EPRI Project Update on International Nuclear Power Plant Waste Classification – 16224

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ABSTRACT

Countries around the globe use varying schemes for the characterization of radioactive waste. Many countries use adaptations of the International Atomic Energy Agency (IAEA) waste classification scheme. Other countries use the Class A, B, and C waste classification scheme that was developed in the United States. General comparisons have been made between the IAEA and the United States (U.S.) classification schemes, but a clear and well researched comparison of the two schemes was not evident in the available research data sets. The Electric Power Research Institute (EPRI) Radiation Safety (RS) Program has conducted a technical evaluation that compares these two waste characterization schemes. EPRI developed a set of reference wastes that are representative of nuclear power plant low-level radioactive waste in form and radioactivity concentrations (e.g. dry active waste, high activity resin, low activity resin, high activity filters and low activity filters). These reference wastes were then classified using the waste classification systems in place in several countries around the world. This paper and presentation will provide a summary of that research, show where strong comparisons and correlations can be made, and provide a discussion on how this information might inform the harmonization of global waste classification standards.

INTRODUCTION

In 2013 EPRI initiated the *Comparison of Global Low and Intermediate Level Waste Management Methods* project. The objective of the project was to understand how six countries managed their low and intermediate level wastes from generation to disposal. The six countries selected were Canada, France, Republic of Korea, Spain, Sweden and the U.S. Each of these countries either has a mature disposal methodology in place or well along in its development. This aspect of a participating country's disposal program is key because it reflects the stage of development of the country's disposal facility's waste acceptance criteria (WAC).

The WACs are developed when the disposal facility's Safety Case (also referred to in the literature as Performance Assessment or Safety Assessment) is completed and the disposal facility meets the regulatory dose-to-the-public limits or is well below those limits. The Safety Case relies on one or some combination of following elements: the disposal facility barrier system, the natural barriers of the surrounding site geology, the waste immobilization method [waste stabilization or use of a High Integrity Container (HIC)], and the use of an overpack to hold a group of waste packages. It is usually up to the site developer to decide which elements will be used in the initial Safety Case analysis. Upon review the regulator may require additional barriers or scenarios to be included in the analysis.

It is the WAC that determines the degree to which the waste will be characterized in order to be accepted for disposal at the disposal facility and in which trench, cell, cavern or vault the waste will be placed due to its radiological makeup/classification.

How waste classification is defined varies from country to country. Some countries use surface or near surface dose rates (Canada, Sweden), other countries rely on activity limits for individual waste packages (U.S., Republic of Korea), while other countries use a combination of both approaches (France), or rely solely on the concentration of a few easy-to-measure nuclides (such as ^{60}Co and ^{137}Cs) in the waste (Spain).

In general terms, TABLE I identifies the waste classification system used for low and intermediate level waste in the six countries studied. TABLES II and III identify the process used by each country to classify their waste. TABLE III identifies those countries that use a surface or near surface dose limit.

TABLE I. Waste Classification by Country

Waste Class	**Canada[1]**	**France[2]**	**Republic of Korea[3]**	**Spain[1,2]**	**Sweden[1,2]**	**U.S.**
Low Level Waste (LLW)	LLW	LLW	LLW[4]	Level 1	BLA[5]	*Class A* *Class B* *Class C*
Intermediate Level Waste (ILW)	ILW	ILW	ILW	Level 2	BTF[6] BMA[6] Silo[6]	-

[1] Has clearance.

[2] Has Very Low Level Waste (VLLW) disposal facility(ies).

[3] VLLW classification implemented 2014, disposal facility planning and development will be initiated when LLW disposal facility is available.

[4] Disposal facility planning for construction is underway.

[5] BLA is the low level waste caverns in the SFR disposal facility. (See Table III)

[6] BTF, BMA (two BTF caverns and one BMA cavern) and Silo intermediate level waste packages with lower to higher surface dose rates (10, 100 and 500 mSv/h) respectively. (See Table III)

TABLE II. Waste Classification Using of Activity Limits

Waste Class	France	Korea	Spain	U.S.
LLW	100 – 20,000 Becquerel/gram (Bq/g)	Activity concentration > than 100 times the IAEA clearance levels but < Low Level Waste activity levels (10 radionuclides including) < 3.70E+3 Bq/g total alpha <1.11E+6 Bq/g tritium	Maximum activity /unit mass < 1.85E+02 Bq/g per total alpha at 300 years < 7.40E+03 Bq/g tritium < 3.70E+04 Bq/g total beta/gamma activity; nuclides with half-life > 5 years	*Class A* 10 CFR Part 61 Class A Concentration limits *Class B* 10 CFR Part 61 Class B Concentration limits *Class C* 10 CFR Part 61 Class B Concentration limits
ILW	20,000 – 1,000,000 Bq/g	Greater than LLW but less than High Level Waste: 4,000 Bq/g of alpha emitting nuclides with half-lives longer than 20 years, with a heat generation rate of less than 2 kW/m^3.	More detailed limits and limits per package for those nuclides in the Reference Inventory ^{60}Co activity below 3.70E+05Bq/g ^{90}Sr activity below 3.70E+05Bq/g ^{137}Cs activity below 3.70E+05Bq/g	Not a U.S. classification Note - Class C (even though defined as LLW by U.S. regulations)[1] and Greater than Class C (GTCC) more closely approximate ILW in the IAEA scheme

[1]10 Code of Federal Regulations (CFR) Part 61 Class C Concentration Limits

TABLE III. Waste Classification Method – Dose

Waste Class	Canada	France	Sweden
LLW	Type 1 < 2 millisievert/hour (mSv/h)	< 2 mSv/h	BLA – 2 mSv/h
ILW	Type 2 2 to 150 mSv/h Type 3 > 150 mSv/h	$\geq$ 2 mSv/h	BTF[1]– 10 mSv/h BMA – 100 mSv/h Silo - 500 mSv/h

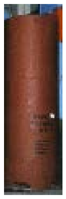
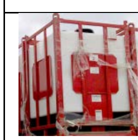
[1] By classification (i.e. 10mSv/h) the BTF is an intermediate level waste cavern. However, much of the waste disposed is dewatered low level resins.

WASTE CONTAINER AND WASTE CONDITIONING

Every country has its own set of containers. Because this study was performed for the nuclear power industry only containers used by nuclear power plants (NPP) or companies that process NPP waste for disposal in a Low and Intermediate Level Waste (LILW) disposal facility are presented. The only containers consistently used by all countries (but not necessarily for the same wastes) are 200 or 220 liter (L) drums.

TABLE IV presents a representative sample of the containers used by each of the countries included in this study. TABLE V includes the solidification and stabilization, i.e., cement material poured around the waste to fill voids in heterogeneous waste packages.

TABLE IV. Containers used by NPP industry in the management of LILW

Waste Type	Canada	France	Korea[1]	Spain	Sweden	U.S.
Wet Waste						
Wet Waste -Resins -Filters -Evaporator Concentrates	 Encapsulat-ed tile hole	 C1 Concrete hull (2 m^3)	 High Integrity Container	 220 L drums	 200 L drum	 Polyethyl-ene liner
	 Resin liner	 C4 Concrete hull (1.2 m^3)	 200 L drum		 Steel mould	 Resin liner
	 LL Resin liner tank				 Concrete mould	
Dry Solid Waste						
Dry Solid Waste - Combustible - Compactible - Contaminated Non-combustible - Non-processible[2] waste	 Compactor box	 Metallic Box	 200 L drum	 220 L drum	 200 L drum	 Steel box in ISO container
	 47" Blue container	 200 L Drums		 CMT Metal box	Steel box 	 ISO container
	 Red drum					

	bin  Non Pro Container					

[1] Korea currently stores its wet waste filters un-conditioned and un-packaged in a sump with a drain.
[2] Canada is the only country to specifically identify non-processible wastes as a waste type.

In addition, each of these countries uses some combination of the following waste solidification, stabilization and overpack systems to ensure the stability of the waste in the entire disposal complex. Note Canada has a specific waste type called “non-processible” which is not amenable to any of the available processing technologies and is therefore not listed as a waste type in TABLE V.

TABLE V. Waste Conditioning

Waste Type	Canada	France	Korea	Spain	Sweden	U.S.
Homogeneous: Resins Filters Sludge Concentrates	Dewater[1] or Cement solidification[2]	Polymer solidification or Cement solidification	Resin Drying or Dewatering and Concrete Overpack[3] Concentrate waste Drying and Polymer solidification	Cement Solidification	Cement solidification or Bituminzation or Dewater[5] Filter Encapsu-lation[6]	Pyrolysis or Dewater or Drying and Concrete Overpack
Heterogeneous: Dry Solid Waste Combustible Compactable Non-combustible	Compaction and/or Incineration or Metal melt	Compaction or Incineration or Metal melt	Compaction or Vitrification	Compaction plus Cement encapsulation or Cement stabilization	Compaction plus Cement Encapsulation or Incineration or Metal melt	Compaction (rare) or Incineration (rare) or Metal melt
Final Disposal			Overpack[3]	Overpack[4]		

[1] In Canada intermediate level wastes are not conditioned, except for dewatering resins at the NPP site.

[2] Used on Active Liquid Waste Treatment System sludge – relatively small (pail size) quantities generated.

[3] Final disposal container – all wastes

[4] Final disposal container – most wastes

[5] Low activity resins – are dewatered and placed in concrete tanks for disposal in the ILW BTF cavern.

[6] Containers holding a combination of filters and other wastes are backfilled with cement (encapsulation.)

These differences are identified because they show the complexity of the comparison of the individual waste types depicted in TABLE V for the six countries studied. In addition, the fact that countries such as Canada, Sweden, Spain and France are primarily concerned with the inventory in the individual disposal vault and/or the total inventory of the disposal facility – not necessarily the exact inventory of any individual waste package where concentrations of individual nuclides may vary considerably, adds to the complexity of the comparison.

This emphasis on the disposal facility inventory is based on the inventory developed from the Safety Case (sometimes referred to in the literature as Safety Assessment or Performance Assessment) of the disposal facility. The Safety Case is used to derive total activity for individual radionuclides that would ensure the dose to the public from the disposal facility would not exceed the regulatory limit.

WASTE PACKAGE INFORMATION EVALUATED

In order to conduct a comparison, specific kinds of information were required for each classification, waste type, container and conditioning used in the countries studied. Wastes, containers and waste forms requested were based on the information presented in the previous tables. High and low activity resins and filters, evaporator concentrates and sludges were requested along with Dry Active Waste packages. The following list identifies the kinds of information requested from each country participating in this study.

- Waste Type
- Waste Container
    - Length
    - Width
    - Height
    - Diameter if a cylinder
    - Thickness of walls, top and bottom
- Disposed Volume of Waste Package (m^3)
- Quantity of Waste (kg)
- Waste to conditioning agent ratio
- Weight of Package (kg)
- Activity of all nuclides after scaling factors have been applied
- Activity in Bq when package is received by the disposal facility
    - Nuclides provided depend on country

Each participant was asked to provide data on packages they would consider typical waste for the particular category (i.e., LLW or ILW).

DEVELOPING REFERENCE WASTE STREAMS

The 2007 EPRI Report 1016120, *An Evaluation of Alternative Classification Methods for Routine Low Level Waste from the Nuclear Power Industry* analyzed over 8,500 waste package records from 41 pressurized water reactors (PWR) and 24 boiling water reactors (BWR) over a four-year time period. The data from this 2007 EPRI report was sorted and used to develop reference waste streams that could be applied uniformly among the various global waste classification systems within this study. Reference waste streams were developed for the following waste types:

A. PWR High Activity Ion Exchange Resin (typifies reactor coolant and spent fuel pool purification resins),
B. PWR Low Activity Ion Exchange Resin (typifies waste liquid processing media, deborating and delithiating resins),
C. PWR Cartridge Filters,
D. BWR High Activity Resin and Filter Media (typifies reactor water clean-up media),
E. BWR Low Activity Resin and Filter Media (typifies condensate and radwaste media),
F. BWR Cartridge Filters (typifies filters from submersible clean-up systems and primary process filters),
G. Dry Active Waste-Low Level (e.g. Class A) (compactable, non-compactable [metal] sometimes referred to as combustible and non-combustible except that compactable wastes containing chlorides such as PVC are also not combustible),
H. Dry Active Waste - High Level (e.g. Classes B and C), and
I. PWR Evaporator Concentrates

A summary of the total concentration in each reference waste stream is shown in Fig. 1, with the range from a low of 1.6E+04 Bq/g (PWR Evaporator Bottoms) to a high of 3.4E+06 Bq/g for BWR High Level Resin.

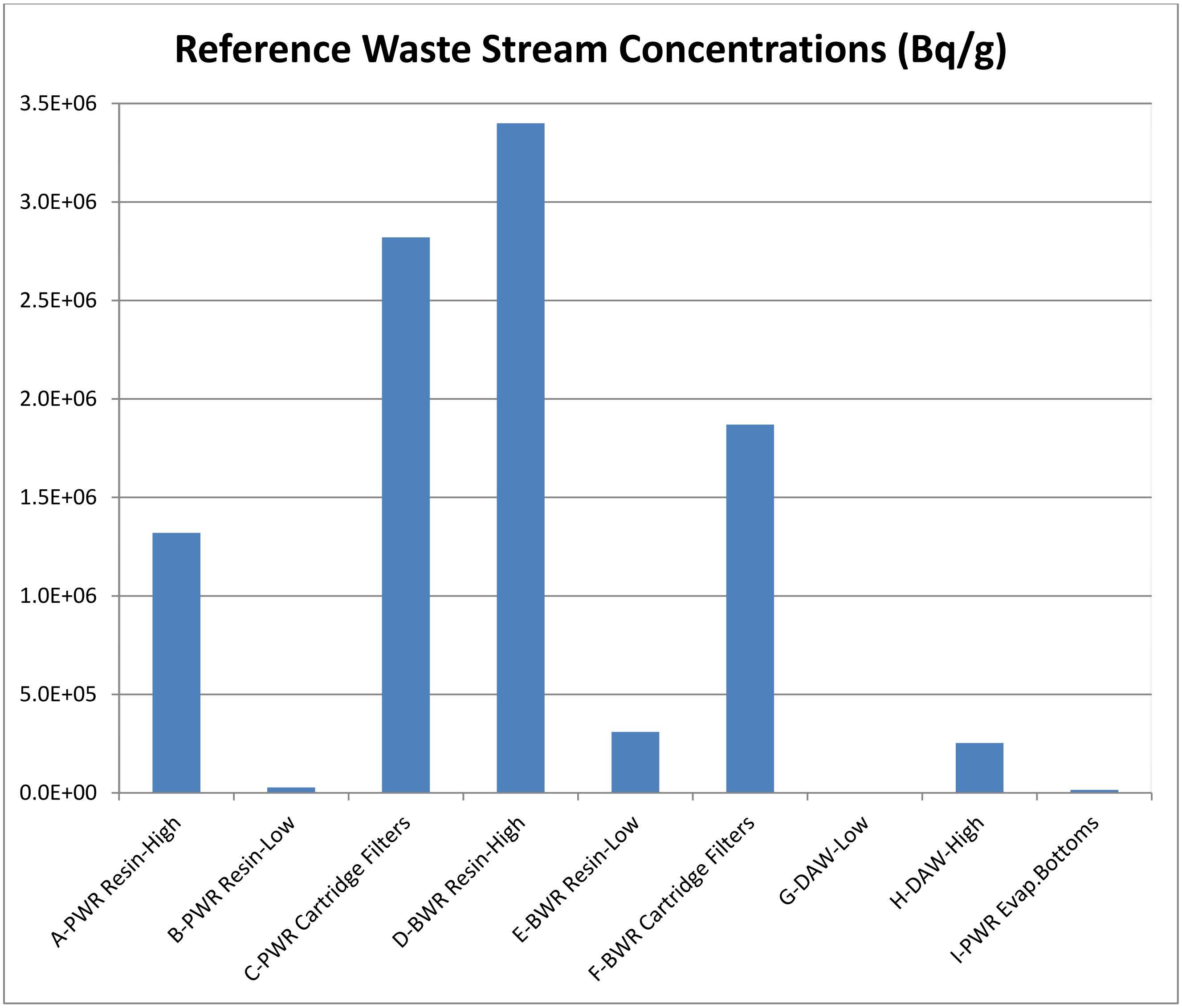


Fig. 1. Comparison of Reference Waste Stream Concentrations.

While this data is U.S. based, it is applicable to PWRs and BWRs in other countries. The reference waste stream for PWR High Activity Resins is shown in TABLE VI as an example. TABLE VII depicts the radionuclide constituents of raw waste prior to conditioning for PWR high activity ion exchange resins in one country as compared to the EPRI reference waste stream.

TABLE VI. PWR High Activity Ion Exchange Resin

Nuclide	Activity (Bq/g)	Fractional Abundance
^{3}H	4.89E+03	3.69E-03
^{14}C	3.72E+03	2.81E-03
^{51}Cr	3.81E+02	2.88E-04
^{54}Mn	3.61E+04	2.73E-02
^{55}Fe	2.34E+05	1.77E-01
^{59}Fe	1.27E+02	9.61E-05
^{57}Co	4.00E+03	3.03E-03
^{58}Co	1.62E+05	1.22E-01
^{60}Co	1.46E+05	1.10E-01
^{59}Ni	2.30E+03	1.74E-03
^{63}Ni	5.05E+05	3.82E-01
^{65}Zn	1.61E+02	1.22E-04
^{90}Sr	7.27E+02	5.50E-04
^{95}Zr	5.17E+02	3.91E-04
^{94}Nb	2.47E+00	1.87E-06
^{99}Tc	2.69E+02	2.03E-04
^{110m}Ag	3.62E+02	2.74E-04
^{125}Sb	9.83E+03	7.43E-03
^{134}Cs	7.50E+04	5.67E-02
^{137}Cs	1.35E+05	1.02E-01
^{144}Ce	2.21E+03	1.67E-03
^{238}Pu	4.70E+00	3.55E-06
$^{239/240}$Pu	1.57E+00	1.19E-06
^{241}Pu	2.86E+02	2.16E-04
^{241}Am	3.47E+00	2.62E-06
^{242}Cm	1.11E+00	8.40E-07
^{243}Cm	4.80E+00	3.63E-06
^{244}Cm	7.08E-01	5.35E-07
Sum	**1.32E+06**	**1.00E+00**

TABLE VII. Radionuclides Constituents of Raw Waste for PWR High Activity Ion Exchange Resin

Nuclide	Concentration (Bq/g)		Fractional Abundance	
	Country Waste	EPRI Reference Waste	County Waste	EPRI Reference Waste
^{3}H	2.22E+03	4.89E+03	9.75E-03	3.69E-03
^{10}Be	1.18E-02	NR	5.16E-08	
^{14}C	1.06E+03	3.72E+03	4.64E-03	2.81E-03
^{36}Cl	5.89E-01	NR	2.58E-06	
^{41}Ca	2.94E-01	NR	1.29E-06	
^{51}Cr	NR	3.81E+02		2.88E-04
^{54}Mn	6.33E+03	3.61E+04	2.77E-02	2.73E-02
^{55}Fe	7.63E+03	2.34E+05	3.34E-02	1.77E-01
^{57}Co	NR*	4.00E+03		3.03E-03
^{58}Co	NR	1.62E+05		1.22E-01
^{59}Ni	6.48E+01	2.30E+03	2.84E-04	1.74E-03
^{60}Co	5.65E+04	1.46E+05	2.48E-01	1.10E-01
^{63}Ni	8.22E+04	5.05E+05	3.60E-01	3.82E-01
^{65}Zn	2.34E+00	1.61E+02	1.03E-05	1.22E-04
^{79}Se	1.90E-01	NR	8.33E-07	
^{90}Sr	6.63E+03	7.27E+02	2.90E-02	5.50E-04
^{93}Mo	5.89E-02	NR	2.58E-07	
^{93}Zr	2.94E-02	NR	1.29E-07	
^{95}Zr	NR	5.17E+02		3.91E-04
^{94}Nb	7.06E+00	2.47E+00	3.10E-05	1.87E-06
^{99}Tc	4.75E-01	2.69E+02	2.08E-06	2.03E-04
^{107}Pd	4.75E-03	NR	2.08E-08	
^{108m}Ag	5.88E+01	NR	2.58E-04	
^{110m}Ag	1.04E+04	3.62E+02	4.56E-02	2.74E-04
^{121m}Sn	1.17E+00	NR	5.14E-06	
^{125}Sb	3.32E+01	9.83E+03	1.45E-04	7.43E-03
^{126}Sn	4.28E-01	NR	1.87E-06	
^{129}I	4.75E-02	NR	2.08E-07	
^{134}Cs	7.77E+03	7.50E+04	3.40E-02	5.67E-02
^{135}Cs	2.38E-01	NR	1.04E-06	
^{137}Cs	4.72E+04	1.35E+05	2.07E-01	1.02E-01
^{144}Ce	NR	2.21E+03		1.67E-03
^{151}Sm	3.32E+01	NR	1.45E-04	
^{238}Pu	NR	4.70E+00		3.55E-06
$^{239/240}Pu$	NR	1.57E+00		1.19E-06

*NR Denotes Not Reported

TABLE VII. Radionuclides Constituents of Raw Waste for PWR High Activity Ion Exchange Resin (continued)

Nuclide	Concentration (Bq/g)		Fractional Abundance	
	Country Waste	EPRI Reference Waste	Country Waste	EPRI Reference Waste
^{241}Pu	NR	2.86E+02		2.16E-04
^{241}Am	NR	3.47E+00		2.62E-06
^{242}Cm	NR	1.11E+00		8.40E-07
^{243}Cm	NR	4.80E+00		3.63E-06
^{244}Cm	NR	7.08E-01		5.35E-07
Sum	2.28E+05	1.32E+06	1.00E+00	1.00E+00

*NR Denotes Not Reported

Reviewing the data in TABLE VII it can be seen that both the country's and the reference waste contain reasonably comparable total activities (approximately a factor of 6). However, the country's waste contains approximately ten hard-to-measure radionuclides determined to be of importance to the host country that are not contained in the EPRI reference waste. The EPRI reference waste radionuclides include a number of alpha emitters that are not specifically called out for measurement in the other country's mix. While the EPRI reference waste is based on a substantial number of PWR waste samples over four years it is also from U.S. reactors where analysis for these hard-to-measure radionuclides has not been a regulatory requirement and as such there is no comparable data. The country waste in TABLE VII was classified as ILW whereas the EPRI reference waste was LLW Class B.

ASPECTS OF CLASSIFICATION DATA DEVELOPED

The reference waste streams do not necessarily reflect every possible radionuclide but they do represent a large fraction of the most common radionuclides typically found in nuclear power plant waste. Similarly, the reference waste streams developed do not necessarily represent every radionuclide of import to various disposal entities.

Most of the countries studied primarily depend upon direct gamma spectroscopy of the conditioned waste or ^{60}Co and ^{137}Cs dose rate to activity models of the conditioned waste, to determine the concentration of key radionuclides. With few exceptions, once the key radionuclide concentrations are identified, scaling factors are used to formulate the final radionuclide mix in the waste stream. In a few instances slightly differing regimes are used for determining certain radionuclides. Sweden in particular uses the following approaches:

- For ^{14}C, the amount activity entering the disposal site is based on calculations of total ^{14}C produced per power plant. A portion of that calculated total is assumed to be present in the various waste streams.For transuranics, the annual concentration of $^{239/240}Pu$ in reactor coolant is used to scale the remaining transuranics to $^{239/240}Pu$.

This approach to the waste characterization data will allow the same waste to be modeled into each country's waste conditioning and packaging regime. These details will be identified and addressed as appropriate for each of the remaining countries in the EPRI final report.

HOW CLASSIFICATION DATA WERE COMPARED

It was important to begin with the radionuclides concentrations of raw waste streams as generated. These raw waste streams are common to all power plants. The different waste conditioning and packaging schemes used in the countries studied result in changes to the initial volumes and densities. The comparisons were made on the unconditioned waste, and it is recognized that the final form could affect the classification due to changes in volume, density, and shielding effectiveness of the conditioned waste.

For three countries, the United States, South Korea, and Spain, the classifications can be made based on radionuclide concentrations alone, with very few additional assumptions. For Sweden, France, and Canada, there are additional criteria based on dose rates on the packages (see Table III). For this initial review, the classification comparisons were conducted for those countries that use only concentration criteria.

For the US, the criteria are based on activity concentration in terms of microcuries per cubic centimeter (uCi/cc), and for South Korea and Spain, the criteria are based on concentration in Bq/g. A numerical comparison of the limits shows that there are many differences, but in general, the US and South Korea have similar limits, while Spain's LLW limits (Level 1) are much lower. For example, the tritium limits for the US Class A LLW is 1.5 E+06 Bq/g, and South Korea has a value of 1.1 E+06 Bq/g. Spain's tritium limit for LLW (Level 1) is 7.4 E+03 Bq/g, about a factor of 100 lower.

The basic method of comparison of classification criteria is as follows:

1. Obtain the reference waste stream nuclide mix (e.g., as in Table VI).
2. For the US, convert concentrations to uCi/cc for comparison to the US criteria. A density of 0.8 grams per cubic centimeter (g/cc) was assumed for resin waste streams, and a density of 1.0 was assumed for all other waste streams.

3. For South Korea and Spain, use the same radionuclide mix in units of Bq/g.
4. For each classification, compare the concentration to the countries limits (Class A, B, C for US, LLW and ILW for South Korea, and LLW and ILW for Spain).
5. This was performed for each of the nine reference waste streams.

RESULTS OF COMPARISON

It is evident that all of the countries in this study have differing classification schemes with most using the IAEA classification system. However, within the IAEA model there are varied interpretations of how the class breaks are determined. In the U.S. the waste classification is strictly based on the concentration of specific radionuclides provided in regulations and disposal site licenses. Whereas, in some of the IAEA models in this study, the distinction between LLW and ILW could be based on the surface dose rate of the conditioned package. This presentation will address those countries that use concentration as the primary criterion for classification (United States, South Korea, and Spain).

The results of the comparison are shown in Table VIII. South Korea's classification scheme results in most of the reference waste streams as LLW, the US has roughly an equal number designated Class A and Class B, and Spain has most of the reference waste streams designated as ILW.

Table VIII. Comparison of US, Korea, and Spain Classification of Reference Waste Streams

	Reference Waste Type	US Classification	S. Korea - Classification	Spain - Classification
A	PWR High Activity IX Resin	Class B	LLW	ILW (level 2).
B	PWR Low Activity IX Resin	Class A	LLW	LLW (Level 1).
C	PWR Cartridge Filters	Class B	ILW	ILW (level 2).
D	BWR High Activity Resin/filter media	Class B	LLW	Exceeds ILW (Level 2)
E	BWR Low Activity Resin/filter media	Class A	LLW	ILW (level 2).
F	BWR Cartridge Filters	Class A	LLW	ILW (level 2).
G	DAW-low level (Class A)	Class A	LLW	LLW (Level 1).
H	DAW-higher level (Class B and C)	Class B	LLW	ILW (level 2).
I	PWR Evaporator Concentrates	Class A	LLW	ILW (level 2).

Note: Color coding is as follows: green = Class A or LLW; orange = Class B or ILW, and red = HLW or greater than ILW.

SUMMARY AND CONCLUSION

EPRI is conducting a study of international classification of LILW waste classification and management practices, from generation through disposal. This research attempts to reconcile the differences between the waste classification systems in several countries and depicts how the same waste is conditioned, packaged and classified in these countries. Additionally, it brings forth other possible radionuclides that are of import to the host country and that may be of interest to others.

The LILW of six countries were evaluated and compared against each other to provide a better understanding of how the various classification schemes align with each other. This was accomplished using LILW classification data from the participating countries along with an EPRI developed set of reference wastes. EPRI then showed how the reference waste is classified in the various different classification schemes.

The ultimate purpose of this research is to provide a common understanding of how LILW is managed and classified internationally to facilitate the development and application of universally relevant LILW management technologies and methodologies. The complete results of this study will be published in a 2016 EPRI technical report.

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