final product of mixture. In a normal scenario, spent resins are segregated by their activity levels in holding tanks by spent resin transfer and storage subsystem. It is designed to transfer the expended radioactive resins from their vessels to the spent resin tanks where the resin is held up prior to being processed [17]. In this study, the LLW and ILW spent resins would be pumped from holding tanks which are High and Low activity storage tanks into the 200 L drum in the proper proportions such that final mixture would meet LLW disposal concentration limits. The LLW and ILW spent resin would be blended together in a mechanical mixing process to create a final homogeneous mixture and then dewatered or dried. After that, the blended waste would then be placed in shielded shipping casks, as appropriate, and transported to a disposal facility. Blending provides a disposal pathway for ILW concentration spent resins. There are two options of blending method can be performed, either in-drum mixing or an external mixing process. The 200 L in-drum mixing process does not require blending tank and illustrated in Fig. 6.

On the other hand, external mixing process requires a blending tank as shown in Fig. 7. Continuous in-line mixers which allow small hold up and easy cleaning, as well as batch mixers of various types, can be used for blending spent resin wastes all together prior to leading the storage drum. This process also called as an external mixing process of blending. From both option processes, there is no change in chemical structure and volume of spent resins since the operations conducted without artificial heating or cooling.

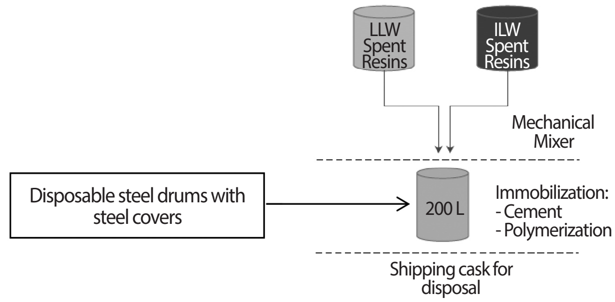

Fig. 6. In-drum mixing process of blending.

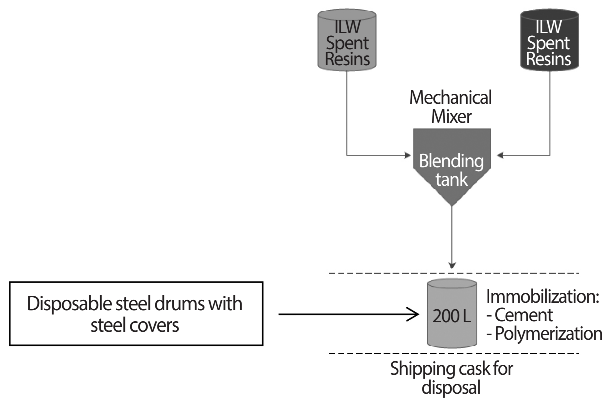

Fig. 7. External mixing process in blending tank.

3.5 Performance requirements

In order to satisfy the performance requirements of the blending process, two main parameters are measured: (i) radionuclide concentrations that meet WAC limits, and (ii) blending mixing ratio between high and low activity spent resins for homogeneity. Blending waste must meet the lim-

Table 7. Limits of radionuclide concentration for disposal [19]

Radionuclide	Concentration Limit for Disposal($Bq\cdot g^{-1}$)	Radionuclide	Concentration Limit for Disposal($Bq\cdot g^{-1}$)
^{3}H	1.11×10^{6}	^{94}Nb	1.11×10^{2}
^{14}C	2.22×10^{5}	^{99}Tc	1.11×10^{3}
^{60}Co	3.70×10^{7}	^{129}I	3.70×10^{1}
^{59}Ni	7.40×10^{4}	^{137}Cs	1.11×10^{6}
^{63}Ni	1.11×10^{7}	^{90}Sr	7.40×10^{4}
Gross-a	3.70×10^{3}		

Table 8. Final mixture concentration of each radionuclide after mixing

Radionuclides	High Activity SR Concentration ($Bq\cdot g^{-1}$)	Low Activity SR Concentration ($Bq\cdot g^{-1}$)	Final Mixture Concentration ($Bq\cdot g^{-1}$)	Concentration Limit for Disposal ($Bq\cdot g^{-1}$)
^{54}Mn	1.47×10^{6}	3.02×10^{1}	1.47×10^{6}	-
^{55}Fe	1.51×10^{6}	2.30×10^{1}	1.51×10^{6}	-
^{58}Co	5.95×10^{4}	8.49×10^{1}	5.96×10^{4}	-
^{60}Co	7.33×10^{5}	1.01×10^{2}	7.33×10^{5}	3.7×10^{7}
^{65}Zn	4.21×10^{5}	9.64×10^{0}	4.21×10^{5}	-
^{137}Cs	9.16×10^{6}	1.87×10^{2}	9.16×10^{6}	1.11×10^{7}
Total	1.34×10^{7}	4.26×10^{2}	1.34×10^{7}	-

its on radiation exposures at the disposal facility and limits on how much the radioactive concentration may vary [18]. The objective for the blending operation is to determine the optimal amount of spent resins required for adequate mixing to meet the WAC of the disposal facility. Table 7 shows the limits of radionuclides concentration for disposal as mentioned in NSCC Notice No. 2014-003.

According to [9], some cases of multiple blendable waste streams of the same waste type, for example, primary and secondary spent resins may be combined in the same container without blending. If the WAC limits in Table 7 are not exceeded, there is no need for the waste to be blended and the radionuclide concentration can be averaged over the volume of the waste or container. In this study, it is necessary to determine the radionuclide concentration based on volume in different waste streams. To blend the spent resins, mass balance approach is determined as the best approach to be used and the blending materials are described in Eq. (1) below.

$$\text{WAC of RN concentration limit} \geq \begin{pmatrix} \text{High activity SR concentration} \\ + \\ \text{Low Activity SR concentration} \end{pmatrix} \quad (1)$$

Where

WAC of RN concentration = Disposal Facility WAC for radionuclides limit ($Bq\cdot g^{-1}$)

Table 9. Optimal mixing ratio of blending process

	Before Blending		After Blending	
SR waste streams	High activity SR	Low activity SR	High activity SR	Low activity SR
Volume ($m^3 \cdot yr^{-1}$)	17.06	54.3	9.50	61.86
Mixing ratio	1	3.18	1	7.18

High activity SR concentration = Radionuclides concentration averaged over the volume in the waste stream ($Bq \cdot g^{-1}$)

Low activity SR concentration = Radionuclides concentration averaged over the volume in the waste stream ($Bq \cdot g^{-1}$)

From Table 8, the values of ^{60}Co and ^{137}Cs concentrations from FSAR were compared with the WAC concentration limits stipulated by NSSC Notice No. 2014-003. The calculation shows that only ^{137}Cs concentration is above the WAC limits. Therefore, the ^{137}Cs was used to calculate mixing ratios of ILW and LLW spent resins in order to meet the WAC limit for safe disposal of spent resins blendable waste.

Creating a homogeneous mixture is often the ideal situation when performing waste treatment or stabilization [5]. Regulatory guidance as provided by NRC stated that blended waste must ensure safe disposal which includes uniformity or how well-mixed the waste must be [18]. To achieve homogeneity of the mixture, the optimal mixing ratio should be determined and sufficient enough to satisfy the performance requirements of the disposal facility. The calculation of blending ratio is based on FSAR for Shin-Kori 3&4:

- 71.36 $m^3 \cdot yr^{-1}$ spent resin maximum generated for both units
- Dewatering for pre-treatment has been factored in
- Packing efficiency of 90% is considered
- Saturated spent resin density is 1.28 $g \cdot cm^{-3}$ [20]

From the concentration limits given in the NSSC Notice No. 2014-003, dominant radionuclides ^{137}Cs and ^{60}Co are used in this study and considered for the following calculation. The optimal mixing ratio between low and high activity spent resins concentration for can be calculated as shown in Eq. (2). Summary results of blending process are then tabulated in Table 9.

$$C_1 X_1 + C_2 X_2 = C_{LT} (X_1 + X_2) \quad (2)$$
$$X_1 + X_2 = 0.9$$

where,

C_1 = High activity SR concentration
C_2 = Low activity SR concentration
X_1 = Ratio of high activity SR
X_2 = Ratio of low activity SR
C_{LT} = Radionuclide concentration limit

4. Results and Discussion

The HIC is used to package dewatered and dried spent resin [17] and is currently being stored in HIC in the NPP sites for more than 20 years. Basically, spent resins are dewatered and stored in-drum with 10 cm concrete liner. The old practice done by KHNP used cementation for waste immobilization, but leakage problem raised due to internal corrosion caused by free-standing water at the bottom. Thus, repackaging of the wastes become necessary and will result in additional occupational exposure [21]. A drying process is also applied to treat spent resin, which complete-

Table 10. Summary results of blending method in terms of amount of spent resins stored and disposal class

	High activity SR		Low activity SR	
	Before blending	After blending	Before blending	After blending
Volume (m^3)	17.06	9.50	54.30	61.86
Percentage (%)	23.91	13.3	76.09	86.70
Note	44.3% disposal, 55.7% stored		100% disposal	

ly dried and filled in HIC container. Unfortunately, HIC is deemed not fit for acceptance at the Wolsong Disposal Site. HIC is expensive and stored spent resin requires constant monitoring of free-standing water. According to US NRC, the HIC is not acceptable for disposal unless special provisions have been arranged with disposal repository site [22]. The US NRC also not approved any HIC fabricated solely of HDPE, although the US NRC has approved HICs with major components fabricated from HDPE [21].

Currently, there is no WAC for ILW, so it must be kept in on-site interim storage. Even if the WAC for ILW is established, the disposal cost for ILW is expected to be higher than LLW. Therefore, blending contributes to solving the ILW disposal problems and it is suitable as a way to minimize ILW. On the other hand, the blending method can also be a waste management strategy in reducing interim storage of LLW, with optimization of life cycle cost. All blendable wastes produced from the blending process are intended for final disposal. There is no increase in disposal volume since blending is a mixing between different levels of contaminated materials in appropriate portion. As safety is always a priority, blending results in no decreasing in health and safety issues such as occupational safety and exposure.

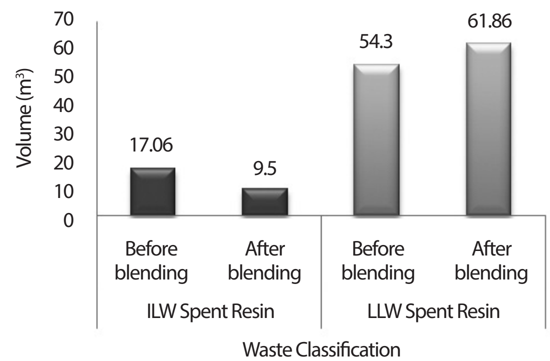

Fig. 8. Effects of blending method in terms of amount of spent resins stored and disposal class.

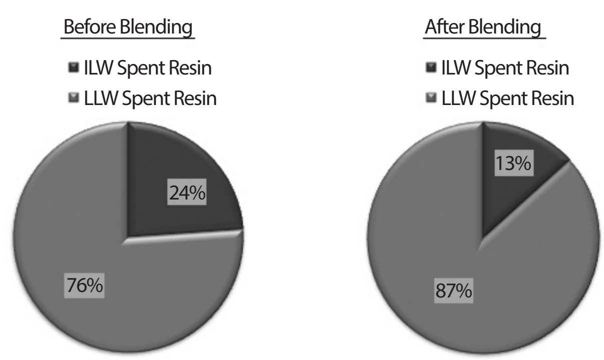

Fig. 9. Activity distributions by classification of spent resins before and after blending.

4.1 Effects of Blending Method

From blending method application, it is obvious that amount of spent resins stored is reduced and also give effects in lowering a disposal class. Table 10 and Fig. 8 summarized the findings from this study.

Fig. 9 focuses on activity distribution of spent resins before and after the blending process. It is shown that after the blending process, there is a significant reduction of high level SR. It is calculated that approximate 44.3% of ILW

Table 11. Estimated disposal cost per year for spent resins

Unit: $ 1,000

	Option 1		Option 2	
Spent resin waste streams	High activity spent resin	Low activity spent resin	High activity spent resin	Low activity spent resin
Mixing ratio	1	3.18	1	7.18
Volume ($L \cdot yr^{1}$) from FSAR	17,060	54,300	9,500	61,860
Projected volume per year ($L \cdot yr^{1}$)	2,075	6,600	1,022	6,600
No. of drums/container	2	33	1	33
Disposal cost ($)	155.77	364.05	77.88	364.05
Total Disposal cost ($)	519.82		441.93	

Table 12. Total waste management cost for spent resins in 40 years operation time

Unit: $ 1,000

Item		Option 1	Option 2
Blending cost ($)	Facility purchase cost	-	-
	Electric cost	-	4
	Manpower cost	-	88
	Material cost	-	-
Polymerization cost ($)		9,567	9,567
Disposal cost ($)		20,792.50	17,677.15
Total waste management cost ($)		30,359.50	27,336.15

spent resins blended together with LLW spent resins, which almost near to half of ILW can be disposed in LLW repository after applying the blending method.

4.2 Waste Management Cost

The optimal treatment and disposal option needs to be chosen wisely based on research and international experiences. To manage spent resins, there are two options considered:

a) Option 1: Polymerization of low activity spent resins and HIC for high activity spent resins storage
b) Option 2: Blending and polymerization process for mixing spent resins and HIC containers for unblended high activity spent resins storage

Efforts to minimize ILW by blending ILW high activity spent resin with LLW low activity spent resin will contribute to minimizing disposal costs [2]. In Korea, the LILW management cost is regulated by MOTIE Notice No. 2015-132 “Regulation on the estimation of management cost of radioactive waste and management share of spent fuel” [23]. The LILW disposal cost, which is required for store and disposal after waste acceptance from KHNP, is charged $11,031.67 per unit drum (200 L) by repository operator KORAD according to MOTIE Notice No. 2015-132. Meanwhile, HIC disposal cost is applied as $ 77,883.62 per unit HIC, which driven from disposal cost in MOTIE Notice. In this study, economic evaluation considering treatment cost and disposal cost is performed and projected from data in [4]. To find the final economic feasibility, both treatment and disposal cost were compared of each option. According to [4], the transportation cost to the low and medium radioactive waste disposal area is excluded because the selected spot for the waste drum storage is not yet decided. The assumptions for both options are listed as below:

- High activity spent resin (ILW) are packaged in the HIC
- Low activity spent resins (LLW) are packaged in 200 L steel drum
- Filling ratio of 0.90 to meet WAC at the disposal site.
- No new equipment/ facility purchase is required for blending process
- In-drum mixing for blending and polymerization
- Mixing ratio of spent resins (high activity: low activity):7.18 is applied
- Manpower used for blending is same for polymerization
- HIC remain at the plant for on-site interim storage
- Maximum exposure dose of 20 mSv per worker in a year is factored-in

According to [4], Shin-Kori 3&4 (APR1400) are operating units and the expected generation rate of spent resins is 33 drums per year, which is 6,600 L per year in volume. The estimation is made by considering the power output of the plant and application of Polymer Solidification System (PSS) to process low activity spent resins. By using the data above, the estimated disposal cost per year for each option was calculated and shown in Table 11.

The economic evaluation result for polymerization is done by [4]. In their research, it is assumed that the process time for spent resins is 580 hours, operation time per year is 176 hours, and 40 years of polymerization operation time. As a basic input data, inflation rate of 1.03% [4] and currency conversion of $1 equals to ₩1,105 were used. The other parameters such as facility cost, material cost, manpower, personnel expenses, and electricity are also factored in. Therefore, the total polymerization treatment cost for 40 years is estimated as $9,567,000. Since both options applied polymerization process, it can be assumed that cost of polymerization will be same to dispose 33 unit drums per year. In option 2, blending process is applied before polymerization. By considering the assumptions as listed above, the total waste management cost in 40 years operation time for both options is tabulated in Table 12.

It can be seen from the above Table 11 and 12, the estimated waste management cost for Option 2 with blending application is approximately 10% smaller than Option 1 with the current PSS in APR1400. This is caused by the reduction of disposal cost resulting from the blending of spent resins before the polymerization process. Other than that, blending approach also gives several advantages. These include a significant reduction of ILW spent resins by approximately 44.3% and it can be considered as an alternative treatment for high activity spent resin to be safely disposed in the LLW disposal facility if satisfied WAC requirement. Blending attends the issues such as the required continuous monitoring of free-standing water in HIC.

4.3 Considerations

To implement blending method, several considerations are needed to be taken into account and discussed as follows.

4.3.1 National policy

The proposed blending method is suitable for batch scale processing. Regarding the current national policy of radioactive waste management, dilution of radioactive waste is not allowed to be performed. According to [5], “Blending of radioactive wastes should not only be formally recognized as an acceptable practice, it should be encouraged as a legitimate and practical solution to promote efficient use of available disposal capacity and to reduce risks of handling the waste by workers.” Therefore, it is suggested that a national policy may need to be revised in order to allow the blending application in radioactive waste management in the future. Moreover, this approach must be supported by a rational discussion between related stakeholders, authorities and the public to gain acceptance. Public participation is vital because without it a sound policy development for blending would not be possible.

4.3.2 Waste package for final disposal

Wastes must be remains in a stable form and placed in the container as a final waste package. After blending process, the blendable spent resins are further treated by polymerization in the same 200 L disposable steel drum. The final mixture of blendable spent resins is classified as LLW, thus vault type of repository for LLW is recommended and the WAC requirement of repository site is fulfilled. This recommendation is supported by reference [24], which stated disposal of spent resins in a conditioned form may be possible for the low-level category in engineered structures. Other than that, a facility needs to consider and prepare a disposal of high-activity waste in terms of dose limits. In this case, it is important to do a performance measure by checking the dose rate of the waste package after applying blending method. Then, it is verified by measuring the external dose rate of the final waste form to be shipped if the waste package is compliance with the WAC requirement. However, implication of blended spent resin disposal in a LLW facility to the licensed total and nuclide specific inventory limits of the Wolsong disposal facility also needs to be considered.

4.3.3 Long-term stability prior to disposal

Long-term stability of the waste form is generally required for both storage and disposal. According to [25], with the evolution of performance-based disposal facility acceptance criteria, it is now required that spent ion exchange materials meet specific quality requirements prior to disposal. This is the reason why WAC is important in order to clarify the quality of waste forms for final disposal and appropriate treatment options. Therefore, the immobilization concept then being a general practice to stabilized spent resins only after a short period of interim storage. The conditioning technologies are essential for the immobilization of radioactive solid waste and forming the initial engineered barrier required for their transportation, storage, and disposal [26]. In this study, it is proposed to apply blending method then followed by polymerization as a waste stabilization. However, this approach of a conditioning process will depend on the requirements for the Wolsong disposal site and supported by the national policy. Obtaining a free-standing final product after waste conditioning is a basic criterion [24] and always considered. As reported in NRC Final Report on 2013 [2]:

"It is an NRC regulatory requirement in 10 CFR 61.56 (b) (2) that waste must be converted into a form that contains as little free standing and noncorrosive liquid as is reasonably achievable, but in no case shall the liquid exceed 1 percent of the volume of the waste when the waste is in a disposal container designed to ensure stability or 0.5 percent of the volume of the waste for waste processed to a stable form." [2:4-1]

In general, most of the disposal facilities define acceptable levels of free liquids and requirements for waste form stability as part of WAC requirement. These waste acceptance criteria will determine if spent ion exchange materials must be dewatered, stabilized or treated in some other manner prior to disposal [25]. The water content of the resins was calculated according to ASTM Standard Test Method D2187-77, "Physical and Chemical Properties of Ion Exchange Resins," [27]. According to this document, water content can be calculated as in Eq. (3):

$$\text{Weight water percentage (\%)} = [\,(A - B\,)\,/\,A\,] \times 100 \quad (3)$$

Where,
A: weight of wet spent resins before treatment
B: weight of dry spent resins after treatment

4.3.4 Performance assessment at disposal site

Protection to the public, intruder, and environment is a crucial part that needs more concern to dispose blendable waste in repository site. Generally, ILW requires packaging and shielding to protect workers handling the waste and must also meet physical stability requirements. In addition, disposal facilities must also meet special requirements to protect against an inadvertent human intruder after site closure and after institutional controls have lapsed [28]. Performance of the blended wastes in the disposal facility must be determined by performance assessment to meet the performance objectives of repository site. Moreover, methods used for demonstrating compliance with the homogenization requirements that are derived from the performance assessment for specific low level wastes can be documented in the generator's waste certification program [5].

The blending process is suggested by the US NRC to be risk-informed and performance-based. Referring to [29], a final blended waste form could be safely disposed by clarifying several considerations need regarding the blending method, such as:

i. Clarify that a site-specific intruder analysis must be performed to determine whether an intruder could be protected, or the conditions necessary for such protection
ii. Develop criteria defining acceptable homogeneity and sampling considerations
iii. Homogeneity of mixing waste for the relatively uniform concentration of final mixture will be in the context of a site-specific intruder scenario.

According to [6], protection of an inadvertent intruder is one of the four performance objectives for a LLW disposal facility as stated in 10 CFR Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste." This special requirement made to prevent an intruder from receiving an unsafe exposure to radioactivity. The Concentration Averaging-Branch Technical Position in their document also mentioned that site-specific concentration averaging approaches may be proposed by disposal facility licensee. Therefore, information provided to the regulatory authority should include [9]:

i. An overview of the proposed alternative approach and how it will protect an inadvertent intruder
ii. A details description of the waste forms covered by the alternative averaging approach
iii. An analysis of the effects of degradation on packaging and engineered barriers over the period that the waste remains hazardous to an intruder.
iv. Proposed inadvertent intruder exposure scenarios by following criteria;
   - The scenario should be reasonably foreseeable in that it is based on the intruder performing normal activities consistent with regional social customs; current well drilling, excavation and construction practices; and land uses similar to land uses in the region currently or reasonably foreseeable in the near future (i.e., approximately 100 years or during the operational lifetime of a facility).
   - The time period for intrusion should be appropriate for the class of the waste (e.g., 100, 300, or 500 years) as discussed in 10 CFR 61.7(b). In some cases, averaging approaches based on the depth of burial, or the use of intruder barriers or durable waste forms or containers, may be proposed.

4.3.5 Health and safety requirement

The operational safety and exposure is a part of health and safety requirement that need to be considered in applying blending method for spent resins management. It is more efficient to combine these wastes into one or several tanks in such a facility, rather than keep them separate after they are removed from service [29]. Since the doses from a mixture of waste streams with different radiation levels may result in lowering radiation levels of combined mixture, blending might be performed to keep radiation exposures to workers as low as reasonably achievable. A guiding principle that has been proposed is that waste management practices should always consider waste blending at all stages of waste management to reduce the hazards of handling the waste during treatment, storage, and characterization or preparation for final disposal. The objective of this principle is to promote blending as a cost-effective method for disposing higher activity wastes within available disposal facilities in a way that will reduce risks of handling the wastes [5]. In addition, combining high-activity wastes with a large volume low activity wastes prior to disposal as applied in blending method will reduce concentrations and result in a more uniform distribution within the disposal facility.

5. Conclusion

In many cases in the nuclear industry, spent ion-exchange resins are considered as a problematic solid waste and it requires a special treatment and precautions to meet the waste acceptance criteria for the disposal site. A new treatment method was proposed for the improvement of the solid radioactive waste management system which focused on spent resins in the APR1400 based on feasibility, performance, and economic studies. The proposed treatment method is a suitable method for ILW minimization and in-turn reduced disposal cost. The blending of ILW was selected as an option for the current system since it will enable the NPP operators to safely dispose ILW exceeding the Wolsong WAC.

In this paper, the management of spent resins was studied and proposed with respect to the blending treatment method, the feasibility of blending, and economic study for spent resins management cost. Application of the blending method has the potential to (i) reduce the amount of spent resins stored on-site, (ii) lower disposal class, and (iii) minimize workers exposure. These advantages of blending might result in cost saving for spent resins waste management, as it can give a reduction in disposal cost. The blending approach proved that there will be a reduction in the disposal cost in the Wolsong repository site. Thus, concentration averaging and blending may be highly beneficial from waste class and disposal cost reduction perspective. Through all the considerations as discussed in the previous chapter, the planning to manage the spent ion-exchange resins waste generated from the NPPs in Korea by blending method approach could be implemented in future.

Acknowledgment

The work is supported by the Research Fund of the KEPCO International Nuclear Graduate School (KINGS), Republic of Korea.

REFERENCES

[1] International Atomic Energy Agency (IAEA). Management of Spent Ion-Exchange Resins from Nuclear Power Plants, TECDOC-2380 (1981).

[2] United States National Reguratory Commission. Final Comparative Environment Evaluation of Alternatives for Handling Low Level Radioactive Waste Spent Ion-Exchange Resins from Commercial Power Plants (2013).

[3] International Atomic Energy Agency (IAEA). Application of Ion Exchange Processes for the Treament of Radioactive Waste and Management of Spent Ion Exchangers. Technical Report Series No. 408 (2002).

[4] K.J. Kim, Y.B. Kim, and M.G. Shin, Design and Economic Evaluation of Vitrification Method for a Solid Radioactive Waste System at APR+. KEPCO Engineering and Construction Company (2010).

[5] W.T. Goldston, "Public and Regulatory Acceptance of Blending of Radioactive Waste vs Dilution", Proc. of Waste Management Conference, Pheonix, Arizona (2011).

[6] United States National Reguratory Commission, "Analysis of Blending of Low Level Radioactive Waste", Accessed May 2017. Available from: https://www.nrc.gov/docs/ML0904/ML090410260.pdf.

[7] P. Tran. Final Report on an Evaluation of Alternative

Classification Methods for Routine Low Level Waste from the Nuclear Power Industry, EPRI, Palo Alto (2007).

[8] N.H. Min, L.D. Hee, A.O. Micheal, R.J. Nthato, T. Akhona, and K.J. Min, Subject Unit 3 Project Report on Improvement of Radioactive Waste Management System", KINGS (2016).

[9] United States National Reguratory Commission. Concentration Averaging and Encapsulation Branch Technical Position, Rev. 1, Vol. 1 (2015).

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

[11] V.M. Efremenkov, "Radioactive Waste Management at Nuclear Power Plants - An Overview of the Types of Low and Intermediate Level Wastes and How They are Handled", IAEA (1989).

[12] D.S. Kessel and C.L. Kim, "US Policy and Current Practices for Blending Low-Level Radioactive Waste for Disposal", J. Nucl. Fuel Cycle Waste Technol., 14(3), 235-243 (2016).

[13] K.I. Jung, J.H. Kim, M.J. Kwon, M.S. Jeong, S.W. Hong, and J.B. Park, "Comprehensive Development Plans for the Low- and Intermediate-Level Radioactive Waste Disposal Facility in Korea and Preliminary Safety Assessment", J. Nucl. Fuel Cycle Waste Technol., 14(4), 385-410 (2016).

[14] D.M. Buede, The Engineering Design of System - Model and Methods, 2nd Ed., John Wiley & Sons, New Jersey (2009).

[15] Electric Power Research Institute. Implementation Guidance for the NRC Branch Technical Position on Concentration Averaging and Encapsulation, Rev. 1 (2016).

[16] R. Mohanty, S. Mohanty, B.K. Mishra, and R. K. Soni, "Numerical Analysis of Mixing of Particles in Drum Mixers Using DEM", Advanced Powder Technol., 27(2), 531-540 (2016).

[17] Korea Hydro & Nuclear Power Co. APR 1400 Design Control Document Tier 2 Chapter 11 - Radioactive Management Waste Management, APR-k-F-FS-14002-NP, Rev. 0 (2014).

[18] R. Brenna, R. Yuen, C. Hoskins, and L. Ying, "Downblending Contaminated Radioactive Wastes", Environmental Monitoring and Analysis, 3(2-1), 11-14 (2015).

[19] Nuclear Safety and Security Commission (NSSC). Regulation on Classification and Self-Disposal of Radioactive Waste. NSSC Notice No. 2014-003 (2014).

[20] P. Colombo, R. Doty, E.M. Franz, M. Fuhrmann, P. Kalb, P. Kmeny, R.M. Neilson, and S.R. Arnold, Solidification of Ion-Exchange Resin Wastes, New York (1982).

[21] B. Siskind, February 03 1992, "Technical Considerations and Problems Associated with Long-Term Storage of Low Level Waste (BNL-NUREG-47066)", Accessed September 15 2017. Available from: http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/23/040/23040428.pdf.

[22] United States National Reguratory Commission. Limitation on the Use of Waste Forms and High Integrity Containers for the Disposal of Low Level Radioactive Waste, Information Notice No. 89-27 (1989).

[23] Nuclear Safety and Security Commission (NSSC), Regulation on Estimation of Management Cost of Radioactive Waste and Management Share of Spent Fuel, NSSC Notice No. 2015-132 (2015).

[24] International Atomic Energy Agency (IAEA). Treatment of Spent Ion-Exchange Resins for Storage and Disposal. Technical Series No. 254 (1985).

[25] D. Charpentier B. Certner, S. Vanderperre, and J. Braet, "Radioactive Spent Ion-Exchange Resins Conditioning by the Hot Supercomposition Process at Tihange NPP - Early Experience", Proc. of Waste Management Conference, Pheonix, Arizona (2012).

[26] M.I. Ojovan, Handbook of Advance Radioactive Waste Conditioning Technologies, Woodhead Publishing Ltd, Cambridge (2011).

[27] American National Standard. Standard Test Methods

for Physical and Chemical Properties of Particulate Ion-Exchange Resin (2002).

[28] International Atomic Energy Agency (IAEA). Disposal of Radioactive Waste. Specific Safety Requirements No. SSR-5 (2011).

[29] R.W. Borchardt, Blending of Low-Level Radioactive Waste, United States National Reguratory Commission Policy Issue SECY-10-0043 (2010).