

## **Not All Greater-Than-Class C (GTCC) Waste Streams are Created Equal-15373**

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### **ABSTRACT**

Greater-Than-Class C (GTCC) waste is a low level radioactive waste (LLRW) that exceeds the Class C concentration limits in Part 61.55 of Title 10 of the *Code of Federal Regulations*. Typically, this waste consists of irradiated metal components from reactors such as core shrouds, support plates, and core barrels, as well as filters and resins from reactor operations and decommissioning. Sealed sources used at hospitals, medical schools, research facilities, and universities can also be classified as GTCC waste. A third category, "Other Waste," consisting of contaminated equipment, rubble, scrap metal, filters, soil, and solidified sludges may be classified as GTCC waste based on their differing radionuclides and concentration levels. The Low-Level Radioactive Waste Policy Amendments Act of 1985 requires the Federal Government to take responsibility for the disposal of GTCC waste. All GTCC waste created from U.S. Nuclear Regulatory Commission (NRC) licensed activities, under the Atomic Energy Act of 1954, as amended, must be disposed of in an NRC licensed facility that has been determined to be adequate to protect public health and safety.

Information from Argonne National Laboratory's supplemental report on GTCC waste from 2010 anticipates that the total volume of GTCC waste will be approximately 8,800 m<sup>3</sup> (311,000 ft<sup>3</sup>) and the projected activity of that waste will be 5.92 x 10<sup>6</sup> TBq (160 MCi) with generation activities ending in 2083. Currently, there is no pathway for the disposal of GTCC waste in the United States. A performance-based approach may be used to subdivide GTCC waste into various waste streams<sup>1</sup> by reviewing the characteristics of GTCC waste with its associated hazards. Characteristics of GTCC waste include half-life and concentration. In creating the 10 CFR Part 61 waste classification tables, which define GTCC concentrations, a number of assumptions were made regarding waste inventory and exposure scenarios for the inadvertent intruder for a generic LLRW disposal facility. The findings from other exposure scenarios (e.g., construction, agriculture, well drilling), together with the findings from evaluations of radiological characteristics of GTCC, could be used as part of a performance-based approach for categorizing GTCC waste. The findings may determine that some GTCC waste streams will be closer in characteristics to Class C waste, while other GTCC waste streams will have characteristics similar to high-level waste and may require a higher degree of isolation from the public. The application of a site-specific and performance-based approach to GTCC waste stream characterization could assist the NRC in developing specific technical requirements for future disposal of various types of GTCC waste. Examples of part of a performance-based approach that examine and evaluate the radiological characteristics of GTCC waste will be presented.

### **INTRODUCTION**

Radioactive waste results from a variety of non-defense and defense activities in the United States. Defense-generated radioactive waste is defined as "Radioactive waste that is generated by atomic energy defense activities, which are defined by the Nuclear Waste Policy Act of 1982 to mean activities of the

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<sup>1</sup> "Waste stream" is defined here as meaning waste with relatively uniform radiological and physical properties. Often the waste results from a single process.

DOE (and predecessor agencies) that are/were performed in whole or in part in carrying out any of the following functions: naval reactor development; weapons activities, including defense inertial confinement fusion; verification and control technology; production of defense nuclear material; management of defense nuclear waste and material byproducts; defense nuclear material security and safeguards and security investigations; and defense research and development [10].” Non-defense- waste is waste that is not generated by atomic energy defense activities (such as the waste that results from commercial nuclear power production). Radioactive waste management policies in the United States have arisen from the origin of the waste streams rather than its radiological properties. This in turn has determined the preferred disposal pathway for various radioactive wastes.

The Low-Level Radioactive Waste Policy Act (LLRWPA) (Pub. L. 96-573) defines low-level radioactive waste (LLRW) as: “Radioactive waste not classified as high-level radioactive waste, transuranic<sup>2</sup> waste, spent nuclear fuel, or byproduct material as defined in section 11e.(2) of the Atomic Energy Act of 1954.”

Title 10 of the *Code of Federal Regulations* (CFR) Part 61, “Licensing Requirements for Land Disposal of Radioactive Waste,” includes a waste classification system for LLRW. In 1982, the NRC developed this classification system categorizing LLRW as Class A, Class B, or Class C. Waste that is not generally acceptable for near surface disposal is waste for which form and disposal methods are generally more stringent, than those specified for Class C waste. Class A was considered the least radiologically hazardous with GTCC being the most hazardous form of LLRW due to the threat posed to the inadvertent intruder beyond the period of institutional controls. The classification system is explained in 10 CFR 61.7 and the classification criteria in 10 CFR 61.55 defines the waste based on short-lived and long-lived radionuclides. The disposal criteria in 10 CFR Part 61 are based on performance objectives. 10 CFR Part 61 provides for increased physical and administrative controls for LLRW disposal according to increased hazards.

Responsibility for the disposal of GTCC LLRW was assigned to the Federal Government in the Low-Level Radioactive Waste Policy Amendment Act (LLRWPA) of 1985. The responsibility for disposal of GTCC LLRW has been assumed by DOE. The LLRWPA further requires that commercially generated GTCC waste “shall be disposed of in a facility licensed by the Nuclear Regulatory Commission.” There is currently no disposal facility for GTCC waste.

Consistent with NRC’s and DOE’s authorities under the Atomic Energy Act of 1954, amended (P.L. 83-703), the NRC LLRW classification system does not apply to radioactive waste that is owned or generated by DOE and disposed of in DOE facilities. However, DOE owns or generates both LLRW and non-defense- generated transuranic (TRU) waste, which have characteristics similar to those of GTCC LLRW and for which there may be no path for disposal<sup>3</sup>. In 2011, DOE published its “Draft Environmental Impact Statement [EIS] for the Disposal of Greater-Than-Class C (GTCC) Low-Level Radioactive Waste and GTCC-Like Waste,” which considered the potential environmental impacts associated with constructing and operating a new facility or facilities, or using an existing facility, for the disposal of GTCC and GTCC-like waste. The draft EIS analyzes methods (geologic repository, above grade vault, enhanced near surface trench and intermediate depth borehole) and locations for the disposal of GTCC waste. As part of their responsibilities under the LLRWPA, DOE has included these GTCC-like wastes for evaluation in its Draft EIS because a common approach and/or facility could be used [10].

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<sup>2</sup> Transuranic means any element whose atomic number is higher than that of uranium (atomic number 92), including neptunium, plutonium, americium, and curium.

<sup>3</sup> The Waste Isolation Pilot Plant (WIPP) is a DOE facility designed and authorized to permanently dispose of defense-generated TRU waste. The WIPP Land Withdrawal Act, as amended (P.L. 102-579) limits the use of WIPP to the disposal of TRU waste generated by atomic defense activities.

While the waste classification approach used here could be applied to this GTCC-like waste, the focus will be on commercially generated GTCC waste.

## BACKGROUND

There are three categories for GTCC waste: activated metals, sealed sources, and other waste. The activity levels of these various materials span a wide range. Some of the radionuclide concentrations in these waste streams will be close to their respective Class C concentration limits. On the other hand, a small portion of the GTCC waste is greater than the activity range for high-level waste, which typically has levels of activity concentrations in the range of  $10^4$ - $10^6$  TBq/m<sup>3</sup> [4]. DOE has forecasted the stored and projected volume of GTCC LLRW from these three categories (Table I). The total stored and projected volume of GTCC waste will be approximately 8,800 m<sup>3</sup> (311,000 ft<sup>3</sup>) and the projected activity of that waste will be  $5.92 \times 10^6$  TBq (160 MCi) with generation activities assumed to end in 2083 [10].

**Table I:** Current Stored and Future Projected Volumes of GTCC LLRW<sup>4</sup> [10]

GTCC LLRW Waste Type	In Storage		Projected		Total Stored and Projected	
	Volume (m <sup>3</sup> )	Activity (MCi)	Volume (m <sup>3</sup> )	Activity (MCi)	Volume (m <sup>3</sup> )	Activity (MCi)
<i>Groups 1 and 2</i>						
Activated Metals (RH)	59	1.4	1900	160	1959	161.4
Sealed Sources (CH)	<sup>a</sup>	<sup>a</sup>	2900	2	2900	2
Other Waste (CH)	42	0.00091	1600	0.024	1642	0.02491
Other Waste (RH)	33	0.0042	2300	0.51	2333	0.5142
<b>Total</b>	<b>134</b>	<b>1.41</b>	<b>8700</b>	<b>163</b>	<b>8834</b>	<b>164</b>

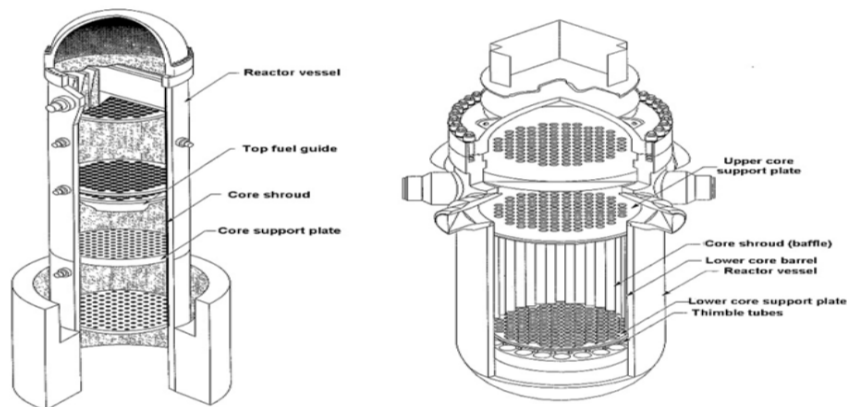
<sup>a</sup>NRC licensees currently possess sealed sources that may become GTCC waste when no longer needed by the licensee; the estimated volume and activity of those sources are included in the projected inventory.

DOE has focused on two groups of GTCC waste in the draft EIS. Group 1 consists of wastes from currently operating facilities such as commercial nuclear power plants. Some of the Group 1 wastes have already been generated and are currently in storage awaiting disposal while the rest will be generated from these operating facilities in the future. Group 2 consists of projected wastes from proposed actions by DOE or planned facilities not yet in operation. Group 2 wastes could also contain mixed waste (i.e., radioactive and hazardous waste combined) which would be regulated under the Resource Conservation and Recovery Act in addition to the Atomic Energy Act. Some portion of the entire Group 2 waste may never be generated, depending on the outcomes of proposed disposal actions that are beyond the scope of the draft EIS.

Activated metals waste can be subdivided into two categories: routinely generated activated metal (e.g., the nonfuel-bearing components that are activated through exposure to neutron flux which are periodically replaced during routine operations) and decommissioning activated metals (e.g., the nonfuel-bearing structural components within the reactor vessel that are activated by neutron exposure and removed at decommissioning). The activated metal waste consists of steel, stainless steel, and a number of specialty alloys used in nuclear reactors. Portions of the reactor containment vessel and other internal components near the irradiated nuclear fuel assemblies are activated by high fluxes of neutrons during reactor operations, and high concentrations of some radionuclides are produced as a result. Most of the GTCC activated metal waste will be generated in the future from the decommissioning of commercial nuclear power plants that are currently operating in the United States [1].

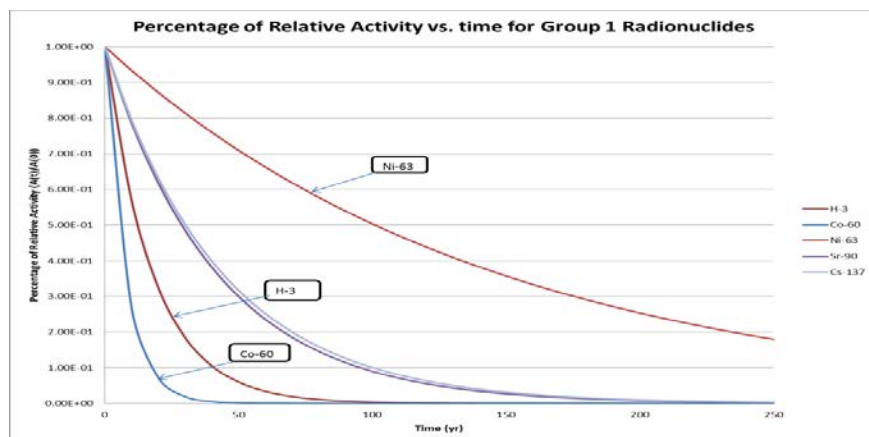
<sup>4</sup> CH = contact-handled (waste), RH = remote-handled (waste), 1MCi = 37,000 TBq

The generation of activated metals depends on the plant's type, size, fuel cycle length, and average exposure during each fuel cycle. Typical boiling water reactor (BWR) components classified as GTCC waste during decommissioning are the top fuel guide, the core shroud, fuel support castings and the core support plate. Pressurized water reactor (PWR) components classified as GTCC waste during decommissioning are the upper core support plate, the core shroud (i.e., baffle), the lower core barrel and the lower core support plate [8]. The location of some of these components in the PWR and BWR vessel can be seen in Figure 1.



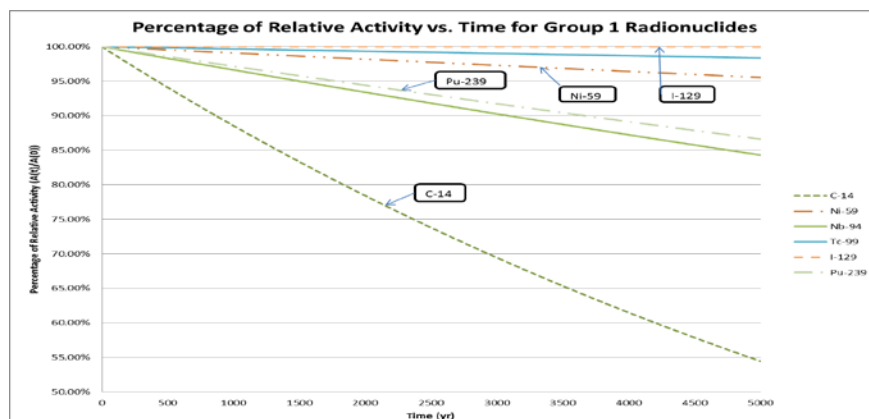
**Fig. 1:** Location of activated metal for BWR (Left) and PWR (Right) [8]

The neutron activation products expected to be most dominant in activated metals at the time of disposal are C-14, Mn-54, Fe-55, Ni-59, Co-60, Ni-63, Mo-93, and Nb-94. Lower concentrations of some fission products such as Sr-90, Tc-99, I-129, and Cs-137 and actinides (such as various isotopes of plutonium) are also expected to be present on these materials as surface contamination [1]. The graph in Figure 2 indicates that some of the short-lived<sup>5</sup> neutron activation products will decay to a level that prevents these radionuclides from being classified as GTCC waste (e.g., Co-60, and Fe-55). Institutional control of access to a LLW disposal site cannot be relied upon for more than one hundred years, and the effective life of intruder barriers such as concrete covers should be five hundred years [6]. Figure 3 indicates that the GTCC waste concentration in activated metals is primarily driven by the concentrations of Ni-59, Nb-94, and C-14.



**Fig. 2:** Radioactive decay of short lived radionuclides in activated metal [1]

<sup>5</sup> Long-lived radionuclides are identified in Table 1 of 10 CFR 61.55 and short-lived radionuclides are identified in Table 2 of 10 CFR 61.55.



**Fig. 3:** Radioactive decay of long lived radionuclides in activated metal [1]

The projected total volume of activated metal waste is 2,000 m<sup>3</sup> (71,000 ft<sup>3</sup>), and most of the commercial reactors are not scheduled to undergo decommissioning for several decades [10].

Sealed sources are widely available and are used extensively in a broad range of industrial or institutional applications. They are generally small and the radionuclides are generally enclosed in capsules made, with very few exceptions, of stainless steel, titanium, platinum or other inert metals. Source capsules are designed to be airtight and robust in order to prevent the inadvertent release of the active component. The recommended useful life of most sealed sources is five to fifteen years, but they can represent a possible radiological hazard long after the devices containing them have been set aside for disposal. GTCC sealed sources may contain one of many radionuclides including Cs-137, Pu-238, Pu-239, Am-241, and Cu-244, and their activities can range from  $4.07 \times 10^{-4}$  TBq (0.011Ci) to  $1.5 \times 10^5$  TBq (4.1 MCi). Most sealed sources have activities of less than  $5.0 \times 10^{-3}$  TBq (135 mCi). Sealed sources can encompass several physical forms, including ceramic oxides, salts, or metals. Cesium chloride salt was commonly used in older Cs-137 sources, and newer sealed sources typically have the radionuclide bonded in a ceramic. Of these two forms, cesium chloride salt is much more water soluble. The projected volume of GTCC commercial sealed sources is 2,900 m<sup>3</sup> (102,000 ft<sup>3</sup>) [10]. In many cases, the volume includes the device, as well as the source since it may be expeditious to dispose of the device and source as a unit.

The third category of GTCC waste is identified as “Other Waste,” which consists of contaminated equipment, rubble, scrap metal, filters, resins, soil and solidified sludges. A very small percentage of this waste was produced in the commercial sector as a result of radionuclide manufacturing, research and other activities. About 95% of this waste volume is classified as Group 1 Other Waste and is associated with DOE activities [1]. In the operation of nuclear facilities, GTCC Other Waste may be generated from the processing of cooling water and storage pond water at a nuclear power plant, as well as from equipment used in decontamination procedures, and from routine maintenance operations. GTCC Other Waste generated from routine operations includes contaminated clothing, floor sweepings, paper and plastic. GTCC Other Waste is also produced from the processing of primary coolant water in the reactor coolant system (RCS) and the off-gas system, which includes spent resins and cartridge filters as well as various contaminated tools. GTCC Other Waste may also be generated from the replacement of activated core components such as control rods or neutron sources during refueling operations at nuclear power plants. GTCC Other Waste from the operation of nuclear power plants is normally contaminated with fission products and activation products. The presence of fission products results from failed or damaged fuel assemblies.

Another possible source of GTCC Other Waste are the NRC-Licensed Disposal Area (NDA) and State-Licensed Disposal Area (SDA) at the West Valley Site, which contains the higher-activity radioactive waste that was disposed in the near-surface during operations. . A wide spectrum of radionuclides is present in these wastes, with the isotopes of various actinides (uranium, neptunium, plutonium, americium, and curium) being of most concern with regard to long-term waste management [1]. Some of the major components of the NDA waste are hardware, ion exchange, and failed equipment. As announced in the April 20, 2010, Record of decision (ROD) for the *Final Environmental Impact Statement for Decommissioning and/or Long-Term Stewardship at the West Valley Demonstration Project and Western New York Nuclear Service Center*, DOE decided to implement the Preferred Alternative, Phased Decision-making. Under this alternative, exhumation of the NDA and SDA wastes is deferred until Phase 2 decision (to be made within 10 years of the ROD). DOE has not announced its decision at this time.

## **DISCUSSION**

The waste classification system developed for the 10 CFR Part 61 regulation follows directly from the performance objectives and technical criteria found in Subpart C and Subpart D, respectively. It is intended to ensure, as far as possible, on a non-site specific basis, that the 10 CFR 61.42 requirements are met for the protection of individuals from inadvertent intrusion. As noted above, GTCC waste is generally unacceptable for near-surface disposal; however, in 1988, NRC promulgated a revision to 10 CFR Part 61 that allowed the Commission to consider alternative methods. The revision states that “In the absence of specific requirements in this part, such waste (i.e., GTCC), must be disposed of in a geologic repository as defined in 10 CFR Part 60 or 63 of this chapter unless proposals for disposal of such waste in a disposal site licensed pursuant to this part are approved by the Commission.”

The varied range of types of GTCC waste could be categorized via a performance based approach. This categorization of the various forms of GTCC waste could help determine the appropriate level of isolation for disposal that may be required to protect the health and safety of the public and the environment. Some GTCC waste may be closer in characteristics to Class C waste, while other GTCC waste streams may pose a greater hazard and require a higher degree of isolation from the public.

An analytical approach could be used to subdivide GTCC waste into various waste streams by reviewing the characteristics of GTCC waste with its associated hazards. The primary characteristics of interest include half-life and concentration. Exposure pathways have helped define GTCC, as demonstrated by the intruder scenarios used in the draft environmental impact statement for 10 CFR Part 61, which was published by the NRC in 1981 [11]. This included exposure of an inadvertent intruder during the construction of a foundation for a home, and an agricultural scenario using soil from the excavated foundation. The findings from assessments on plausible exposure scenarios, together with the findings from evaluating half-life and concentration of radionuclides found in GTCC, could be used as part of a performance-based approach for the categorization of GTCC waste to help determine whether particular site characteristics, or disposal methods, could safely isolate GTCC waste from the biosphere. The following examples attempt to demonstrate the portion of the performance-based approach which examines and evaluates the radiological characteristics of GTCC waste.

### **Activated Metals**

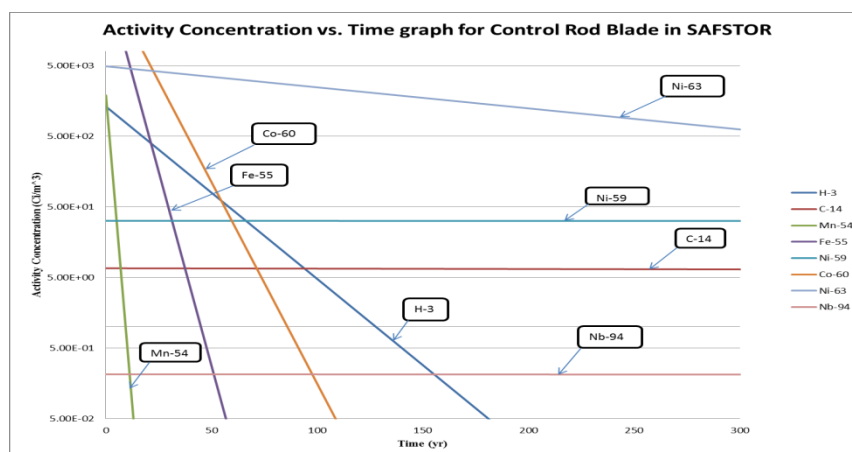
For activated metals, the GTCC waste comes from the routine replacement and decommissioning of components in the reactor seen in Figure 1. The graph in Figure 4 describes the decay of the radionuclides that were identified in a BWR control rod blade assembly. The activity estimates are based on the average concentration of the control rod blades used in conventional and controlled cell mode of

operation [3]. Based on the waste classification system in 10 CFR Part 61, the control rod blade assembly would be considered GTCC. The three basic structural materials used in reactor facility internals and support structures are stainless steel, aluminum, and zirconium alloys. The long lived radionuclides of significant concern in activated metals are C-14, Ni-59, and Nb-94.

NUREG-1713, "Standard Review Plan for Decommissioning Cost Estimates for Nuclear Power Reactors," dated November 2001, defines three decommissioning methods for nuclear power plants: DECON, SAFSTOR, and ENTOMB. The NRC defines SAFSTOR as, "A method of decommissioning in which a nuclear facility is placed and maintained in a condition that allows the facility to be safely stored and subsequently decontaminated (deferred decontamination) to levels that permit release for unrestricted use." Most nuclear power plants will begin decommissioning during SAFSTOR.

The estimated radioactive waste volumes in NUREG-1713 indicate that the majority of the low-level waste generated from decommissioning will be classified as Class A waste. The majority of the low-level waste activity will be in the GTCC waste, which will primarily be due to the activated metal components. The internal components classified as GTCC waste would require a significant amount of lead and concrete shielding due to the high concentration of gamma-emitting radionuclides.

The graph in Figure 4 compares the rate of decay for the concentration of radionuclides in a control rod blade assembly to the waste classification limit for the radionuclides in 10 CFR 61.55 Table 1 and Table 2. It should be noted that the concentration of Ni-63 in activated metals will be the primary radionuclide of concern. The radionuclide concentrations are based on the data in DOE/LLW-114F. The sum of the fractions method indicates that this assembly would remain above the Class C limit for more than 7,000 years based on the activity concentration of the long-lived radionuclides in 10 CFR 61.55. Table II gives a comparison of the decay times using the sum of the fractions method for activated metal components in PWR and BWR plants at decommissioning.



**Fig. 4:** Decay of radionuclides in BWR control rod blade assembly<sup>6</sup> [3]

A similar analysis of the other internal components can be prepared for both BWR and PWR facilities using the data from DOE/LLW-114F which relied on the methodology developed in NUREG/CR-3474

<sup>6</sup> This figure demonstrates the relevance of short-lived radionuclides in the near term management of GTCC. While these radionuclides do not contribute to the GTCC classification, they do represent a significant consideration regarding worker and public protection during the handling and transportation of the waste for storage or disposal.

“Long Lived Activation Products in Reactor Materials.” The sum of the fractions rule for mixtures of radionuclides in 10 CFR 61.55 (a) (7) assists with the classification of radioactive waste streams containing various radionuclides. The data in Table II indicates that the radionuclide activity concentrations in the thimble plug, in-core detector assemblies and the thermal shield may be below the 10 CFR 61.55 Class C limit since the sum of the fractions value is less than 1.0. It should be noted that the flux profile over the life of the reactor will have a significant impact on the concentration of radionuclides in the activated metal components of the nuclear system. The majority of the activated metal components in the PWR and BWR will be classified as GTCC waste and may require a higher degree of isolation.

**TABLE II:** Comparison of decay time for internal components in PWR & BWR [3]

Activated Metal Component	Sum of the Fractions Value	10 CFR 61 Class C Decay Time (yr)
PWR Thermal Shield	0.6887	500
PWR In-Core Detector	0.8223	500
PWR Thimble Plug	0.9012	500
BWR Control Rod Blade	0.9997	7850
PWR Instrument String	0.9981	8390
PWR Core Barrel	0.9929	11700
BWR Local Power Range Monitoring String	0.9998	13320
PWR Thimble Tube	0.9998	24560
BWR Core Shroud	0.9991	128700
PWR Core Baffle	0.9026	150500
BWR IRM/SRM Dry Tube	0.9984	227820

The BWR top fuel guide and the PWR core support columns will need to be evaluated during the decommissioning process in order to determine the appropriate path for disposal. The radiological hazard of removing the majority of the internal components from a decommissioned reactor vessel may outweigh the benefit of being able to dispose of them in a near surface disposal facility prior to the opening of a GTCC facility. A detailed analysis of the radionuclide concentrations in these components is one feature that needs to be considered in order to determine the best disposal option for these components.

### Sealed Sources

The GTCC sealed sources can be divided into two groups: industrial cesium sources and commercial plutonium, americium and curium sources. The DOE draft EIS for the disposal of GTCC (DOE/EIS-0375-D) estimates that there are approximately 1,435 commercial Cs-137 irradiators with no pathway for disposal in the United States. Given the 30 year half-life of Cs-137, a typical blood irradiator source is in service for approximately 30 years before needing to reload the source material, with the common practice being the replacement of the entire irradiator to maintain the sample exposure time. Currently, there is no disposal capacity for disused sealed sources that may be classified as GTCC. These sources are being managed as radioactive material. Therefore, waste classification per 10 CFR Part 20 Appendix G is not required. In many cases, these sources are being retrieved by NNSA in its GTRI. These sources become the responsibility of NNSA per its Atomic Energy Act Authority. Other devices are returned to the manufacturer for source replacement. Large Cs-137 sources cannot be packaged in 0.21 m<sup>3</sup> (55-gallon) drums; instead it is assumed the 1,435 Cs-137 sources will be disposed in their original shielded devices, which will reduce the worker dose levels during processing and disposal. Since the volume of most of these source devices is unknown, an estimated single package volume of 0.71 m<sup>3</sup> (25 ft<sup>3</sup>) was assumed in DOE/EIS-0375-D. For the purposes of transportation and disposal analyses, the CIS-US Inc. Blood Irradiator Model IBL-437C, which has a similar volume, was chosen to represent the Cs-137



irradiator sources in DOE/EIS-0375-D. The activity range for the Cs-137 sources used in this model is between 63 TBq (1.7 kCi) and 189 TBq (5 kCi). Figure 5 shows that the majority of the activity in commercial sealed sources is due to the blood irradiators that use Cs-137 as their primary source material.

Figure 5 provides the approximate decay rate of commercial sealed sources based on their initial activity at disposal. The average activity of the 1,435 Cs-137 blood irradiators that are projected to be disposed of will be approximately 44 TBq (1.2 kCi) [10]. The specified generic disposal limit for Cs-137 sealed sources in the 1995 Branch Technical Position (BTP) on Concentration Averaging and Encapsulation is 1.11 TBq (30 Ci). However, the revised draft BTP published for comment in 2012 has proposed that a higher limit could be used. The final BTP is anticipated to be published shortly. A site-specific performance assessment and inadvertent intrusion assessment would need to be evaluated by the NRC in order to determine the required disposal criteria for Cs-137 sealed sources in blood irradiators. Based on the assumed volume of 0.71 m<sup>3</sup> the activity concentration of the Cs-137 irradiator will be  $6.3 \times 10^{-4}$  TBq/m<sup>3</sup> (0.017 Ci/m<sup>3</sup>) after 500 years of decay. In comparison the Class C limit for Cs-137 in 10 CFR 61.55 is 170 TBq/m<sup>3</sup> (4,600 Ci/m<sup>3</sup>) which decays to  $1.7 \times 10^{-3}$  TBq/m<sup>3</sup> (0.047 Ci/m<sup>3</sup>) after 500 years. The projected activity concentration after five hundred years indicates that the Cs-137 irradiators may not require a much higher degree of isolation for disposal.

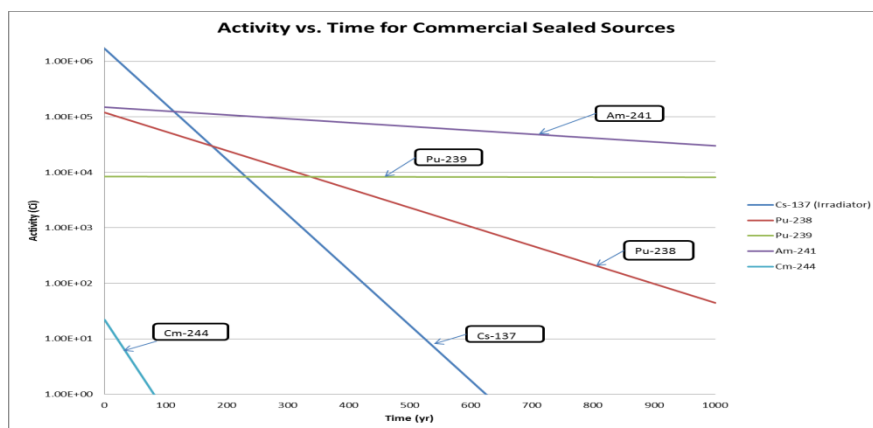


Fig. 5: Decay of commercial sealed sources over time [8]

The activity level of the commercial sealed sources containing Cm-244 is projected to be 81 TBq (2,200 Ci) [10]. After seven half-lives the projected activity of the Cm-244 sealed sources will be  $8.1 \times 10^{-3}$  TBq (0.22 Ci). A site-specific performance assessment will need to be conducted for Cm-244 sealed sources in order to determine the appropriate path for disposal.

Primary neutron sources containing alpha emitting radionuclides mixed with a low atomic weight non-radioactive material are used in PWR and BWR reactors. Babcock & Wilcox plants use two primary neutron sources that are stainless steel-clad americium beryllium. Combustion Engineering plants also use two primary source assemblies. Each source contains one antimony-beryllium and two plutonium-beryllium sources. Westinghouse primary source rods contain either californium, or plutonium-beryllium. Typically, the radioactive material is in the form of an oxide that is blended with either beryllium metal (Be) or beryllium oxide (BeO). Source strengths will vary by vendor, but the typical activity levels after twenty years of service (i.e., the expected useful life) are 2 TBq (50 Ci) Pu-Be for Westinghouse plants, 12.6 TBq (340 Ci) Pu-Be for Combustion Engineering plants, and 0.93 TBq (25 Ci) Am-Be for Babcock & Wilcox plants [3]. Figure 6 compares the decay of primary neutron sources (e.g., in interim storage) removed from light water reactors after twenty years of service. The activity concentrations for the primary neutron sources after 500 years of decay are projected to be  $2.18 \times 10^6$  Ci/m<sup>3</sup> (B&W),  $1.48 \times 10^6$  Ci/m<sup>3</sup> (C.E.) and  $1.42 \times 10^5$  Ci/m<sup>3</sup> (West.) [3].

The calculated neutron yield per  $10^6$  primary alpha particles is 79 for Pu-Be and 82 for Am-Be sources [5]. The neutron emissions from these sources could be significantly reduced by chemically separating the radioactive material from the non-radioactive Be or BeO material which would reduce the radioactive waste volume and neutron generation rate. Hot cells and glove boxes would be required to protect workers from exposure to high neutron emission sources during the chemical separation and extraction process. A performance based approach for the disposal of neutron sources may provide a pathway for disposal of the sealed neutron sources. The activity limit in the BTP for sealed sources with alpha-emitting transuranic (TRU) radionuclides with a half-life greater than 5 years (excluding Pu-241 and Cm-242) is  $1.1 \times 10^{-3}$  TBq (30 mCi). The activity limits in the BTP are based on a five hundred year decay time.

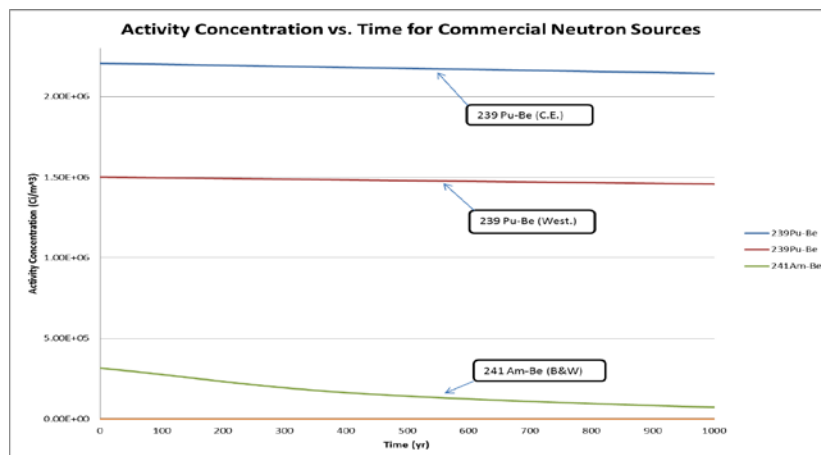


Fig. 6: Decay of Pu-Be or Am-Be ( $\alpha$ , n) sources [3]

### GTCC Other Waste

For the most part the volume of GTCC “Other Waste” will be higher than the volumes of activated metals, and sealed sources. The GTCC Other Waste components by generator are listed in Table III. Three of the C-14 users surveyed by DOE reported the presence of hazardous materials within their GTCC LLW which include ignitable (40 CFR 261.24) and toxic (40 CFR 261, Subpart D) materials. Chemicals in their GTCC LLW include alcohols, acetone, hexane, xylene, and miscellaneous aromatics [3]. Mixed waste is waste that contains both (1) source material, special nuclear material, or by-product material subject to the Atomic Energy Act of 1954, as amended, and (2) a hazardous component subject to the Resource Conservation and Recovery Act (RCRA, P.L. 94-580). A relatively small amount of the Group 1 GTCC Other Waste may be characterized as mixed waste. The total volume of mixed waste was estimated to be  $170 \text{ m}^3$  ( $6,000 \text{ ft}^3$ ) in the draft EIS [10].

Burnup laboratories must store GTCC LLW on site after completing post-irradiation spent fuel examination. Burnup laboratories conduct post-irradiation examinations (PIE) of highly activated fuel assemblies and structural materials that are subject to the extreme environment inside a nuclear reactor. This GTCC waste typically consists of polyethylene, polyvinyl chloride bags, cemented liquid from dissolved fuel (burnup solution), standard laboratory glassware, Dowex anion or cation exchange media, and glovebox parts. The variety of the waste material and unknown activities make it difficult to concentration-average the waste. The containers holding the waste inside the hot cells have surface dose rates greater than  $0.43 \text{ Gy/hr}$  ( $50 \text{ R/hr}$ ) [3].

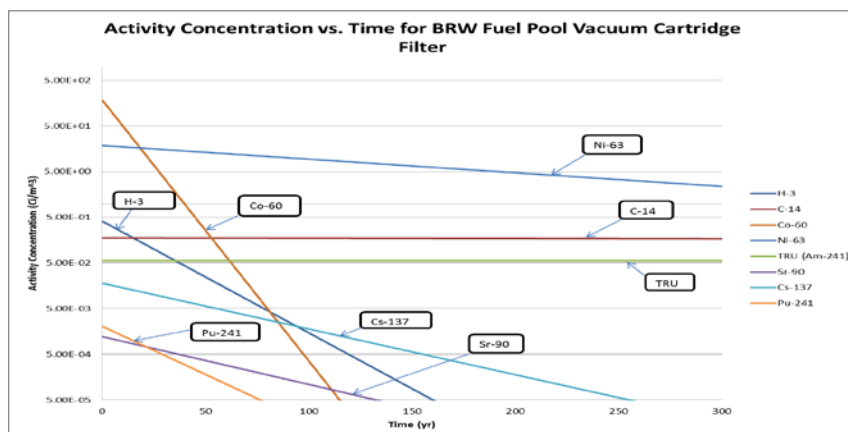
Americium oxide (AmO) in a matrix of gold is the radioactive component for sealed sources used in smoke detectors. Generators anticipate that about half of the AmO that enters the plant leaves the plant as

a product; the other half remains in the plant as scrap foil. The GTCC waste is 70% metal scrap and 30% glass materials. Concentrations of Am-241 GTCC waste range from 3.7 kBq/g (100 nCi/g) to 19 MBq/g ( $5.1 \times 10^5$  nCi/g) with an estimated 19 TBq (500 Ci) total activity [3].

Process wastes consist of the wet wastes that are produced from the cleanup of liquids containing soluble and insoluble radionuclides. These wastes contain cartridge filters and the cation bead resin produced during full reactor coolant system (RCS) decontamination. Cartridge filters are generated routinely, while decontamination resins are generated infrequently. The cartridge filter radiation dose levels can range from 0.5 to 2 Gr/hr (50 to 200 rad/hr) based on the radionuclide content. At these radiation levels, some cartridge filters are potentially GTCC LLW [3].

BWRs routinely generate control rod drive strainers and cartridge filters that are potential GTCC LLW. Each control rod drive contains three metallic strainers. The two strainers at the spud end of the drive can exceed Class C limits. About 50% of the strainers generated from this source exceed Class C limits with no concentration averaging. Control rod drive strainers are replaced when control rod drives are refurbished or replaced during refueling outages. The typical contact radiation levels for the control rod drive strainers are 1.5 Gr/hr (150 rad/hr) [3].

In addition, GTCC waste can also be generated from BWR fuel pool vacuum and control rod filters during refueling outages. During a typical refueling outage, more than a dozen filters at GTCC concentrations can be generated. BWR cartridge filter can exceed Class C limits since the activity is relatively high and the volume of the filter is relatively low. Active waste management practices can be employed to ensure the radionuclide concentration on the filters does not exceed Class C limits by reducing the operational service life. In general the activities from non-transuranic radionuclides are below the Class C limits. However, Figure 7 shows that transuranic radionuclides drive the classification of vacuum cartridge filter above the Class C limits. Typically 25% of the vacuum filters (per fuel cycle) will be GTCC waste with no concentration averaging. The average contact radiation dose levels for these filter assemblies will be greater than 1 Gr/hr (100 rad/hr) [3].



**Fig. 7:** Decay of radionuclides in BWR Cartridge Filter assembly [3]

PWRs generate a wide range of filter types, some of which can potentially be GTCC waste. Generation rates are dependent of filter type and plant operational procedures. PWR cartridge filters are: reactor coolant, seal water injection, cavity drain, and fuel pool. Typical values can range from 1.5 to 4 times the Class C limits. The average activity for the cartridge filters from a PWR is 0.14 TBq (3.7 Ci). The average contact radiation (ionizing) exposure level from these filters is 0.87 Gr/hr (100 R/hr) [3].

**Table III:** Other Generator Waste, GTCC LLW components by generator [3]<sup>7</sup>

Generator Types	GTCC LLW Components
Carbon 14 Users	Organic Liquids
Fuel Fabricators and Burnup Laboratories	Metal Shavings, Ion-Exchange Resins, Cartridge Filters, Compactible Trash, Mixed Oxide Fuel Pellets
Industrial Research and Development	Mixed Oxide Fuel Pellets
Manufactures of Devices with Sealed Sources	Cartridge Filters, Solidified Resins, Compactible Trash
Nuclear Research/Test Reactors	Reactor Internal Parts, Control Rod Blade Parts
Sealed Source Distributors	Metal Parts, Organic Liquids
Sealed Source Manufacturers	Compactible Trash, Contaminated Equipment, Filter Media, Noncompactible Trash

About 67% of GTCC Other Waste has already been generated and is in storage. The remaining 33% is projected to be generated in the future [1]. The DOE expects that the majority (i.e., 95 % of the Group 1 Other Waste) of this “Other Waste” will meet the definition for TRU waste as defined in the WIPP Land Withdrawal Act (P.L. 102-579), as amended by P.L. 104-201 “The term "transuranic waste" means waste containing more than 100 nanocuries (nCi) of alpha-emitting transuranic isotopes per gram of waste, with half-lives greater than 20 years, except for (A) high-level radioactive waste; (B) waste that the Secretary has determined, with the concurrence of the Administrator, does not need the degree of isolation required by the disposal regulations; or (C) waste that the Nuclear Regulatory Commission has approved for disposal on a case-by-case basis in accordance with part 61 of title 10, Code of Federal Regulations.”

## CONCLUSION

Since some GTCC waste remains potentially dangerous for a few thousand years, it must be safely processed and disposed of in a manner that protects future populations and the environment. Based on the characteristics of the various GTCC waste streams, the majority of the activated metal waste will require a higher degree of isolation due to the activity concentrations of C-14, Ni-59, and Nb-94. However the sum of the fraction method indicates that the thermal shield, in-core detectors, and thimble plug assemblies in PWRs may be categorized as Class C waste. The projected Cs-137 sealed source activity concentration after five hundred years (i.e.,  $6.3 \times 10^{-4}$  TBq/m<sup>3</sup> (0.017 Ci/m<sup>3</sup>)) indicates that the Cs-137 irradiators may not require a much higher degree of isolation for disposal. The effective use of concentration averaging and encapsulation techniques may dramatically reduce the volume of GTCC Other Waste. It appears that some of the GTCC waste could be managed differently from the majority of the remaining GTCC waste volume and may not require a higher degree of isolation for disposal. Site-specific performance assessments and intruder assessments may be able to identify near-surface disposal options with appropriate engineered features to address these portions of the GTCC waste stream.

<sup>7</sup> Some organic liquids have been solidified with cement, or precipitated as calcium or barium carbonate. Salts or solvents often exist in the mixtures (i.e., Mixed Waste). Some of this waste group is still stored as free liquids. Most of this waste is generated using C-14 as a “tagged” chemical tracer in the testing and manufacture of pharmaceuticals and agricultural chemicals [3].

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