Technical Paper

https://doi.org/10.7733/jnfcwt.2023.024

Proposal of Application Method for Concentration Averaging of Radioactive Waste in Korea by Using CA BTP of US NRC

Jiyoung Yi and Chang-Lak Kim*

KEPCO International Nuclear Graduate School, 658-91, Haemaji-ro, Seosaeng-myeon, Ulju-gun, Ulsan 45014, Republic of Korea

(Received January 18, 2023 / Revised March 9, 2023 / Approved May 26, 2023)

United States Nuclear Regulatory Commission (U.S. NRC) specifies regulations on obtaining licenses and describes the technical position on the average waste concentration, also known as Concentration Averaging and Encapsulation Branch Technical Position (CA BTP); CA BTP helps classify blendable waste and discrete items and address concentration averaging. The technical position details are reviewed and compared in a real environment in Korea. A few cases of concentration averaging based on the application of CA BTP to domestic radioactive waste are presented, and the feasibility of the application is assessed. The radioactive waste considered herein does not satisfy the Disposal Concentration Limit (DCL) of the second-phase disposal facility while applying the preliminary classification. However, if CA BTP is applied when the radioactive waste is mixed with other radioactive waste items in a large and heavy container, it can be disposed of at the second-phase disposal facility in Gyeongju Repository. To apply the CA BTP of the U.S. NRC, it is necessary to investigate the safety assessment conditions of the US and Korea.

Keywords: CA BTP, Blendable waste, Discrete item, Disposal Concentration Limit, 2nd phase disposal facility

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

ORCID

Jiyoung Yi http://orcid.org/0000-0001-7713-2712 Chang-Lak Kim http://orcid.org/0000-0002-6931-9541

1. Introduction

Radioactive waste is classified into intermediate level, low level and very low level. It is based on the potential amount of radioactivity per unit gram, that is, the concentration limit. This method of classifying radioactivity per unit weight is not a problem if all packaged wastes are homogeneous. However, the reality is that not all waste is homogeneous. Relative hotspots may exist.

Also, when several items are mixed, if one item has a relatively higher concentration than other items, it can become a relative hotspot.

If the waste generated is diversified and the container is large, the possibility of mixing different kinds of waste increases. Considering the mass generation of decommissioning waste and the enlargement of packaging containers, a technical position for mixed packaging of waste is also needed in Korea.

U.S. NRC has proposed the "Concentration Averaging and Encapsulation Branch Technical Position (hereafter CA BTP) [1]" and the EPRI Implementation Guidance can be benchmarked by International nuclear power plants, utilities, and regulatory bodies. By examining the contents of the CA BTP, some examples of concentration averaging applying CA BTP to radioactive waste in Korea will be presented, and the feasibility of application will be reviewed.

2. Background

2.1 Comparison of Classification for LILW

Class A, B, and C radioactive waste are classified as low-level radioactive waste (LLW) such as Class A LLW, Class B LLW, Class C LLW in US. It corresponds to the LLW and VLLW in Korea. Class A, B, and C are divided by ratio in US in accordance with 10 CFR 61.55 Fig. 1 [2]. For example, in the case of ^{63}Ni, if it is less than 70 Ci·m^{-3}, it is Class B, and if it is less than 700 Ci·m^{-3}, it is Class C.

US (Class A to C)					Korea (LLW)	
Radionuclide	Concentration [Ci·m^{-3}]			Half life	Nuclides	Concentration [Bq·g^{-1}]
^{3}H			40	Short	^{3}H	1.11×10^{6}
^{14}C			8	Long	^{14}C	2.22×10^{5}
^{14}C in activated metal			80	Long		
^{60}Co			700	Short	^{60}Co	3.70×10^{7}
^{59}Ni in activated metal			220	Long	^{59}Ni	7.40×10^{4}
^{63}Ni	3.5	70	700	Short	^{63}Ni	1.11×10^{7}
^{63}Ni in activated metal	35	700	7,000	Short		
^{90}Sr	0.04	150	7,000	Short	^{90}Sr	7.40×10^{4}
^{94}Nb in activated metal			0.2	Long	^{94}Nb	1.11×10^{2}
^{99}Tc			3	Long	^{99}Tc	1.11×10^{3}
^{129}I			0.08	Long	^{129}I	3.70×10^{1}
^{137}Cs	1	44	4,600	Short	^{137}Cs	1.11×10^{6}
α emitting TRU nuclides with half-life greater than 5 years			100 [nCi·g^{-1}]	Long	Gross α	3.70×10^{3}
^{241}Pu			3,500 [nCi·g^{-1}]	Long		
^{242}Cm			20,000 [nCi·g^{-1}]	Long		
Total of all nuclides with less than 5 years half-life [Class A]			700	Short		

Korea (VLLW)	
Nuclides	Concentration [Bq·q^{-1}]
257 ea	100 times the Clearance level

Fig. 1. Comparison of reference nuclides for LILW classification [2-5].

In Korea, the NSSC notices a limit on the concentration of LLW, and if it exceeds the Concentration Limit (hereafter CL) of LLW, it becomes Intermediate level waste (ILW) in accordance with NSSC Notice No. 2020-6 and Notice No. 2019-10 [3-4]. The nuclides used to classify LLW are similar in the United States and Korea. Within 100 times of concentration limit for clearance level, which suggested by IAEA (257 nuclides) [5] is the standard for the Very-Low level waste in Korea.

2.2 Comparison of Post Closure Management Period

Generally, regulatory bodies determine performance objectives for each post-closure management period for each waste classification. The disposal facility operator performs a safety assessment to prove whether the performance objectives are satisfied in the event of an inadvertent intruder after the post-closure management period. In the case of the US, Class A, B, and C have management periods after closure of 500, 300, and 100 years, respectively, and the performance objectives by inadvertent intruders is 5 mSv·year^{-1}.

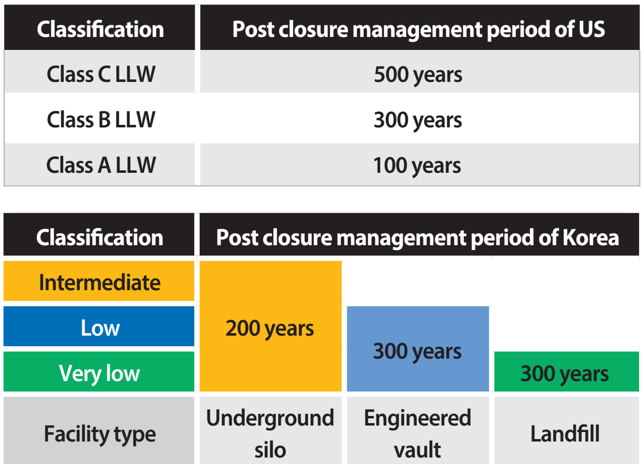

Fig. 2. Post closure management period [1, 6].

In the case of Korea, Intermediate, Low, and Very-Low levels radioactive waste have management periods after closure of 200 years, 300 years, and 300 years, respectively, and the performance objectives by inadvertent intruders is 1 mSv·year^{-1}. By comparison, Korea's performance objectives are about five times more conservative than those in the US.

3. Methodology

3.1 Purpose of Applying CA BTP

Radioactive waste packaged in a container is considered radiologically homogeneous under 10 CFR 61. However, in the case of actual waste, it is not easy to be ideally homogeneous, and especially discrete items, it is not physically and radiologically homogenous. To supplement this, the U.S. NRC developed CA BTP to create a guide for waste classification.

3.2 Blendable Waste of CA BTP

In U.S. NRC's BTP, Blending Wastes are not expected to contain significant radioactivity in durable items. Examples of blendable wastes include Ion-exchange resins, filter media, evaporator bottom concentrates, soil, and ash [1].

If the CA BTP thresholds are not exceeded, the waste does not need to be blended. In Table 1, SOF refers to the Sum of Fraction (hereafter SOF) Rule of 10 CFR 61.55.

Table 1. Thresholds for demonstrating adequate blending (CA BTP Table 1) [1]

Characteristics of most concentrated influent waste stream	Volume of mixture in m^3 (ft^3)		
	Class A mixture	Class B mixture	Class C mixture
SOF less than 10	No limit	No limit	No limit
SOF 10–20	No limit	No limit	50 (1,800)
SOF 20–30	60 (2,100)	No limit	20 (700)
SOF 30–50	20 (700)	No limit	6 (210)
SOF 50–100	6 (210)	40 (1,400)	2 (70)

3.3 Discrete Items of CA BTP

Discrete items contain belonging to one of the waste types such as sealed sources, activated metals, contaminated materials, cartridge filters, and components incorporating radioactivity. These waste types are expected to be durable and often have concentrations of radioactivity or relatively high amounts.

In case of the discrete item mixtures has same waste types, screening criteria can be used to simplify classification. This "screening criteria" is a conservative approach and also may give efficient operation to licensees. Also, for Discrete Items Mixtures, CA can be applied in the manner shown in Fig. 3.

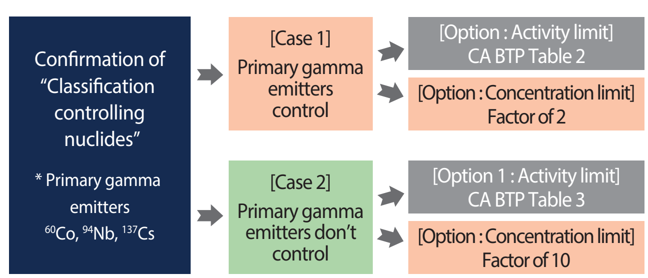

Fig. 3. Process of classification of discrete items mixtures.

Table 2. U.S. NRC CA BTP Table 2 [1]

Nuclide	Waste classified as		
	Class A	Class B	Class C
^{60}Co	5.2 TBq (140 Ci)	No limit	No limit
^{94}Nb	37 MBq (1 mCi)	37 MBq (1 mCi)	37 MBq (1 mCi)
^{137}Cs	266 MBq (7.2 mCi)	27 GBq (0.72 Ci)	4.8 TBq (130 Ci)

Table 3. U.S. NRC CA BTP Table 3 [1]

Nuclide	Waste classified as	
	Class A	Class B
^{3}H	0.3 TBq (8 Ci)	No limit
^{14}C	0.04 TBq (1 Ci)	0.4 TBq (10 Ci)
^{59}Ni	0.15 TBq (4 Ci)	1.5 TBq (40 Ci)
^{63}Ni	0.26 TBq (7 Ci)	55 TBq (1,500 Ci)
Alpha-emitting TRU waste with half-life greater than 5 years (excluding ^{241}Pu and ^{242}Cm)	111 MBq (3 mCi)	1.1 GBq (30 mCi)

Discrete items should be classified from SOF of 10 CFR 61.55 Tables 1 and 2 at first. And then, the primary gamma emitters should be checked whether it is controlling classification or not. The primary gamma emitters are ^{60}Co, ^{94}Nb, and ^{137}CS. Each classes activity limit of primary gamma emitter is given in Table 2 of CA BTP. A primary gamma emitter is considered a "classification-controlled nuclide" if it accounts for more than 50% of the SOF. If the primary gamma-emitting radionuclide is a classification control nuclide, there are two options. One is the active limit value according to "CA BTP Table 2". The other is the concentration limit value according to "Factor of 2".

Tables 2 and 3 of CA BTP for CA application of discrete items are as shown.

4. Application of CA BTP Based on Implementation Guidance of EPRI

In order to apply CA BTP to Korea, several cases of blendable waste and discrete items were applied in Sections 4.1 and 4.2 based on the Implementation Guide published by EPRI [7].

4.1 Blendable Waste

4.1.1 (EPRI Guide Example #1 [7]) Single Blendable Stream/Single Type

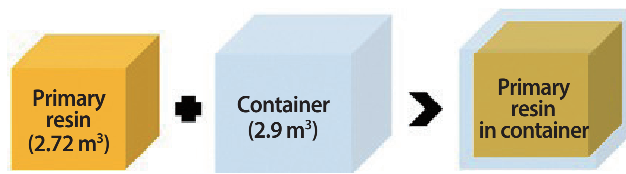

Fig. 4. Packaging plan.

When radioactive waste, which is a single waste type, single blendable waste stream, is disposed of in a container larger than the amount of waste, the waste class may be changed after CA. The waste volume of this primary resin is 2.72 m^3 (96 ft^3). This waste will be disposed of in an EL-142 container (2.9 m^3). As a result of the evaluation based on the amount of waste (2.72 m^3), the preliminary waste classification is Class B. When this waste is put in an EL-142 container with a size of 2.9 m^3, the total volume increases, so the final classification is Class A as shown in Fig. 4. In this case, the filling rate is more than 90% of the CA application standard.

Unlike the US case, the standard for concentration in Korea is Bq·g^{-1}, which is the radioactivity per weight. CA cannot be applied here because it is assumed that the volume increase, but the weight does not change.

For reference, the spent resin generated during operation at the nuclear power plant is currently solidified in a 200-liter drum or stored in a waste resin storage tank. In the future, the low-concentration spent resin will be disposed of in 860 L PC-HIC (0.86 m^3).

After applying CA, the waste classification changed in the US, but the waste classification did not change in Korea.

4.1.2 (EPRI Guide Example #3 [7]) Multiple Blendable Waste Stream/Single Waste Type With Volumes and/or Concentrations That Exceed Table 1 Conditions

The two ion exchange resins, which have same waste type and different waste streams, has different radiological characteristics. It will be mixed to make radioactive waste of a Class A.

In US case, the preliminary waste classification of secondary resin is Class A and primary resin is Class C. As a result of blending two radioactive waste, if this waste is determined as Class A, the final waste volume (1,015 ft^3) exceeds the threshold (210 ft^3) of CA BTP Table 1. So, adequate blending should be demonstrated. But if it is classified as Class B, the final waste volume (1,015 ft^3) does not exceed the Threshold (1,400 ft^3) of CA BTP Table 1 as shown in Fig. 5. For classification as Class B, no need to prove adequate blending.

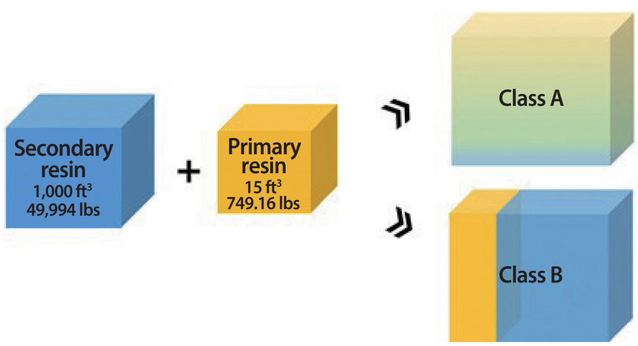

Fig. 5. Packaging plan (US) for resin.

In Korea case, SOFs of secondary resin are 11.65 based on VLLW Limit and 0 based on LLW. It means that the classification of secondary resin is LLW. And SOF of primary resin is 3.20 based on the LLW Limit. So, primary resin is ILW. When two types of resins are mixed, SOF is 17,426 based on VLLW and 0.06 based on LLW, respectively, so it is LLW. Since LLW corresponds to Class C in the US and SOF is less than 10 in accordance with Table 1 (CA BTP Table 1), so there is no volume limitation. For classification as LLW, no need to prove adequate blending as shown in Fig. 6. So, the final classification after CA is LLW without the need to prove well-mixed.

Based on US standards, the secondary resin was Class A and the primary resin was Class C, but it can be classified as Class B or Class A after CA. Based on Korea standards, secondary resin is LLW, primary resin is ILW, and final LLW after CA. In both Korea and the US, the waste class has changed after CA as shown in Table 4.

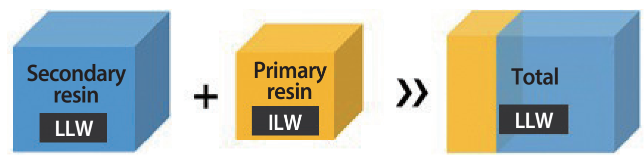

Fig. 6. Packaging plan (Korea) for resin.

Table 4. Result of waste classification

Nation	Waste classification		
	Sec. resin	Pri. resin	After CA
US	Class A	Class C	Class B*
Korea	LLW	ILW	LLW

*It is optional: Class A or Class B

4.2 Discrete Items

4.2.1 (EPRI Guide Example #9 [7]) Collection of Multiple Discrete Items

If the total activity is less than 1 mCi (37 MBq), it can use simplified screening criteria. It is derived from total activity divided by the total volume or weight of the mixture. Fig. 7 shows that one activated bolt with the highest activity is mixed with 99 activated bolts of relatively low level.

In US case, the preliminary classification of the highest activity bolt is greater than Class C. Each total activities of two items are less than 1 mCi. So, it can use simplified screening criteria. The final classification is Class A.

In Korea case, the preliminary waste classification and after applying CA is ILW. LLW concentration limit of ^{94}Nb is very low compared to US Limit. As a result of applying

CA, the waste classification was lowered in both Korea and US as shown in Table 5.

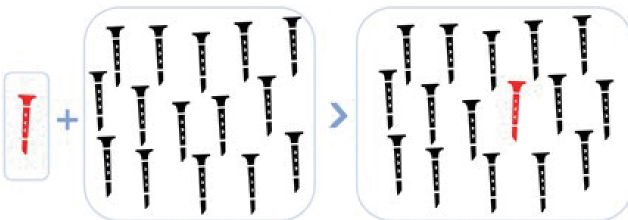

Fig. 7. Packaging plan for activated bolts.

Table 5. Result of waste classification

Nation	Waste classification	
	Highest activity bolt	After CA
US	GTCC	Class A
Korea	ILW	ILW

4.2.2 (EPRI Guide Example #10 [7]) Collection of Multiple Discrete Items Meeting Tables 2 and 3 Criteria

This example is related to Collection of Multiple Discrete Items Meeting CA BTP Tables 2 and 3 Criteria.

In US case, the CRB#1 is GTCC. The fraction of ^{137}Cs is less than 50%, So primary gammas do not control classification of it. CRB#2 is Class C. ^{94}Nb controls classification. However, all nuclides are less than CA BTP Table 2 or 3 values. So, the classification can be based on the total volume and weight. The final classification is Class C.

In Korea case, the preliminary and final Waste Classification are all ILW. As a result of applying CA, the waste classification was changed in US. But the classification was not changed in Korea as shown in Table 6.

Table 6. Result of classification using CA

Nation	Waste classification		
	CRB #1	CRB#2	After CA
US	GTCC	Class C	Class C
Korea	ILW	ILW	ILW

5. Application of CA BTP Based on Actual Radwaste and Disposal Concentration Limit in Korea

CA application is suggested suitably for Korea's current situation. Section 5.1, the current situation in Korea will be reviewed, and in Section 5.2, the CA method is used.

5.1 Status of Disposal Environment in Korea

5.1.1 LILW Disposal Concentration Limit

The type of the 2nd phase disposal facility is near surface facility, which can dispose of LLW, VLLW in accordance with NSSC Notice Regulations on the Radioactive Waste Classification and Clearance of Radioactive Waste (No. 2020-6) Article 4 (Disposal method of radioactive waste) and Article 5 (Restrictions on Disposal of Radioactive Waste).

However, not all waste below the LLW Concentration Limit (hereafter CL) can be disposed of in the 2nd phase disposal facility. Only LLW below the disposal concentration limit (hereafter DCL) derived after the safety assessment reflecting the site characteristics of the 2nd stage facility can be disposed of.

CL is in the notification of the NSSC, but DCL is in the safety analysis report of the second stage disposal facility. Fig. 8 summarizes the LLW CL and the DCL of the 2nd phase disposal facility.

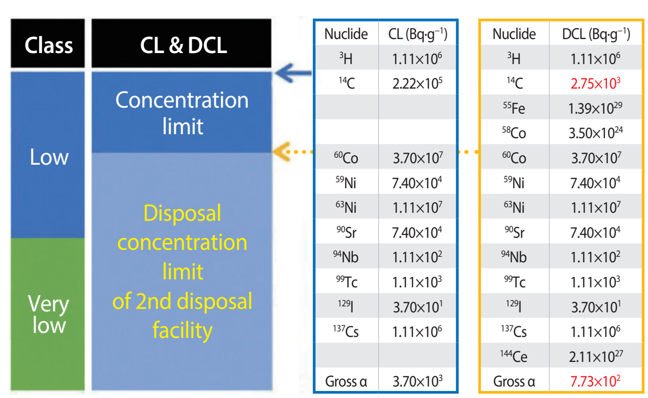

Fig. 8. LLW CL and DCL of 2nd disposal facility.

5.1.2 Decommissioning Waste Containers (Plan)

The decommissioning waste generates a large amount of various waste types within a short period of time. Therefore, several large-capacity radioactive waste containers are being developed.

5.2 Application CA for Korea

5.2.1 [Case 1] Blendable Waste of Kori 2 NPP Into 860 L PC-HIC Container

Among the waste generated from the Kori 2 NPP, the waste classification is LLW, but one of them exceeds the DCL of the 2nd stage disposal facility. The waste cannot be disposed of the facility. However, after CA with other waste, the waste can be disposed in 2nd phase disposal facility.

Furthermore, 860 PC-HIC containers do not exceed the criteria of CA BTP Table 1, so there is no need to prove adequate blending.

Fig. 9 is an example of selecting two wastes among dried spent resins actually generated at the Kori 2 NPP and mixing them in an 860 L PC-HIC container to make them below the DCL of the 2nd phase disposal facility.

In this figure, Kori #1 is below the DCL of 2nd phase disposal facility. However, Kori #2 is below the LLW CL, but below the DCL, so it is a waste that cannot be disposed of in the 2nd stage disposal facility as it is.

Table 7 shows the specific activity of the dried spent resin actually generated at the Kori 2 NPP. As shown in Table 8, the SOF of Kori #1 does not exceed 1. This means

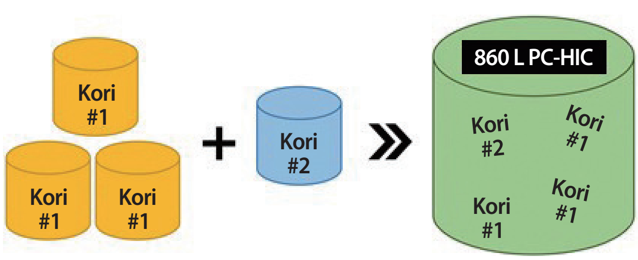

Fig. 9. Application proposed 860 PC-HIC disposal of blendable wastes.

Table 7. Specific activities of dried spent resin of Kori #1 & #2 generated from Kori 2 NPP [8]

Item	KORI #1 (3 ea)	KORI #2 (1 ea)	Total (4 ea)
Waste type	Dried spent resin		
Waste volume (m^3)	0.2	0.2	0.8
Nuclide	$Bq·g^{-1}$	$Bq·g^{-1}$	$Bq·g^{-1}$
^{3}H	$1.09×10^{2}$	$9.97×10^{2}$	$3.31×10^{2}$
^{14}C	$5.04×10^{2}$	$7.71×10^{3}$	$2.30×10^{3}$
^{55}Fe	$3.26×10^{4}$	$2.99×10^{5}$	$9.93×10^{4}$
^{58}Co	$1.16×10^{4}$	$1.06×10^{5}$	$3.53×10^{4}$
^{60}Co	$3.26×10^{4}$	$2.99×10^{5}$	$9.93×10^{4}$
^{59}Ni	$9.32×10^{2}$	$8.56×10^{3}$	$2.84×10^{3}$
^{63}Ni	$1.72×10^{4}$	$2.11×10^{5}$	$6.56×10^{4}$
^{90}Sr	$1.28×10^{0}$	$1.68×10^{1}$	$5.17×10^{0}$
^{94}Nb	$3.78×10^{-2}$	$7.39×10^{-1}$	$2.13×10^{-1}$
^{99}Tc	$3.27×10^{-1}$	$3.01×10^{0}$	$9.98×10^{-1}$
^{129}I	$3.09×10^{-4}$	$2.84×10^{-3}$	$9.43×10^{-4}$
^{137}Cs	$2.24×10^{3}$	$2.06×10^{4}$	$6.83×10^{3}$
^{144}Ce	$1.14×10^{1}$	$1.05×10^{2}$	$3.49×10^{1}$
Gross a	$7.43×10^{-1}$	$6.83×10^{0}$	$2.26×10^{0}$
Total	$9.78×10^{4}$	$9.54×10^{5}$	$3.12×10^{5}$

Table 8. Possibility of disposing of 2nd disposal facility of Kori #1: allowed

Nuclide	Con. ($Bq·g^{-1}$)	DCL	Fraction	LLW CL	Fraction
^{14}C	$5.04×10^{2}$	$2.75×10^{3}$	0.1831	$2.22×10^{5}$	0.0023
^{59}Ni	$9.32×10^{2}$	$7.40×10^{4}$	0.0126	$7.40×10^{4}$	0.0126
^{94}Nb	$3.78×10^{-2}$	$1.11×10^{2}$	0.0003	$1.11×10^{2}$	0.0003
^{99}Tc	$3.27×10^{-1}$	$1.11×10^{3}$	0.0003	$1.11×10^{3}$	0.0003
^{129}I	$3.09×10^{-4}$	$3.70×10^{1}$	0.0000	$3.70×10^{1}$	0.0000
^{3}H	$1.09×10^{2}$	$1.11×10^{6}$	0.0001	$1.11×10^{6}$	0.0001
^{60}Co	$3.26×10^{4}$	$3.70×10^{7}$	0.0009	$3.70×10^{7}$	0.0009
^{63}Ni	$1.72×10^{4}$	$1.11×10^{7}$	0.0015	$1.11×10^{7}$	0.0015
^{90}Sr	$1.28×10^{0}$	$7.40×10^{4}$	0.0000	$7.40×10^{4}$	0.0000
^{137}Cs	$2.24×10^{3}$	$1.11×10^{6}$	0.0020	$1.11×10^{6}$	0.0020
^{55}Fe	$3.26×10^{4}$	$1.39×10^{29}$			
^{58}Co	$1.16×10^{4}$	$3.50×10^{24}$			
^{144}Ce	$1.14×10^{1}$	$2.11×10^{27}$			
Gross-a	$7.43×10^{-1}$	$7.73×10^{2}$		$3.70×10^{3}$	0.0002
SOF			0.2009		0.0203

Table 9. Possibility of disposing of 2nd disposal facility of Kori #2: not allowed

Nuclide	Con. (Bq·g^{-1})	DCL	Fraction	LLW CL	Fraction
^{14}C	7.71×10^{3}	2.75×10^{3}	2.8030	2.22×10^{5}	0.0347
^{59}Ni	8.56×10^{3}	7.40×10^{4}	0.1157	7.40×10^{4}	0.1157
^{94}Nb	7.39×10^{-1}	1.11×10^{2}	0.0067	1.11×10^{2}	0.0067
^{99}Tc	3.01×10^{0}	1.11×10^{3}	0.0027	1.11×10^{3}	0.0027
^{129}I	2.84×10^{-3}	3.70×10^{1}	0.0001	3.70×10^{1}	0.0001
^{3}H	9.97×10^{2}	1.11×10^{6}	0.0009	1.11×10^{6}	0.0009
^{60}Co	2.99×10^{5}	3.70×10^{7}	0.0081	3.70×10^{7}	0.0081
^{63}Ni	2.11×10^{5}	1.11×10^{7}	0.0190	1.11×10^{7}	0.0190
^{90}Sr	1.68×10^{1}	7.40×10^{4}	0.0002	7.40×10^{4}	0.0002
^{137}Cs	2.06×10^{4}	1.11×10^{6}	0.0186	1.11×10^{6}	0.0186
^{55}Fe	2.99×10^{5}	1.39×10^{29}	0.0000		
^{58}Co	1.06×10^{5}	3.50×10^{24}	0.0000		
^{144}Ce	1.05×10^{2}	2.11×10^{27}	0.0000		
Gross-a	6.83×10^{0}	7.73×10^{2}	0.0088	3.70×10^{3}	0.0018
SOF			2.9838		0.2085

Table 10. Possibility of disposing of 2nd disposal facility after CA: allowed

Nuclide	Con. (Bq·g^{-1})	DCL	Fraction	LLW CL	Fraction
^{14}C	2.30×10^{3}	2.75×10^{3}	0.8381	2.22×10^{5}	0.0104
^{59}Ni	2.84×10^{3}	7.40×10^{4}	0.0384	7.40×10^{4}	0.0384
^{94}Nb	2.13×10^{-1}	1.11×10^{2}	0.0019	1.11×10^{2}	0.0019
^{99}Tc	9.98×10^{-1}	1.11×10^{3}	0.0009	1.11×10^{3}	0.0009
^{129}I	9.43×10^{-4}	3.70×10^{1}	0.0000	3.70×10^{1}	0.0000
^{3}H	3.31×10^{2}	1.11×10^{6}	0.0003	1.11×10^{6}	0.0003
^{60}Co	9.93×10^{4}	3.70×10^{7}	0.0027	3.70×10^{7}	0.0027
^{63}Ni	6.56×10^{4}	1.11×10^{7}	0.0059	1.11×10^{7}	0.0059
^{90}Sr	5.17×10^{0}	7.40×10^{4}	0.0001	7.40×10^{4}	0.0001
^{137}Cs	6.83×10^{3}	1.11×10^{6}	0.0062	1.11×10^{6}	0.0062
^{55}Fe	9.93×10^{4}	1.39×10^{29}	0.0000		
^{58}Co	3.53×10^{4}	3.50×10^{24}	0.0000		
^{144}Ce	3.49×10^{1}	2.11×10^{27}	0.0000		
Gross-a	2.26×10^{0}	7.73×10^{2}	0.0029	3.70×10^{3}	0.0006
SOF			0.8974		0.0673

that it does not exceed the DCL of the 2nd disposal facility and therefore can be disposed of in the 2nd disposal facility. As shown in Table 9, Kori #2 is LLW because the LLW CL does not exceed 1. However, since the SOF of DCL exceeds 1, it is impossible to dispose of it in the 2nd disposal facility. As shown in Table 10, after CA, total SOF does not exceed 1 of DCL. So, it is possible to dispose of them in the 2nd phase disposal facility.

5.2.2 [Case 2] Discrete Item in Hanul 1 NPP Into P3 Container

CA BTP is basically evaluated based on the amount of radioactivity per volume or per weight. The volume of 12 solid waste drums are 2.4 m (0.2×12), which is 96% of a P3 container (2.497 m^{3}) as shown in Fig. 10.

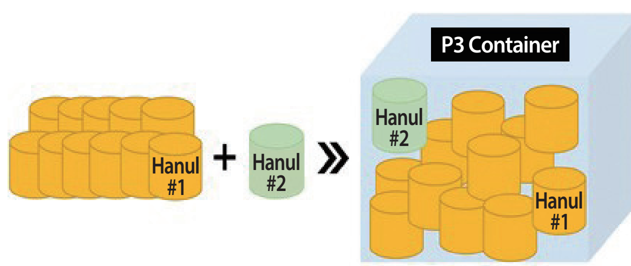

Fig. 10. P3 container plan for discrete items.

There are two types of radioactive waste actually generated at the Hanul 1 NPP. Their specific activities are shown in Table 11.

In the case of Hanul #1 radioactive waste, total SOF is 1 or less, satisfying the 2nd stage DCL as shown in Table 12. If so, it can be disposed of in a second-stage disposal facility.

However, in Table 13, in the case of Hanul #2 radioactive waste, the total SOF of LLW CL is 3.7, so this radioactive waste is ILW.

It can be seen in Table 14 that the total SOF of LLW CL after CA is 0.8484. As a result, in the case of mixing and disposing of wastes, it was possible to dispose of them in the 2nd phase disposal facility.

As a result, in the case of mixing and disposing of

Table 11. Specific activity of solid waste in Hanul 1 NPP [8]

Item	Hanul #1 (11 ea)	Hanul #2 (1 ea)	Total
Waste type	Solid waste		
Volume (m^{3})	0.2	0.2	2.497
Nuclide	Bq·g^{-1}	Bq·g^{-1}	Bq·g^{-1}
^{3}H	5.17×10^{4}	1.03×10^{6}	1.33×10^{5}
^{14}C	2.73×10^{2}	5.45×10^{3}	7.04×10^{2}
^{55}Fe	1.13×10^{5}	2.26×10^{6}	2.91×10^{5}
^{58}Co	4.40×10^{4}	8.78×10^{5}	1.14×10^{5}
^{60}Co	2.57×10^{4}	5.14×10^{5}	6.64×10^{4}
^{59}Ni	6.40×10^{2}	1.28×10^{4}	1.65×10^{3}
^{63}Ni	2.33×10^{4}	4.65×10^{5}	6.01×10^{4}
^{90}Sr	1.02×10^{1}	2.05×10^{2}	2.64×10^{1}
^{94}Nb	4.09×10^{1}	1.11×10^{2}	4.67×10^{1}
^{99}Tc	2.19×10^{1}	4.38×10^{2}	5.66×10^{1}
^{129}I	2.48×10^{-1}	4.96×10^{0}	6.40×10^{-1}
^{137}Cs	6.36×10^{2}	1.27×10^{4}	1.64×10^{3}
^{144}Ce	0.00×10^{0}	0.00×10^{0}	0.00×10^{0}
Gross a	4.89×10^{2}	3.70×10^{3}	7.56×10^{2}
Total	2.60×10^{5}	5.18×10^{6}	6.70×10^{5}

Table 12. Possibility of disposing of 2nd disposal facility of Hanul #1: allowed

Nuclide	Con. (Bq·g^{-1})	DCL	Fraction	LLW CL	Fraction
^{14}C	2.73×10^{2}	2.75×10^{3}	0.0991	2.22×10^{5}	0.0012
^{59}Ni	6.40×10^{2}	7.40×10^{4}	0.0087	7.40×10^{4}	0.0087
^{94}Nb	4.09×10^{1}	1.11×10^{2}	0.3683	1.11×10^{2}	0.3683
^{99}Tc	2.19×10^{1}	1.11×10^{3}	0.0198	1.11×10^{3}	0.0198
^{129}I	2.48×10^{-1}	3.70×10^{1}	0.0067	3.70×10^{1}	0.0067
^{3}H	5.17×10^{4}	1.11×10^{6}	0.0466	1.11×10^{6}	0.0466
^{60}Co	2.57×10^{4}	3.70×10^{7}	0.0007	3.70×10^{7}	0.0007
^{63}Ni	2.33×10^{4}	1.11×10^{7}	0.0021	1.11×10^{7}	0.0021
^{90}Sr	1.02×10^{1}	7.40×10^{4}	0.0001	7.40×10^{4}	0.0001
^{137}Cs	6.36×10^{2}	1.11×10^{6}	0.0006	1.11×10^{6}	0.0006
^{55}Fe	1.13×10^{5}	1.39×10^{29}	0.0000		
^{58}Co	4.40×10^{4}	3.50×10^{24}	0.0000		
^{144}Ce	0.00×10^{0}	2.11×10^{27}	0.0000		
Gross-a	4.89×10^{2}	7.73×10^{2}		3.70×10^{3}	0.1320
SOF			0.5526		0.5867

Table 13. Possibility of disposing of 2nd disposal facility of Hanul #2: not allowed

Nuclide	Con. (Bq·g^{-1})	DCL	Fraction	LLW CL	Fraction
^{14}C	5.45×10^{3}	2.75×10^{3}	1.9802	2.22×10^{5}	0.0245
^{59}Ni	1.28×10^{4}	7.40×10^{4}	0.1729	7.40×10^{4}	0.1729
^{94}Nb	1.11×10^{2}	1.11×10^{2}	1.0000	1.11×10^{2}	1.0000
^{99}Tc	4.38×10^{2}	1.11×10^{3}	0.3949	1.11×10^{3}	0.3949
^{129}I	4.96×10^{0}	3.70×10^{1}	0.1339	3.70×10^{1}	0.1339
^{3}H	1.03×10^{6}	1.11×10^{6}	0.9303	1.11×10^{6}	0.9303
^{60}Co	5.14×10^{5}	3.70×10^{7}	0.0139	3.70×10^{7}	0.0139
^{63}Ni	4.65×10^{5}	1.11×10^{7}	0.0419	1.11×10^{7}	0.0419
^{90}Sr	2.05×10^{2}	7.40×10^{4}	0.0028	7.40×10^{4}	0.0028
^{137}Cs	1.27×10^{4}	1.11×10^{6}	0.0114	1.11×10^{6}	0.0114
^{55}Fe	2.26×10^{6}	1.39×10^{29}	0.0000		
^{58}Co	8.78×10^{5}	3.50×10^{24}	0.0000		
^{144}Ce	0.00×10^{0}	2.11×10^{27}	0.0000		
Gross-a	3.70×10^{3}	7.73×10^{2}		3.70×10^{3}	1.0000
SOF			4.6822		3.7265

Table 14. Possibility of disposing 2nd disposal facility after CA: allowed

Nuclide	Con. (Bq·g^{-1})	DCL	Fraction	LLW CL	Fraction
^{14}C	7.04×10^{2}	2.75×10^{3}	0.2559	2.22×10^{5}	0.0032
^{59}Ni	1.65×10^{3}	7.40×10^{4}	0.0223	7.40×10^{4}	0.0223
^{94}Nb	4.67×10^{1}	1.11×10^{2}	0.4209	1.11×10^{2}	0.4209
^{99}Tc	5.66×10^{1}	1.11×10^{3}	0.0510	1.11×10^{3}	0.0510
^{129}I	6.40×10^{-1}	3.70×10^{1}	0.0173	3.70×10^{1}	0.0173
^{3}H	1.33×10^{5}	1.11×10^{6}	0.1202	1.11×10^{6}	0.1202
^{60}Co	6.64×10^{4}	3.70×10^{7}	0.0018	3.70×10^{7}	0.0018
^{63}Ni	6.01×10^{4}	1.11×10^{7}	0.0054	1.11×10^{7}	0.0054
^{90}Sr	2.64×10^{1}	7.40×10^{4}	0.0004	7.40×10^{4}	0.0004
^{137}Cs	1.64×10^{3}	1.11×10^{6}	0.0015	1.11×10^{6}	0.0015
^{55}Fe	2.91×10^{5}	1.39×10^{29}	0.0000		
^{58}Co	1.14×10^{5}	3.50×10^{24}	0.0000		
^{144}Ce	0.00×10^{0}	2.11×10^{27}	0.0000		
Gross-a	7.56×10^{2}	7.73×10^{2}		3.70×10^{3}	0.2044
SOF			0.8967		0.8484

wastes, it was possible to dispose of them in the 2nd phase disposal facility.

6. Conclusion

Using the example of CA BTP, concentration averaging was applied to radioactive waste in Korea. In general, concentration averaging requirements are specified by selecting acceptance criteria for activity in volume or weight. However, the container size is presented based on the SOF not to allow unconditional blending. For mixing between Discrete Items, suggest Activity Limit or Concentration Limit.

The nuclides used to classify LLW are similar in US and Korea. However, Class A, B, and C grades in the United States are divided by ratio, but in Korea, VLLW was determined as 100 times of 257 exempt nuclides suggested by the IAEA. For this reason, changes in radioactive waste classification after CA are less in Korea than in US.

The radioactive waste selected as examples in Sections 5.2.1 and 5.2.2 do not satisfy the DCL of the 2nd phase disposal facility when applying the preliminary classification. However, if it is mixed with other radioactive wastes in a container with a large volume and weight, it can be disposed of in the 2nd phase disposal facility.

7. Further Review

To apply CA BTP of U.S. NRC, it may be necessary to analyze and compare the safety assessment of two countries. Since the safety assessment is evaluated based on scenarios, the scenarios of the two countries were compared and similarities and differences were reviewed. The VLLW CL has also been selected based on 100 times the IAEA regulatory exemption criteria.

As an alternative, this report compared the scenario for setting the DCL of KORAD, which is the only radioactive waste management organization in Korea that has

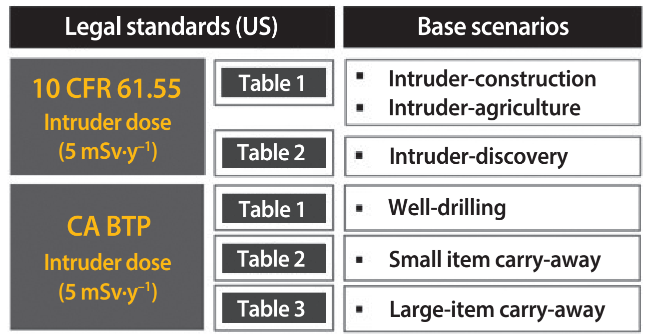

Fig. 11. Legal standard of U.S. NRC.

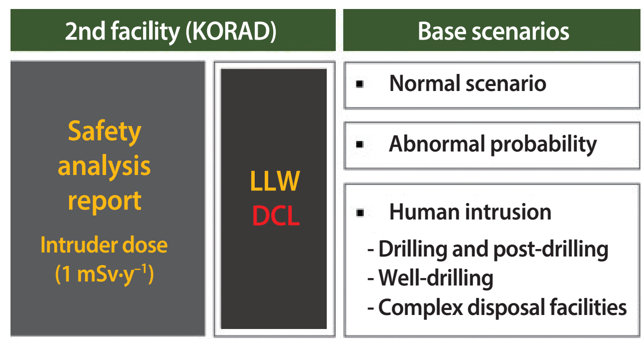

Fig. 12. Safety assessment scenarios of KORAD.

constructed and operated a waste disposal facility. The LLW DCL and scenario can be found in the SAR (Safety Analysis Report), which is the license document for construction and operation of 2nd phase disposal facility. The license for second-stage disposal facility was approved in July 2022, and the SAR is not the final version and may be revised. Figs. 11 and 12 show difference in the safety assessment scenarios of U.S. NRC and KORAD.

The scenarios in the "Human Intrusion" field of the US and KORAD are generally similar. "Intruder-Construction", "Intruder-Agriculture" and "Intruder-Discovery" of 10 CFR 61.55 Tables 1 and 2 are similar to "Drilling" and "Post-drilling" scenarios of KORAD. The base scenario of CA BTP Table 1 of U.S. NRC is a well-drilling scenario, which consists of Mud Rotary Drilling Scenario and Exposed Cuttings Scenario. A similar well-drilling scenario was used in KORAD.

Carry-away scenarios, the standard scenario of CA BTP Tables 2 and 3, was not used in Korea, and the performance objective of an inadvertent intruder is more conservative in Korea.

Therefore, rather than applying CA BTP Table 2 and Table 3 of the U.S. NRC used for CA of discrete items, it is necessary to apply a carry-away scenarios to make domestic criteria. These domestic criteria can also be used in the case of CA for ILW and LLW and the disposal of sealed sources and encapsulated sealed sources.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Acknowledgements

This study was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP No. 20204010600130) and the Ministry of Trade, Industry & Energy (MOTIE) of the Republic of Korea.

REFERENCES

[1] U.S. Nuclear Regulatory Commission, Concentration Averaging and Encapsulation Branch Technical Position, Revision 1, Volume 1, US NRC Office of Nuclear Material Safety and Safeguards (2015).

[2] U.S. Nuclear Regulatory Commission. March 24 2021. "Waste Classification, 10 CFR 61.55." U.S. NRC homepage. Accessed Jan. 16 2023. Available from: https://www.nrc.gov/reading-rm/doc-collections/cfr/part061/part061-0055.html.

[3] Nuclear Safety and Security Commission, Regulations on the Radioactive Waste Classification and Clearance of Radioactive Waste, Notice No. 2023-7 (2023).

[4] Nuclear Safety and Security Commission, Regulation on Radiation Protection, etc., Notice No. 2019-10 (2019).

[5] International Atomic Energy Agency, Application of the Concepts of Exclusion, Exemption and Clearance, IAEA Safety Standards Series, General Safety Guides, No. RS-G-1.7 (2004).

[6] Nuclear Safety and Security Commission, Radiological Protection Criteria for the Long-term Safety on Low and Intermediate-Level Radioactive Waste Disposal, Notice No. 2017-62 (2017).

[7] K. Kim. Implementation Guidance for the Nuclear Regulatory Commission Branch Technical Position on "Concentration Averaging and Encapsulation, Revision 1", Electric Power Research Institute Technical Report, 3002008189 (2016).

[8] Korea Radioactive Waste Agency. Nuclide Inventories Assessment Report of 2nd Phase Disposal Facility, KORAD Report (2020).