GREATER-THAN-CLASS C LOW-LEVEL RADIOACTIVE WASTE AND DOE GREATER-THAN-CLASS C-LIKE WASTE INVENTORY ESTIMATES

Prepared by Sandia National Laboratories
for the U.S. Department of Energy
Washington, DC
July 2007

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

ACKNOWLEDGEMENTS

This report was prepared by Sandia National Laboratories with the assistance of Dade Moeller and Associates for the Department of Energy's Office of Environmental Management.

EXECUTIVE SUMMARY

This report presents estimates of Greater-Than-Class-C (GTCC) Low-Level Radioactive Waste (LLW) volumes and activities in storage and projected in the future. It updates the inventory estimates in the U.S. Department of Energy's (DOE's) 1994 report, "Greater-Than-Class C Low-Level Radioactive Waste Characterization: Estimated Volumes, Radionuclides, Activities, and Other Characteristics" (DOE/LLW-114). The estimates provided in this report used the best available data and are intended to assist the DOE in planning for the disposal of GTCC LLW, as required by the "Low-Level Radioactive Waste Policy Amendments Act of 1985" (LLRWPAA).

The Nuclear Regulatory Commission (NRC), in 10 CFR 61.55, classifies LLW into the following four categories: Class A, Class B, Class C, and waste that is not generally acceptable for near-surface disposal. The latter class of LLW exceeds the maximum concentration limits of radionuclides established by NRC for Class C waste and is referred to as "Greater-Than-Class-C." This report examines waste inventories for the following waste types: nuclear utility waste, sealed sources, and other generator waste. In addition to these waste types, this report also examines DOE waste with characteristics similar to GTCC LLW and which may not have a path to disposal (referred to in this report as DOE GTCC-like waste). DOE GTCC-like waste may include LLW and transuranic waste. The DOE GTCC-like waste is not subject to NRC regulation and licensing if disposed at DOE facilities. The use of the term GTCC-like does not have the intent or effect of creating a new classification of radioactive waste.

NUCLEAR UTILITY GTCC LLW - This report estimates GTCC LLW volumes that would be generated upon decommissioning the 104 commercial nuclear reactors that are operating in the United States in 2007, and from 18 decommissioned reactors. Data sources included several NRC and DOE reports and data provided by the Electric Power Research Institute (EPRI) and Maine Yankee. The inventory of GTCC LLW from nuclear utilities was estimated using scaling factors developed from NRC analyses of reference reactor decommissioning.

SEALED SOURCE GTCC LLW - Sealed sources are typically small, high-activity radioactive materials encapsulated in closed metallic containers. Sealed source inventory information was obtained from the NRC Interim Sealed Source Database, the DOE Radiological Source Registry and Tracking (RSRT) Database, and forecast source recovery rates provided by DOE's Off-Site Source Recovery Project (OSRP). The NRC Interim Sealed Source Database included GTCC LLW sealed sources from NRC and Agreement State licensees possessing aggregate quantities of radionuclides in excess of International Atomic Energy Agency (IAEA) Category 2 thresholds. The DOE RSRT Database included only DOE sealed sources, some of which are GTCC-like, and some of which have been recovered under the OSRP. OSRP recovery rates were used to estimate projected inventories of GTCC LLW sealed sources, which include IAEA Category 3 and 4 sources. Sealed sources requiring disposal as GTCC LLW, and DOE GTCC-like sealed sources that may not have a path to disposal, identified from the databases were conceptually packaged for disposal.

<u>OTHER GENERATORS GTCC LLW</u> - The Other Generators category of GTCC LLW includes all GTCC LLW that is not generated or owned by commercial nuclear utilities, sealed source licensees, or DOE. Information on potential GTCC LLW was obtained from potential generators identified through several sources as discussed in Chapter 4.

<u>DOE GTCC-LIKE WASTE</u> – Because DOE's waste is not subject to NRC regulation, it is not required to use the NRC LLW classification system for its LLW disposed of at DOE facilities. However, DOE possesses wastes similar to GTCC LLW, which may not have a path to disposal, referred to as "DOE GTCC-like waste." DOE GTCC-like waste may include LLW and transuranic waste. Information on DOE GTCC-like waste was obtained through an August 2005 data call to DOE sites, which was updated in 2007.

<u>DATA SUMMARY OF ALL CATEGORIES</u> - The estimates presented in this document are based on the best available information originally compiled in 2005 and subsequently updated from the results of data calls, interviews, and other sources of information. A degree of uncertainty in the results exists due to limitations in the availability of information and assumptions applied in the analysis. These estimates, however, provide reasonable values of the volumes and activities of GTCC LLW and GTCC-like wastes.

Table ES.1 provides a summary of the volumes and activities for these four categories. Figure ES.1 provides a graphical representation of this information.

Table ES. 1 Summary of GTCC LLW and DOE GTCC-like Waste Volume and Activity Estimates[a]

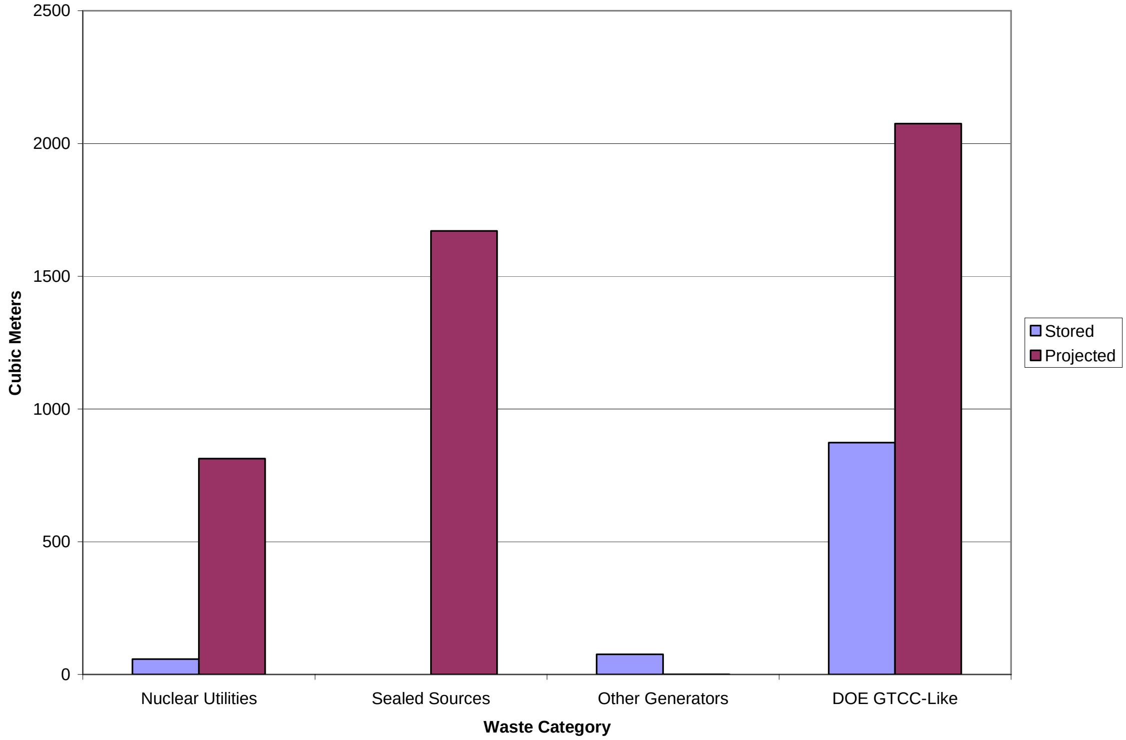
Waste type	In storage		Projected		Total stored and projected	
	Volume (m^3)	Activity (MCi)	Volume m^3	Activity (MCi)	Volume (m^3)	Activity (MCi)
GTCC LLW						
Activated metal[b]	58	3.5	810	110	870	110
Sealed sources[c]	(d)	(d)	1,700	2.4	1,700	2.4
Other waste	76	0.0076	1.0	0.00023	77	0.0078
Total GTCC LLW	130	3.5	2,500	110	2,600	110
DOE GTCC-like waste						
Activated metal	5.0	0.11	29	0.82	34	0.93
Sealed sources[c]	8.7	0.013	25	0.030	34	0.043
Other	860	11	2,000	19	2,900	30
Total DOE GTCC-like waste	870	11	2,100	20	3,000	31
Total GTCC and GTCC-like waste	1,000	15	4,600	130	5,600	140

[a]Values have been rounded to two significant figures.

[b]Activities for the projected inventory estimated at six years following reactor shutdown. Activities for the stored inventory have been decayed to 2007. The year 2062 was used for the overall nuclear utility GTCC LLW projections in order to include the 20-year license renewal that a number of commercial nuclear reactors are likely to receive and a minimum six-year cooling period before the waste would be available for disposal. Waste from operating reactors is assumed to start becoming available in 2035; waste from six reactors, accounting for 51.9 m^3 and $6.7x10^{+6}$ Ci, will become available after 2055.

[c]Sealed source activities estimated as of January 1, 2007.

[d]NRC licensees currently possess sealed sources that may become GTCC LLW when no longer needed by the licensee; the estimated volume and activity of those sources are included in the projected inventory.



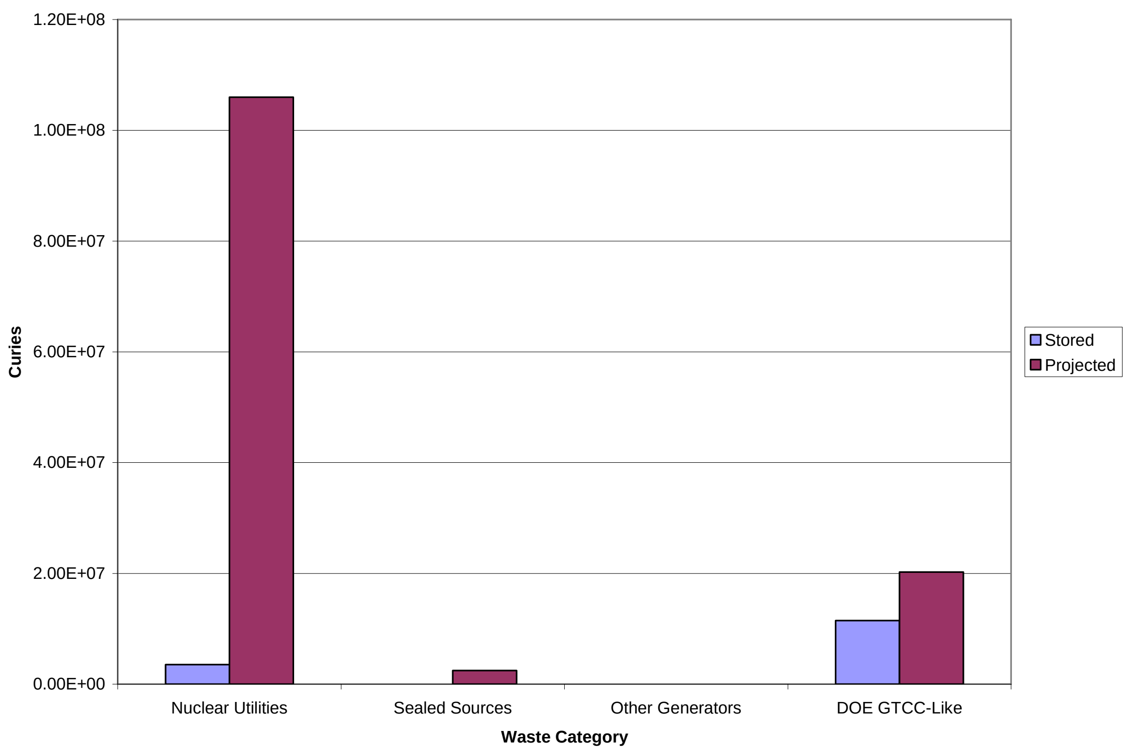


Figure ES. 1 GTCC and GTCC-like Volume and Activity Estimates (Stored and Projected)

Estimated volumes of GTCC and DOE GTCC-like mixed waste, which may require treatment prior to disposal, are provided in Table ES.2. The mixed waste activity estimate is uncertain, but likely relatively small in relation to the overall inventory.

Table ES. 2 Mixed Waste Inventory Summary

Origin	Volume (m^3)		
	Stored	**Projected**	**Total**
Other Generator GTCC Waste	4	0	4
DOE GTCC-like Waste	64	22	86
Total	**68**	**22**	**90**

In order to better appreciate the magnitude of GTCC LLW and DOE GTCC-like waste requiring disposal by 2062, a comparison was made to NRC Class A, B, and C LLW volumes disposed of in fiscal year 2006 (see Figure ES.2) (DOE, 2007). As can be seen from this figure, the total volume of GTCC LLW and GTCC-like waste requiring disposal by 2062 (5,567 cubic meters) is less than 5% of the volume disposed of at the three NRC-licensed disposal facilities (117,282 cubic meters) in fiscal year 2006.

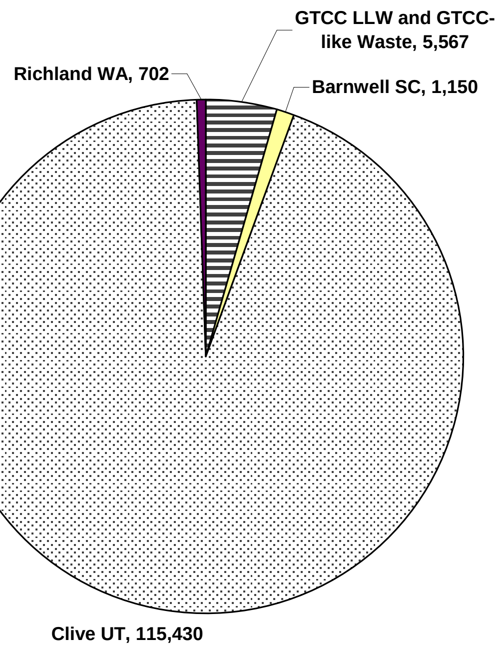


Figure ES. 2 Comparison of GTCC LLW and GTCC-like Waste Total Disposal Volume (Cubic Meters) with Fiscal Year 2006 Annual Disposal Volumes (Cubic Meters) from Operating LLW Disposal Facilities

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Acronyms and Abbreviations

ACA	After Concentration Averaged
ALARA	As Low As Reasonably Achievable
BWR	Boiling Water Reactor
CFR	Code of Federal Regulations
CH	Contact-Handled
Ci	Curies
DOE	U.S. Department of Energy
DOE/EM	U.S. DOE Office of Environmental Management
DOT	U.S. Department of Transportation
EFPY	Effective Full Power Year
EIS	Environmental Impact Statement
EIA	Energy Information Administration
EPRI	Electric Power Research Institute
GAO	Government Accountability Office
GTCC	Greater-Than-Class-C
IAEA	International Atomic Energy Agency
INL	Idaho National Laboratory
kCi	kilocurie (1000 curies)
LANL	Los Alamos National Laboratory
LLRWPAA	Low-Level Radioactive Waste Policy Amendments Act
LLW	Low-Level Radioactive Waste
MCi	Megacurie (1 million curies)
MIMS	Manifest Information Management Systems
MSRE	Molten Salt Reactor Experiment
MW(e)	Mega Watts of Electrical Output
NNSA	National Nuclear Security Administration
NRC	U.S. Nuclear Regulatory Commission
OSRP	Off-Site Source Recovery Project
PWR	Pressurized Water Reactor
RCRA	Resource Conservation and Recovery Act
RH	Remote-Handled
RPS	Radioisotope Power Systems
RSRT	Radiological Source Registry and Tracking
SC	South Carolina
SNL	Sandia National Laboratories
TRU	Transuranic Waste
U.S.	United States
UT	Utah
WA	Washington
WIPP	Waste Isolation Pilot Plant

Elements

Am	Americium
Be	Beryllium
Bk	Berkelium
C	Carbon
Cf	Californium
Cm	Curium
Co	Cobalt
Cs	Cesium
Fe	Iron
H	Hydrogen
I	Iodine
Mn	Manganese
Nb	Niobium
Ni	Nickel
Np	Neptunium
Pu	Plutonium
Sr	Strontium
Tc	Technetium

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1. INTRODUCTION

1.1. PURPOSE OF THIS REPORT

The purpose of this report is to update and summarize the GTCC LLW inventory information to support issuance of the Notice of Intent (NOI) for preparation of the environmental impact statement (EIS) for development of a disposal capability for Greater-Than-Class-C (GTCC) low-level radioactive waste (LLW). This report updates the inventory estimates in DOE's 1994 report, "Greater-Than-Class C Low-Level Radioactive Waste Characterization: Estimated Volumes, Radionuclides, Activities, and Other Characteristics" (DOE/LLW-114), which provided estimates of the 1993 inventory, inventory projections to the year 2035 for all waste categories, and to 2055 for nuclear utility GTCC LLW (DOE, 1994a). The year 2055 was used for the nuclear utility GTCC LLW projections in order to include the 20-year license renewal that a number of commercial nuclear reactors are likely to seek. The current report extends the projections to 2062 assuming a six-year cooling period before the waste becomes available for disposal.

GTCC LLW or DOE GTCC-like LLW?

- **GTCC LLW** is low-level radioactive waste generated by activities licensed by the U.S. Nuclear Regulatory Commission (NRC) or Agreement States that exceeds the maximum concentration limits of radionuclides established by NRC for Class C waste. This waste is generally unacceptable for near-surface disposal under NRC requirements.
- **DOE GTCC-like waste** is radioactive waste generated or owned by DOE with characteristics similar to GTCC LLW, and which may not have a path to disposal. DOE GTCC-like waste may include LLW and transuranic waste. However, because DOE's LLW is not subject to NRC regulation, DOE does not use the NRC LLW classification system. For purposes of this report, it is considered to be "GTCC-like." The use of the term GTCC-like does not have the intent or affect of creating a new classification of radioactive waste.

1.2. BACKGROUND

The Low-Level Radioactive Waste Policy Amendments Act of 1985 (LLRWPAA), section 3(b)(1)(D), assigned the U.S. Federal Government the responsibility for disposing of GTCC LLW resulting from activities licensed by U.S. Nuclear Regulatory Commission (NRC) or Agreement States (42 USC 2021 as amended). Section 3(b)(2) of the LLRWPAA requires the Federal Government to provide for the disposal of such GTCC LLW in a facility that adequately protects the safety and health of the public and is licensed by NRC.

NRC classifies LLW based on the presence of certain long- and short-lived radionuclides. These classes of LLW, referred to as Class A, Class B, and Class C, are defined in 10 CFR 61.55. Tables 1 and 2 from 10 CFR 61.55 are used to determine waste classes, as described below.

Class A: Waste whose long-lived radionuclide concentration does not exceed 0.1 times the value in Table 1 from 10 CFR 61.55, see Table 1.1 below, or whose short-lived radionuclide concentration does not exceed the value in Column 1 from Table 2 of 10 CFR 61.55, see Table 1.2 below. Also see 10 CFR 61.55, sections 3(i) and 4(i) respectively.

Class B: Waste whose short-lived radionuclide concentration exceeds the value in Column 1 of Table 1 in 10 CFR 61.55, see Table 1.1 below, but does not exceed the value in Column 2 of Table 2 in 10 CFR 61.55, see Table 1.2 below. Also see 10 CFR 61.55, section 4(ii).

Class C: If the waste concentration exceeds 0.1 times the value but does not exceed the actual value provided in Table 1 from 10 CFR 61.55, see Table 1.1 below, the waste is Class C. Also, the waste can be classified as Class C if the concentration exceeds the value in Column 2 but does not exceed the value in Column 3 of Table 2 in 10 CFR 61.55, see Table 1.2 below. Also see 10 CFR 61.55, sections 3(ii) and 4(iii) respectively.

Waste that is referred to as "Greater-Than-Class-C" is LLW that exceeds the maximum concentration limits of radionuclides established by NRC for Class C waste.

Table 1.1. Table 1 from 10 CFR 61.55.

Radionuclide	**Concentration**
C-14	8 Ci/m^3
C-14 in activated metal	80 Ci/m^3
Ni-59 in activated metal	220 Ci/m^3
Nb-94 in activated metal	0.20 Ci/m^3
Tc-99	3 Ci/m^3
I-129	0.08 Ci/m^3
Alpha emitting transuranic nuclides with half-lives greater than 5 years[1]	100 nCi/g
Pu-241	3,500 nCi/g
Cm-242	20,000 nCi/g

[1] *Alpha emitting transuranic nuclides with half-lives greater than 5 years include Am-241, Am-243, Bk-247, Cf-249, Cf-250, Cf-251, Cm-243, Cm-244, Cm-245, Cm-246, Cm-247, Cm-248, Cm-250, Np-237, Pu-238, Pu-239, Pu-240, Pu-242, and Pu-244.*

Table 1.2. Table 2 from 10 CFR 61.55.

Radionuclide	Concentration (Ci/m^3)		
	Col 1	Col 2	Col 3
Total of all nuclides with less than a 5-year half-life	700	(1)	(1)
H-3	40	(1)	(1)
Co-60	700	(1)	(1)
Ni-63	3.5	70	700
Ni-63 in activated metal	35	700	7,000
Sr-90	0.04	150	7,000
Cs-137	1	44	4,600

(1) There are no limits established for these radionuclides in Class B or C wastes. Practical considerations such as the effects of external radiation and internal heat generation on transportation, handling, and disposal will limit the concentrations for these wastes. These wastes shall be Class B unless the concentrations of other nuclides in Table 1.2 determine the waste to be Class C independent of these nuclides.

Under NRC regulations (10 CFR 61.55), Class A, B, and C waste can generally be disposed of in a near-surface disposal facility licensed by NRC or an Agreement State (10 CFR Part 61). According to 10 CFR 61.7 (b)(5), waste with concentrations above Class C limits (i.e., GTCC LLW) is generally unacceptable for near-surface disposal. However, 10 CFR 61.7 (b)(5) also states that "There may be some instances where waste with concentrations greater than permitted for Class C would be acceptable for near-surface disposal with special processing or design." (10 CFR Part 61).

1.3. TYPES OF GTCC LLW AND DOE GTCC-LIKE WASTE

GTCC LLW includes activated metals, sealed sources, and other wastes generated by users of radioactive material. In addition, DOE generates or owns waste with characteristics similar to GTCC LLW and which may not have a path to disposal (referred to in this report as DOE GTCC-like waste). DOE GTCC-like waste was considered for purposes of the current study. (See Figure 1.1 below for a depiction of terminology used in this report.)

This report examines the following waste categories:

GTCC LLW

- **Nuclear utility waste**, including activated metals and other wastes generated by commercial nuclear power plants.
- **Sealed sources**, consisting of radioactive materials contained in small, metallic capsules and used in devices for such purposes as measurement or calibration.
- **Other generator waste**, including contaminated debris and other wastes generated by radionuclide manufacturing, commercial research, and similar types of operations.

DOE – GTCC-Like Waste

- **DOE GTCC-like waste** is DOE-generated or owned waste with similar characteristics to GTCC LLW and which may not have a path to disposal. DOE GTCC-like waste may include LLW and transuranic waste (TRU). DOE GTCC-like waste includes sealed sources generated or owned by DOE and sources recovered by DOE under the Off-Site Source Recovery Project (OSRP) that may not have a path to disposal. For purposes of this inventory, DOE sealed sources are discussed in Chapter 3, Sealed Sources.

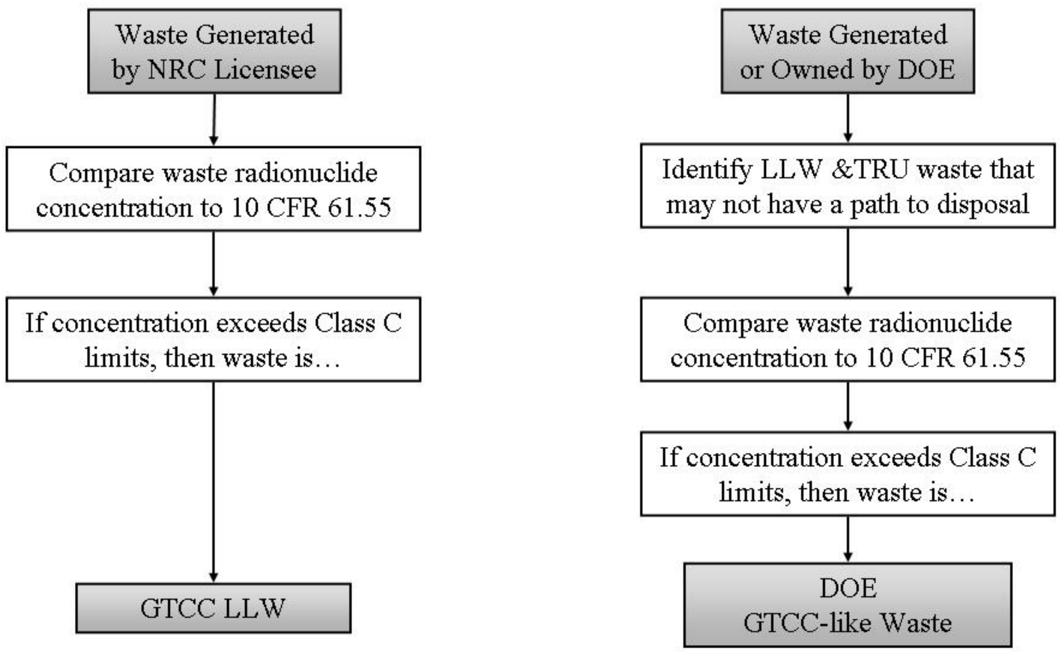

Figure 1.1. Process for Determining Appropriate Waste Terminology as Used in this Report.

1.4. CONCENTRATION AVERAGING

An NRC requirement in 10 CFR 61.55(a)(8) states: "The concentration of a radionuclide may be averaged over the volume of a waste, or the weight of the waste if the units are expressed as nanocuries per gram." NRC's "Branch Technical Position on Concentration Averaging and Encapsulation" provides guidelines for concentration averaging and encapsulation practices that NRC would find acceptable when licensees are trying to determine the concentration of radionuclides in their LLW (NRC, 1995). The guidelines are based on the premise that waste types are largely homogenous, in that they are volume distributed and "…the radionuclide concentrations are likely to approach uniformity in the context of the intruder scenarios used to establish the values…" included in the 10 CFR 61.55 waste classification tables (NRC, 1995). The amount of GTCC LLW available for disposal has decreased as a result, because the waste activity can be averaged over the disposal container, allowing some of this waste to be disposed of as Class A, B, or C LLW.

1.5. REPORT ORGANIZATION

This report is organized according to the following waste inventory categories:

Commercial – GTCC LLW

- Nuclear utility waste (Chapter 2)
- Sealed sources (both commercial and DOE) (Chapter 3)
- Other generator waste (Chapter 4)

DOE GTCC-like Waste

- DOE GTCC-like waste (Chapter 5)

This report estimates the quantities of GTCC LLW and DOE GTCC-like waste in storage and the projected (to 2035) quantities of these wastes. In addition, nuclear utility waste projections are made to 2062. Chapters 2, 3, 4, and 5 address the above four waste inventory categories and each chapter includes a description of the waste; a summary of previous inventory studies; a discussion of the current study, including the methodology used, assumptions, stored and projected inventory results, and uncertainties. Chapter 6 addresses the small quantity of mixed hazardous waste represented in the inventory. Chapter 7 summarizes the overall inventory of GTCC LLW and DOE GTCC-like waste in the four waste categories.

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2. NUCLEAR UTILITIES

2.1. WASTE DESCRIPTION

GTCC LLW from nuclear reactors is produced as a result of normal operations and becomes available for disposal during facility decommissioning.

The majority of GTCC LLW generated by nuclear reactors is activated metal (DOE, 1994a). The waste consists of components internal to the reactor that have become radioactive from exposure to a neutron flux, resulting in neutron absorption (DOE, 1994a). These components can include the core shroud, top fuel guide assembly components, core support plates, the lower core barrel, thermal shields, and lower grid plate components. Figures 2.1 and 2.2 depict the locations of these components.

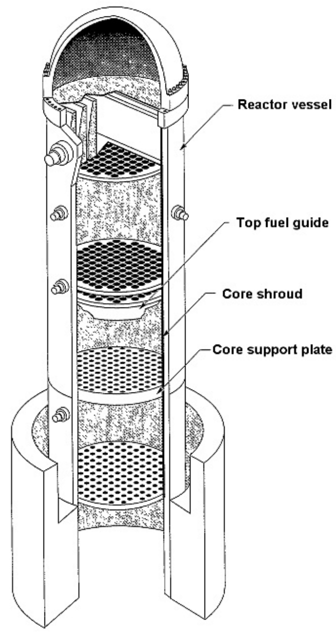


Figure 2.1. Location of Some BWR Decommissioning Components (DOE, 1994a).

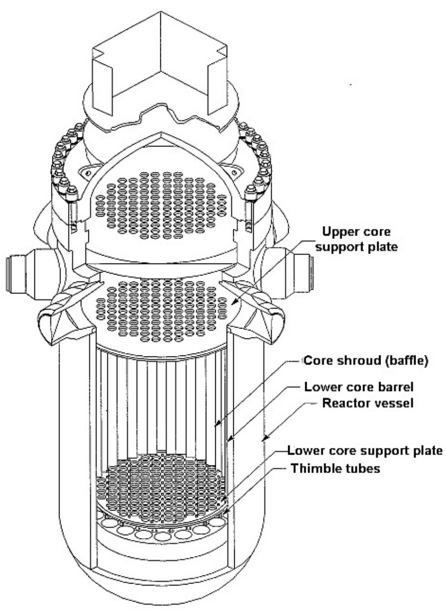


Figure 2.2. Location of Some PWR Decommissioning Components (DOE, 1994a).

Radionuclides in the activated metal components include C-14, Mn-54, Fe-55, Co-60, Ni-59, Ni-63, and Nb-94. The bulk of the total activity in the activated metals initially is from the short-lived radionuclides Co-60 and Fe-55, which do not have Class C limits as defined in 10 CFR 61.55. The high concentrations of longer-lived radionuclides, such as Ni-63, Ni-59, and Nb-94, in the activated metal are responsible for the material resulting in GTCC LLW.

Another type of utility waste that has the potential to be classified as GTCC LLW is process waste, such as water filter cartridges and ion-exchange resins used in normal reactor operations. However, the quantity of such waste is very small in comparison to decommissioning waste (DOE, 1994a). Most process waste is Class C or below after concentration averaging[1], and can be disposed of at an existing LLW disposal facility. Current practice is to select resins that will not create mixed waste and to remove filters using these resins before the concentration exceeds Class C limits.

NRC considers other small activated metal components such as control rod elements, burnable poison rod assemblies, and thimble plugs (non-fuel components) stored as part of spent fuel assembly packages to be spent fuel and not GTCC LLW (NRC, 2001); these components were therefore excluded from the analysis.

2.2. SUMMARY OF PREVIOUS DOE STUDY

The DOE report, "Greater-Than-Class C Low-Level Radioactive Waste Characterization: Estimated Volumes, Radionuclide Activities, and Other Characteristics" (DOE/LLW-114) (DOE, 1994a), provides a detailed analysis of GTCC LLW projections for the 109 commercial nuclear reactors (37 Boiling Water Reactors (BWRs) and 72 Pressurized Water Reactors (PWRs)) that were operating in the United States in 1993. The DOE/LLW-114 report estimated volumes and activities of GTCC LLW available for disposal in 2035 and 2055 under three different decommissioning scenarios. 2035 was used as the projected year at which a majority of the reactors would have reached the end of their licensed operating lifetimes, and 2055 was used as the projected year assuming the possibility of 20-year license extensions.

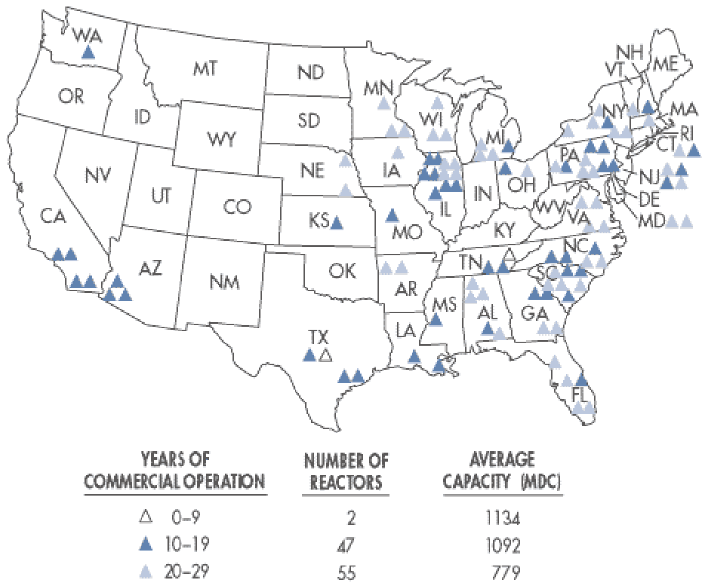
The base case inventory of GTCC LLW already in storage from nuclear utilities in 1993 was estimated in DOE/LLW-114 to be 26 m^3 for the after concentration averaged (ACA) volume and an activity of 3.89 MCi (DOE, 1994a). The values include operational wastes deemed GTCC LLW stored onsite by the 109 operational commercial nuclear reactors, as well as GTCC LLW from the 12 commercial reactors that had been shut down by 1993.

DOE/LLW-114 analyzed three decommissioning scenarios (identified as "low", "base", and "high") for the 109 operating commercial reactors. For the "base case" scenario (37% of plants with 20 year license extensions, 25% early shutdown, and 38% average 40 year operation), by 2035 the GTCC LLW from nuclear utilities was estimated to be 937 m^3 for the ACA volume with an activity of 35.5 MCi. By 2055, the base case was estimated to be 1,347 m^3 for the ACA volume with an activity of 88.4 MCi (DOE, 1994a).

[1] Concentration averaging is done by averaging the radionuclides in the waste over the volume or mass of the container (DOE, 1994a). Note: The 1995 NRC "Branch Technical Position on Concentration Averaging" is used as the basis for concentration averaging in this report (NRC, 1995).

2.3. CURRENT STUDY

As of 2007, there were 104[2] reactors in commercial operation, and 18 decommissioned reactors. The operational inventory includes 35 BWRs and 69 PWRs. The decommissioned inventory includes 8 BWRs and 10 PWRs. Figure 2.3 shows the location of these reactors. Estimates of the volumes of GTCC LLW in the current study used scaling factors based on detailed NRC analyses of the decommissioning of two reference reactors.



Note: There are no commercial reactors in Alaska or Hawaii. Calculated data as of 12/00.

Figure 2.3. Location of 104 U.S. Nuclear Reactors (NRC, 2003).

2.3.1. METHODOLOGY

Several NRC and DOE reports rely on GTCC LLW estimates originally developed in two NRC documents: 1) "Technology, Safety, and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station" (NUREG/CR-0130) (NRC, 1978), and 2) "Technology, Safety, and Costs of Decommissioning a Reference Boiling Water Reactor Power Station" (NUREG/CR-0672) (NRC, 1980). Both of these documents were updated in 1995 (as NUREG/CR-5884 [NRC, 1995a] and NUREG/CR-6174 [NRC, 1995b], respectively). NUREG/CR-5884 [Vol.1, Section 3.6 (p. 3.60)] estimates 386 ft^3 or 11 m^3 of GTCC LLW for the reference PWR, and NUREG-/CR-6174 [Vol. 1, Section 3.6 (p. 3.40)] estimates 244 ft^3 or 6.90 m^3 of GTCC LLW for the reference BWR.

An appendix to the DOE document, "Integrated Data Base Report – 1994: U.S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics," Rev. 11 (DOE/RW-006) (DOE, 1995), established scaling factors from the reference reactor estimates to scale the volumes and activities of GTCC LLW resulting from the

[2] Since 1993, six nuclear reactors have shut down (Big Rock Point, Millstone 1, Haddam Neck, Maine Yankee, Zion 1, and Zion 2), and one, Watts Bar 1, started operation.

decommissioning of BWRs and PWRs to reactor power capacities, as shown below in Table 2.1.

Table 2.1. DOE/RW-006 Estimating Factors

Reactor Type	GTCC LLW Waste Volume Estimating Factor (m^3/MW(e))	GTCC LLW Activity Estimating Factor (Ci/MW(e))
BWR	5.93×10^{-3}	$5.45 \times 10^{+3}$
PWR	9.36×10^{-3}	$4.07 \times 10^{+3}$

These factors are also derived from the earlier NRC reference reactor decommissioning analyses, NUREG/CR-5884 (NRC, 1995a) and NUREG/CR-6174 (NRC, 1995b).

For the current study, an attempt was made to reproduce the reference reactor analysis, which resulted in slightly different scaling factors (6.03×10^{-3} and 9.40×10^{-3} m^3/MW(e) GTCC LLW waste volume estimating factors, and $5.97 \times 10^{+3}$ and $3.65 \times 10^{+3}$ Ci/MW(e) GTCC LLW activity estimating factors for BWRs and PWRs, respectively), which were used for the analysis. For example, the GTCC LLW waste volume estimated for the Columbia Generating Station 1,155 MW(e) plant selected as the reference BWR in the above reference would be 5.965×10^{-3} m^3/MW(e) * $1.155 \times 10^{+3}$ MW(e) = 6.89 m^3. Applying these estimating factors (given as GTCC LLW volume and activity per megawatt-electric [MW(e)]) to the known power capacity of the 2007 operating reactor fleet of 104 reactors leads to an estimated projected total volume upon decommissioning of 813 m^3 of GTCC LLW and a total activity of 438 MCi. Using these same factors for 16 decommissioned reactors as of 2007 leads to an estimated stored volume of 58 m^3 and activity of 27 MCi, yielding a total (stored plus projected) volume of 871 m^3 and activity of 465 MCi.

Two reactors, Shoreham and Trojan, were decommissioned without generating any GTCC LLW. The Shoreham reactor, a small BWR, was never operational and it is assumed that it did not generate any GTCC LLW. The Trojan reactor, similar to a large Westinghouse PWR, was uniquely decommissioned with no GTCC LLW

GTCC LLW volumes and activities estimated using this methodology appear reasonable in comparison with known volumes and activities from the few commercial reactors that have been decommissioned and for which data is available. Some detailed information is available on the actual packaging of the Connecticut Yankee (2007) and Maine Yankee (2003), which support the observation that the method of packaging described for the reference reactors is consistent with standard practice (EPRI 2003, EPRI 2005, Niles 2006, and Niles 2007). For the Connecticut Yankee 602 MW(e) PWR, 67 FAS (Fuel Assembly Sized) canisters of 0.24m^3 (assumed) volume (i.e., 16 m^3 total) were used. Maine Yankee, a slightly larger PWR (891 MW(e)) was inferred to have used the equivalent of about 20 m^3. In comparison, the DOE/RW-006 scaling factor yields volumes of 6 and 8 m^3 under assumptions of highly efficient packaging and separation of GTCC LLW from other waste.

Stored Inventory

To estimate the stored GTCC LLW inventory, the scaling factor methodology was applied to 16 decommissioned reactors, including:

BWR: Big Rock Point, Dresden 1, General Electric VBWR, Humboldt Bay 3, La Crosse, Millstone 1, and Pathfinder

PWR: Haddam Neck, Indian Point 1, Maine Yankee, Rancho Seco, San Onofre 1, Saxton, Yankee-Rowe, Zion 1, and Zion 2.

Ten shutdown reactors were not addressed in the analysis, including the 5 DOE/AEC-owned (Bonus, Elk River, Hallam, Piqua, and Shippingport) reactors, the Fermi 1 sodium-cooled fast reactor, the Carolinas-Virginia Tube Reactor pressurized heavy water reactor, the Ft. St. Vrain and Peach Bottom 1 high-temperature gas reactors, and Three Mile Island 2. These reactors were not included in the inventory because no information on GTCC LLW from these reactors was available. The exclusion of these reactors has minimal impact on the GTCC LLW estimates given in this report.

This evaluation resulted in an estimate of the existing volume GTCC LLW inventory of 7.1 m^3 from BWRs and 50.6 m^3 from PWRs for a total of 58 m^3. The activity estimate at shutdown for the existing inventory using this method resulted in 7.0 MCi for BWRs and 19.7 MCi for PWRs for a total of 26.7 MCi. Allowing decay from shutdown to 2007 lowers the total activity to 3.5 MCi.

Projected Inventory

Following the same methodology, it is estimated nuclear utilities will produce 813 m^3 of GTCC LLW with an activity of 438 MCi by 2062. This includes 203 m^3 from the BWRs with an activity estimate of 200 MCi and 610 m^3 from the PWRs with an activity estimate of 238 MCi. The total projected activity is lowered to 106 MCi if decayed for a minimum of six years prior to disposal.

2.3.2. ASSUMPTIONS AND UNCERTAINTIES

The methodology uses rough scaling factors for estimating volume and activity of GTCC LLW produced as a function of net capacity, but does not account for other design and operational parameters, operational life, or decommissioning techniques.

As described above, the study did not consider ten shutdown reactors, which is not expected to significantly impact the overall results. It was also assumed that no GTCC LLW was generated by the decommissioning of the Shoreham reactor, which was never operational, or the Trojan reactor, which was uniquely decommissioned as Class C LLW.

The volume of GTCC LLW generated, but not the activity content, is essentially independent of reactor operational time. During the time a reactor operates, short-lived radionuclides reach an equilibrium concentration, but longer-lived radionuclides continue to slowly increase in concentration. The results shown in this study, however, are based on assumed reactor lifetimes. Alternative decommissioning practices (e.g., stabilization in place or concentration averaging over the entire reactor vessel as was done in the case of the Trojan plant) were not applied in the current study. Early license termination for a few plants could also affect the timing of waste availability, and certainly, the number of effective full power years (EFPY) of an operating nuclear reactor affects the inventory of GTCC LLW generated.

2.3.3. SUMMARY RESULTS OF THE CURRENT STUDY

Total Estimated Inventory

The results for both the estimated stored and projected GTCC LLW inventory for are summarized in Table 2.2.

Table 2.2. Summary of Stored and Projected GTCC LLW Inventories (activated metals)

Reactor Type	***Volume (m^3)***	***Activity (MCi)***	
		at shutdown	**after 6-yr cooling**
BWR Stored	7	7	0.5
PWR Stored	51	20	3.0
Total Stored	58	27	3.5
BWR Projected	203	200	30.7
PWR Projected	610	238	75.6
Total Projected	813	438	106
TOTAL	871	465	110

Figures 2.4-2.7 illustrate the annual and cumulative volumes and activities upon availability for the current operational fleet plotted against the availability dates (40 year original license, 20 year license extension, and six year cooling period assumed before the waste becomes available for disposal). The Atomic Energy Act authorizes the NRC to initially issue operating licenses for a 40-year period and allows license renewal for another 20 years. To date, license extensions have been requested and approved for 40% of the operating reactor fleet (NRC, 2006). GTCC LLW activities are approximate and represent the activity at shutdown assuming 30 EFPY (DOE, 1995).

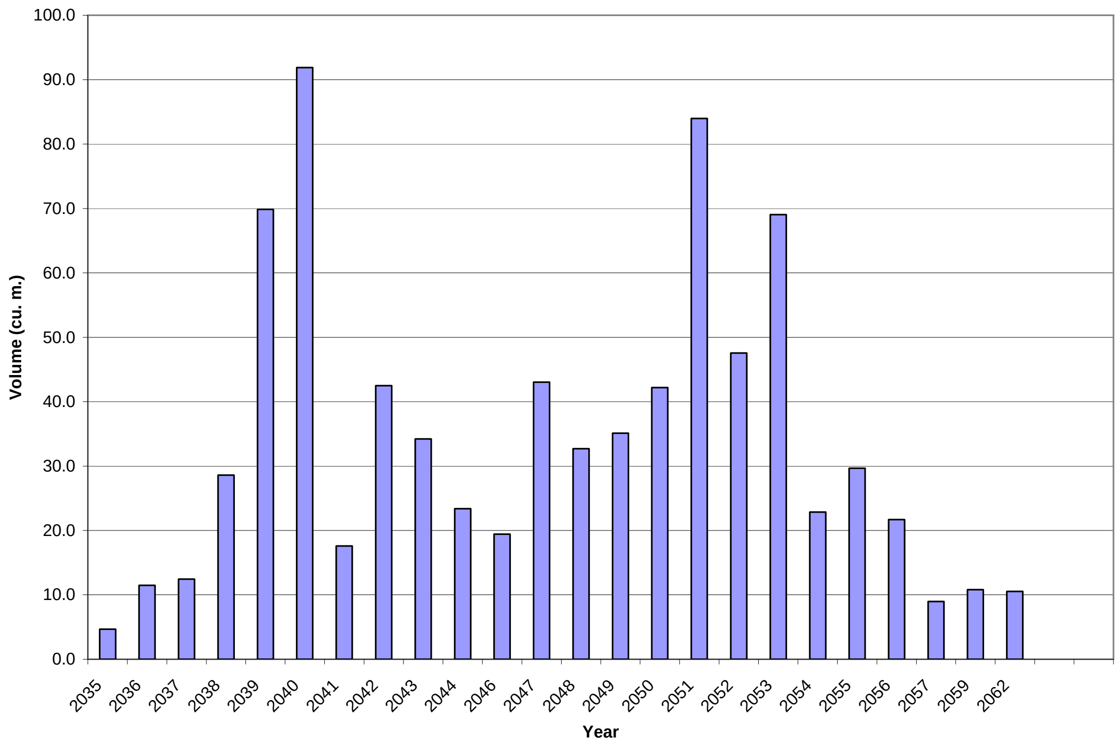


Figure 2.4. Projected Annual GTCC LLW Volumes Based on a 60 Year Plant Life

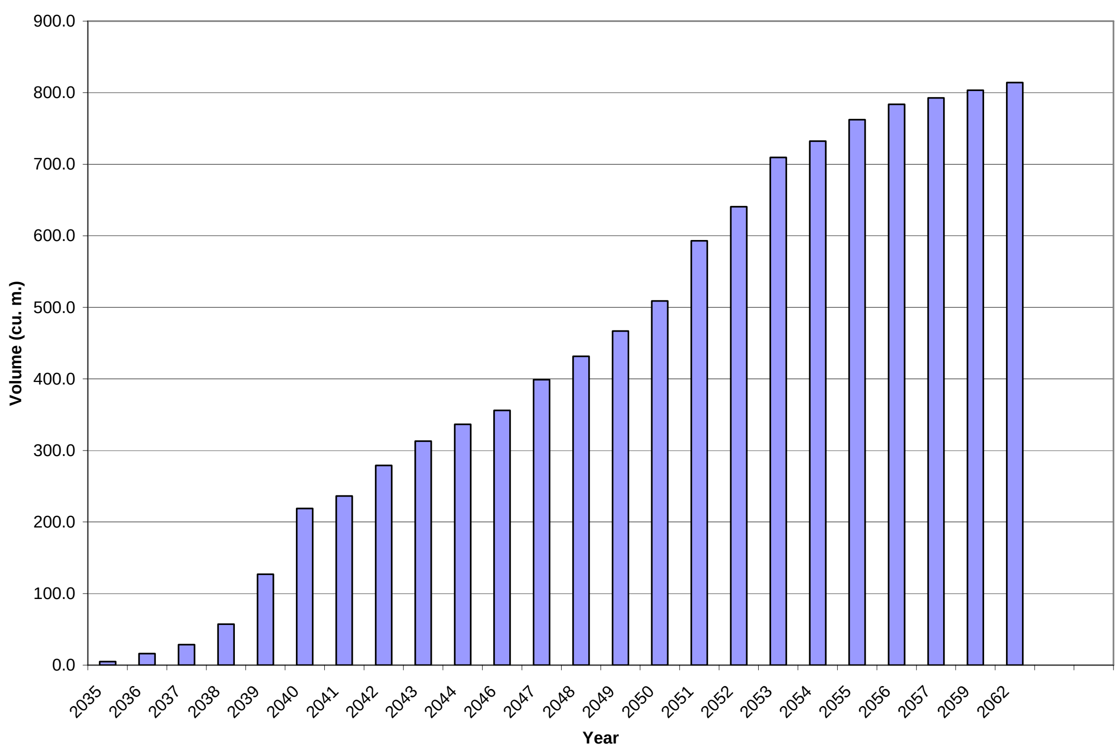


Figure 2.5. Cumulative GTCC LLW Volumes Based on a 60-Year Plant Life (including pre-existing wastes)

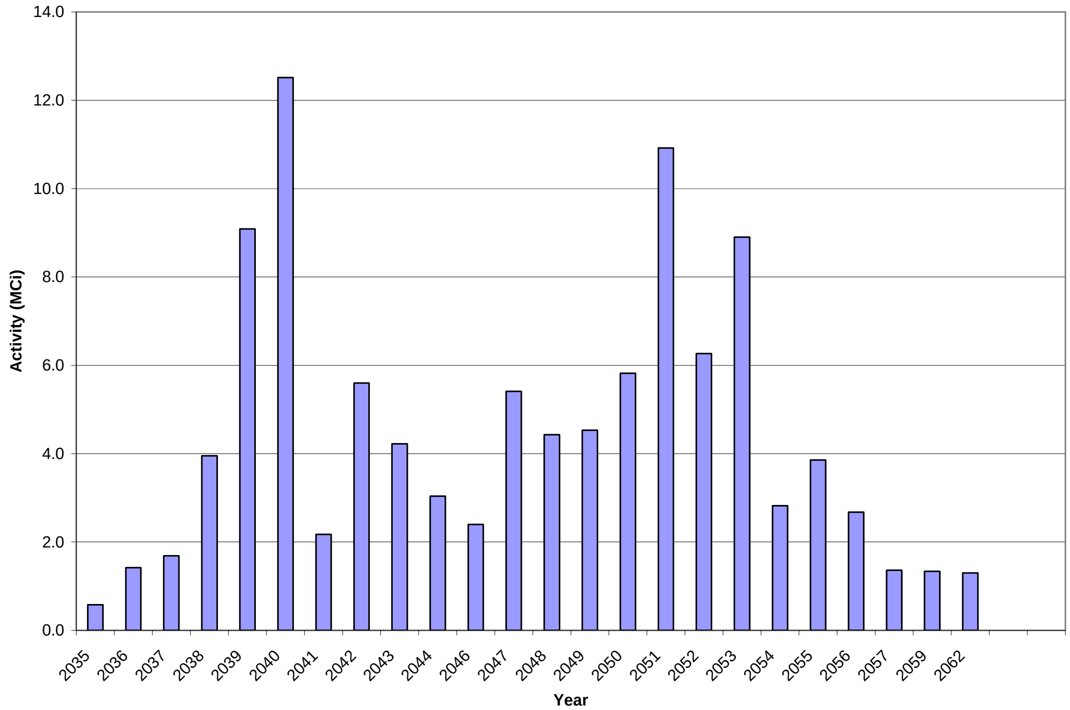


Figure 2.6. Projected GTCC LLW Activities Based on a 60-Year Plant Life

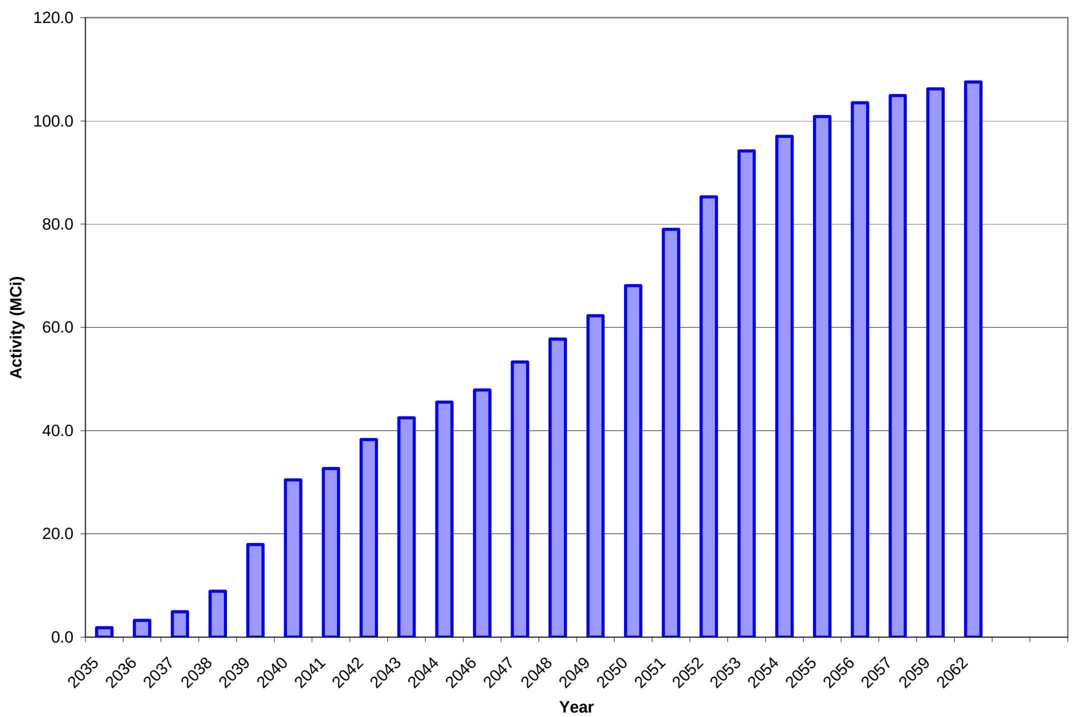


Figure 2.7. Cumulative GTCC LLW Activity at End of 60-Year Plant Life (including pre-existing wastes)

3. SEALED SOURCES

3.1. WASTE DESCRIPTION

Sealed sources are typically small, high-activity radioactive materials encapsulated in closed metallic containers (DOE, 1994b). They are used for a variety of purposes, including irradiating medical products for sterilization, detecting flaws and failures in pipelines and other metal welds, calculating moisture and density content in soil and other materials, and diagnosing and treating illnesses (see Figure 3.1) (GAO, 2003). A September 2005 Government Accountability Office (GAO) report includes an appendix presenting the variability of radioactive sealed sources used in devices and their potential U.S NRC waste classifications (GAO, 2005).

Figure 3.1. Typical Sealed Source
Source capsule (ca. 1950s) used in medical teletherapy units to treat cancer. The radioactive source (lower right) is contained in a stainless steel cylinder approximately 1-inch in diameter.

There are likely several million sealed sources worldwide. A 1998 article in the Health Physics journal entitled "Radioactive materials in recycled metals – an update" estimated two million sealed sources in existence in the United States alone (Lubenau et al., 1998). However, most of these sealed sources are small and of too low an activity to be considered potential GTCC LLW. Because no governmental agency currently tracks the number of sealed sources in existence, it is extremely difficult for DOE to estimate the number of sources that will require disposal in the future. Under the current regulatory structure, NRC authorizes the uses and maximum quantities allowed for each licensee, but does not currently track all sealed sources that could become GTCC LLW when no longer needed by the licensee.

This chapter discusses both GTCC LLW sealed sources and DOE GTCC-like sealed sources. Possession of sealed sources by commercial firms is licensed by NRC or an Agreement State. DOE sealed sources are managed in accordance with DOE policy and procedure.

Through the OSRP, a component of the DOE Global Threat Reduction Initiative, DOE recovers sealed sources that are in the possession of domestic licensees in situations that represent threats to public health and safety or national security. DOE also recovers sealed sources of U.S. origin from entities outside the U.S. when these sources present national security threats.

In addition, DOE and NRC consult and coordinate pursuant to a memorandum of understanding allowing for information exchanges and related activities that assist in prioritizing, recovering, and storing sealed sources. In situations that are outside the normal operation of the OSRP, NRC may request that DOE take certain actions to mitigate or eliminate threats to public health and safety or national security, after other reasonable alternatives have been explored. Figure 3.2 shows a storage facility at the Los Alamos National Laboratory (LANL) for sources recovered by the OSRP.

The sealed sources recovered by OSRP in response to public health and safety and security threats are primarily GTCC LLW sealed sources in possession of domestic licensees. When OSRP recovers any sealed sources, they are considered DOE sealed sources. If they meet the waste acceptance criteria of DOE disposal facilities, they may be disposed of at those facilities.

Figure 3.2. Waste Storage Facility.
Located at LANL for sealed sources recovered by the OSRP (OSRP, 2005).

The inventory of DOE GTCC-like sealed sources in storage includes only those sealed sources that may not have an identified disposal path. The projected inventory for DOE GTCC-like sealed sources does not include sources that may, in the future, be recovered by OSRP. Any such sources are the responsibility of the licensees until the point at which they are recovered by OSRP and, therefore, are included in the projected inventory for commercial GTCC sealed sources.

3.2. SUMMARY OF PREVIOUS STUDIES

Two previous studies examined GTCC LLW sealed sources in detail: DOE LLW-163, “Characterization of Greater-Than-Class C Sealed Sources” (DOE, 1994b) and DOE/LLW-114, “Greater-Than-Class C Low-Level Radioactive Waste Characterization: Estimated Volumes, Radionuclide Activities, and Other Characteristics” (DOE, 1994a). DOE/LLW-163 was the initial study that examined all sealed sources and identified those with the potential to become GTCC LLW based on the radionuclide concentration of individual sealed sources. DOE/LLW-114 used the data from DOE/LLW-163 to estimate the inventory and activity of sealed sources that would be GTCC LLW in 1993 and 2035. It was assumed for the base case DOE/LLW-114 study that sources were removed from their devices, loaded into shielded 55-gallon drums, and packaged by device type and primary radionuclide. A maximum of 500 curies of alpha/beta activity and low activity gamma sources (less than 30 millicuries) was assumed for each drum. Only five gamma and neutron sources with an activity greater than 30 millicuries each were packaged in each drum, and the total activity was averaged over the volume of a drum.

Table 3.1 summarizes the base case estimates for the 1993 and 2035 inventories presented in DOE/LLW-114 (DOE, 1994a).

Table 3.1. Total GTCC LLW Base Case Sealed Source Inventory for 1993 and Projected for 2035 (DOE, 1994a).

Summary Inventory Estimates	1993	2035
Number of Sources	10,134	98,198
Activity (MCi)	0.355	1.58
Unpackaged Volume (m^3)	0.13	1.00
Disposal Packaged Volume (m^3)	38	242

3.3. CURRENT STUDY

3.3.1. METHODOLOGY

Due to the lack of a national database that specifically tracks the number of GTCC LLW sealed sources[3], there continues to be a high level of uncertainty in the estimates of the GTCC LLW sealed source inventory. The major objective of the current study is to develop updated GTCC LLW inventory estimates, including inventories for an additional waste stream that was not included in the DOE/LLW-114 study. The additional waste stream is the DOE GTCC-like waste inventory of DOE sealed sources similar to GTCC LLW that may not have a path to disposal.

The sealed source inventory estimates developed for this study are based on the following information:

- NRC Interim Sealed Source Database,
- DOE Radiological Source Registry and Tracking (RSRT) Database, and
- Forecasts of projected GTCC LLW sealed sources, based on the DOE OSRP source recovery rate.

The stored inventory of DOE GTCC-like sealed sources was based on information from the RSRT database for GTCC-like sealed sources not in active use and which do not have a known disposal path. The projected GTCC LLW sealed source inventory was based on estimates of sources from the NRC Interim Sealed Source database and forecasts using the OSRP recovery rate. In addition, the six largest sealed source manufacturers were contacted for information on future sealed source production.

[3] In 2006 NRC finalized plans for a National Source Tracking System (NSTS) for use in tracking certain sealed sources, including IAEA Category 1 and 2 sources by the U.S. Government and 34 Agreement States. The NRC published its final rule establishing the requirements for the NSTS on November 8, 2006 (FR 71 65686, Nov 8, 2006).

However, because production information is proprietary, none of the identified sealed source manufacturers were willing to provide this information.

The NRC Interim Sealed Source Database contains information on commercial sealed sources compiled in response to the recommendations of the International Atomic Energy Agency (IAEA) for sources requiring higher security and control, some of which are likely to become GTCC LLW. Because the NRC Interim Sealed Source Database was focused on identifying higher activity sources, a number of sources of lower activity (e.g., IAEA Category 3 sources (IAEA, 2003)) that may result in GTCC LLW, long-lived radionuclide sources in particular, will not have been captured in that database. For this reason and to provide a conservative estimate of projected inventories, this report bases the GTCC LLW sealed source estimates for long-lived transuranic nuclides on the experience of the OSRP in recovering sealed sources, as described below. Recent information from the NRC database, which was updated in 2006, provides source activities as of January 1, 2007. The NRC database was used for the projected inventory of Cs-137 sources (and one Cm-244 source), which are assumed will become GTCC LLW by 2035.

The RSRT Database contains information on DOE-owned sealed sources, including those that may become DOE GTCC-like waste. The RSRT Database includes all DOE sealed sources accountable under Title 10 of the Code of Federal Regulations Part 835 (10 CFR Part 835), which establishes controls at very low activity thresholds for all radionuclides. Activities of sources from the 2005 DOE database were decayed to January 1, 2007 for consistency with the NRC data.

The OSRP forecasts a total annual recovery of approximately 2,250 sealed sources per year through the year 2011, based on average annual rates of recovery from 1999 through 2006. (OSRP, 2007) Most of these sources contain the long-lived transuranic nuclides Pu-238, Pu-239, or Am-241, and are likely not captured in the NRC Interim Sealed Source Database because they are smaller sources (e.g., IAEA Category 3). Approximately 2,000 sources are registered for recovery each year. Most of the sources registered for recovery are low in activity, but may be classified as GTCC LLW prior to their recovery due to their concentration of long-lived transuranic nuclides.

Although OSRP only forecasts the annual recovery rate through the year 2011, to develop an upper bounding estimate for the purposes of the GTCC EIS analysis and because of the lack of information on the inventory of lower activity sealed sources that may become GTCC LLW, this report uses the OSRP forecast rate to estimate the projected inventory of GTCC LLW sources containing Pu-238, Pu-239, and Am-241 through 2035. Of the 2,250 OSRP annual forecast rate, 2,020 sources are estimated to contain Pu-238, Pu-239, and Am-241. For conservatism, this report assumes that all Pu-238, Pu-239, and Am-241 sources would be GTCC LLW prior to recovery. Applying the forecast rate for Pu-238, Pu-239, and Am-241 sources through the year 2035 results in a projected GTCC LLW inventory of 54,532 sources containing those radionuclides.

Using Class C radionuclide-specific concentration limits from Tables 1 and 2 in 10 CFR 61.55, the sealed source datasets from the NRC Interim Sealed Source Database and the DOE RSRT Database were refined by removing sealed sources not containing the radionuclides specified in Tables 1 and 2. Sources with a definite disposal path were also removed. The NRC and DOE datasets were further reduced by removing sources that would not exceed Class C concentration limits if the activity of an individual source was averaged over the volume of a 55-gallon drum (see Table 3.2). Concentration averaging in this manner is described in Appendix C of NRC's "Branch Technical Position on Concentration Averaging and Encapsulation," which states that "a maximum solidified volume or mass for encapsulation of a single discrete source (from which concentrations are determined) should be 0.2 cubic meters or 500 kilograms (typical 55-gallon drum)" (NRC, 1995). Pu-238, Pu-239, and Am-241 sources added to the inventory using the OSRP recovery rate were assumed to exceed Class C concentration averaging limits.

Table 3.2. Maximum Class C Concentration Limits from 10 CFR 61.55 and Calculated Maximum Class C Activity Limits per Drum.

Radionuclide	Maximum Class C Concentration	Maximum Class C Activity (Ci per 55-gal Drum)
I-129	0.08 Ci/m^3	0.016
Nb-94 in activated metal	0.2 Ci/m^3	0.04
Tc-99	3 Ci/m^3	0.6
C-14	8 Ci/m^3	1.6
C-14 in activated metal	80 Ci/m^3	16
Ni-59 in activated metal	220 Ci/m^3	44
Ni-63	700 Ci/m^3	140
Cs-137	4,600 Ci/m^3	30[a]
Ni-63 in activated metal	7,000 Ci/m^3	1,400
Sr-90	7,000 Ci/m^3	1,400
Alpha-emitting transuranics with half-lives greater than five years[b]	100 nCi/g	0.05
Pu-241	3,500 nCi/g	1.75
Cm-242	20,000 nCi/g	10

[a]*Although the maximum Class C concentration for Cs-137 is 4,600 Ci/m^3, because it is a strong gamma emitter, only 30 Ci can be packaged in a 55-gallon drum under the NRC guidance on concentration averaging (NRC, 1995).*
[b]*These radionuclides include Am-241, Am-243, Bk-247, Cf-249, Cf-250, Cf-251, Cm-243, Cm-244, Cm-245, Cm-246, Cm-247, Cm-248, Cm-250, Np-237, Pu-238, Pu-239, Pu-240, Pu-242, and Pu-244.*

To develop more realistic volume estimates, the sources were conceptually packaged into 55-gallon drums by radionuclide based on packaging factor limits from the OSRP, which are summarized in Table 3.3.

Table 3.3. OSRP Packaging Limits

Name	Basis of Packaging Limit	Application
DOT A1 Limit	The maximum activity of special form Class 7 (radioactive) material permitted in a Type A package (49 CFR 173.403). Special form materials include sealed sources. A shielded 55-gallon drum is a Type A package.	^{240}Pu: 270 Ci/drum ^{243}Am:140 Ci/drum ^{244}Cm: 540 Ci/drum
Fissile Gram Limit	An isotopic mass of radionuclide normalized to ^{239}Pu (WIPP, 2006).	^{239}Pu/Be neutron sources: 12.4 Ci/drum
^{239}Pu Equivalent Limit	An equivalent radiotoxic hazard of a radionuclide normalized to ^{239}Pu. As a common component of most defense transuranic waste, ^{239}Pu was selected as the radionuclide to which the radiotoxic hazard of other transuranic radionuclides could be indexed (WIPP, 2006).	^{238}Pu: 88 Ci/drum ^{241}Am: 80 Ci/drum
Contact Dose Limit	The limiting surface dose rate of 200 mrem/hr for contact handling (WIPP, 2006).	100 mrem/hr ALARA limit estimated at 35 Ci/drum for neutron sources containing ^{241}Am or ^{238}Pu

Cs-137 sources, which are strong gamma emitters, were assumed to be disposed of individually as shielded devices, using a representative volume of 0.71 m^3 for each.

3.3.2. ASSUMPTIONS

No allowance has been made for imports of isotopes into the U.S. from countries such as Russia and Canada, which are used to produce sealed sources. Recycling was not taken into account for inventory projections. Additionally, in projecting future GTCC LLW and DOE GTCC-like sealed source volumes, manufacturing trends were not considered because sealed source manufacturers did not provide data on future production rates to use as a basis for generating reasonable projections.

The projected Pu-238, Pu-239, and Am-241 GTCC LLW inventories assumed a constant generation rate of approximately 2,020 sources per year through the year 2035, based on an application of the OSRP recovery rate.

For the DOE sealed sources inventory, it was assumed that sealed sources listed as “active” in the RSRT Database were currently being used and were included in the projected inventory; otherwise, they were assumed to be waste and were included in the stored inventory.

3.4. SEALED SOURCE INVENTORIES

Stored Inventory of GTCC LLW Sealed Sources

For purposes of this report, the inventory of stored GTCC LLW was taken to be zero due to the lack of information on the current status (i.e., whether they were waste, in storage, in use, etc.) of sources in the NRC-licensed sector. Therefore, such sources are included in the projected GTCC LLW inventory.

Stored Inventory of DOE GTCC-like Sealed Sources

Following the methodology described in Section 3.3.1, a total of 25 DOE GTCC-like sealed sources with a total activity of 13 kCi and a total conceptually packaged volume of 8.7 m^3 were identified in the RSRT dataset as not in active use and did not have an identified path to disposal, and therefore were included in the DOE stored inventory. Table 3.4 below shows more information on the inventory of stored DOE sealed sources.

Table 3.4. Stored DOE GTCC-like Sealed Source Inventory.

Waste	No. of 55-gallon Drums	No. of Sources	Activity (Ci)[a]	Volume (m^3)
Transuranic radionuclides				
Cm-244	1	13	$9.85\times10^{+0}$	0.2
Non-transuranic radionuclides				
Cs-137[b]	N/A	12	$1.29\times10^{+4}$	8.5
Total	N/A	25	$1.29\times10^{+4}$	8.7

[a]*Activities are given as of January 1, 2007.*
[b] *These high activity Cs-137 irradiator sources exceed 55-gallon drum packaging limits, and were assumed to be disposed as a unit with their shielding devices; a representative device volume of 0.71 m^3 was used to estimate volume.*

Projected Inventory for GTCC LLW Sealed Sources

The NRC Interim Sealed Source Database dataset provided to DOE included information on 17,389 sealed sources. After reducing the dataset to GTCC LLW sources, 1,787 sources remained, 1,435 of which were Cs-137 sources included in the projected 2035 inventory and assumed to be packaged individually for disposal. In addition, the NRC data identified one Cm-244 source, which was assumed packaged in a single 55-gallon drum. As described above, the NRC database does not capture lower activity, long-lived sources for the transuranic nuclides such as Pu-238, Pu-239, and Am-241. An estimate of the projected inventory of these sources was based on the OSRP recovery rate. For conservatism, packaging limits for neutron sources from Table 3.3 were used to estimate volumes for these sources. Refer to Table 3.5 for more information on the projected inventory for GTCC LLW sealed sources.

Table 3.5. Projected Inventory of GTCC Sealed Sources.

Waste	No. of 55-gallon Drums	No. of Sources	Activity (Ci)[a]	Volume (m^3)
Transuranic radionuclides				
Am-241	1,593	44,079	$5.53 \times 10^{+4}$	331
Cm-244	1	1	$2.20 \times 10^{+1}$	0.2
Pu-238	1,269	8,634	$4.38 \times 10^{+4}$	264
Pu-239	270	1,819	$3.04 \times 10^{+3}$	56
Subtotal	3,133	54,533	$1.02 \times 10^{+5}$	652
Non-transuranic radionuclides				
Cs-137[b]	N/A	1,435	$2.34 \times 10^{+6}$	1,019
Subtotal	N/A	1,435	$2.34 \times 10^{+6}$	1,019
Total	N/A	55,968	$2.44 \times 10^{+6}$	1,671

N/A = Not Applicable.
[a]Activities are assumed current as of January 1, 2007.
[b] These high activity Cs-137 irradiator sources exceed 55-gallon drum packaging limits, and were assumed to be disposed as a unit with their shielding devices; a representative device volume of 0.71 m^3 was used to estimate volume.

Projected Inventory for DOE GTCC-like Sealed Sources

A total of 43 DOE GTCC-like sealed sources with a total activity of 30.3 kCi and a total conceptually packaged volume of 24.7 m^3 were identified in the RSRT dataset as projected DOE GTCC-like sealed sources. Table 3.6 shows more information on the projected DOE sealed source inventory.

Table 3.6. Projected (2035) Inventory of DOE GTCC-like Packaged Sealed Sources.

Waste	No. of 55-gallon Drums	No. of sources	Activity (Ci)[a]	Volume (m^3)
Transuranic radionuclides				
Am-243	1	1	3.52×10^{-1}	0.2
Cm-244	1	7	$4.83 \times 10^{+1}$	0.2
Pu-240	1	1	$2.21 \times 10^{+1}$	0.2
Subtotal	3	9	$7.08 \times 10^{+1}$	0.6
Non-transuranic radionuclides				
Cs-137[a]	N/A	34	$3.03 \times 10^{+4}$	24.1
Subtotal	N/A	34	$3.03 \times 10^{+4}$	24.1
Total	N/A	43	$3.03 \times 10^{+4}$	24.7

[a]Activities are given as of January 1, 2007.
[b]These high activity Cs-137 irradiator sources exceed 55-gallon drum packaging limits, and were assumed to be disposed as a unit with their shielding devices; a representative device volume of 0.71 m^3 was used to estimate volume.

3.5. SUMMARY

As summarized in Table 3.7, the inventory of sealed sources (both GTCC LLW and DOE GTCC-like) in storage is estimated to have a total packaged volume of approximately 9 m^3 and an activity (as of January 1, 2007) of 12.9 kCi. The projected inventory is estimated to have a total packaged volume of 1,705 m^3 and an activity (as of January 1, 2007) of 2.48 MCi.

Table 3.7. Sealed Source Summary Inventory

	Volume (m^3)			Activity (Ci)*		
	GTCC LLW	**DOE GTCC-Like**	**Subtotal**	**GTCC LLW**	**DOE GTCC-like**	**Subtotal**
Stored	0	9	9	0	$1.29x10^{+4}$	$1.29x10^{+4}$
Projected	1,671	25	1,696	$2.44x10^{+6}$	$3.03x10^{+4}$	$2.47x10^{+6}$
Total	1,671	34	1,705	$2.44x10^{+6}$	$4.32x10^{+4}$	$2.48x10^{+6}$

** Activities as of January 1, 2007.*

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4. OTHER GENERATORS

4.1. WASTE DESCRIPTION

The "Other Generators" category of GTCC LLW includes all GTCC LLW that is not generated by commercial nuclear utilities and sealed source licensees. It does not include DOE GTCC-like waste, which is discussed in Chapter 5. Examples of other generators include industrial research and development firms, fuel fabrication and irradiation research (burnup) laboratories, research nuclear reactors, and sealed source manufacturers, including sealed source waste, gloveboxes, etc. (DOE, 1994a).

4.2. SUMMARY OF PREVIOUS STUDIES

In 1993, the GTCC LLW Management Program at the Idaho National Laboratory (INL)[4] initiated a program to identify the volume, radionuclides, and radionuclide activity of GTCC LLW produced by other generators, the results of which are presented in DOE (1994a).

Ninety potential generators were identified in the DOE (1994a) study; thirteen were generating GTCC LLW, and seven planned to continue generating GTCC LLW beyond 1993. The GTCC LLW generators were grouped into the following business types: C-14 users, industrial research and development laboratories, irradiation laboratories, fuel fabricators, university reactors, sealed source manufacturers, and non-medical academic institutions. Total volumes and activities, including projections to 2035, were estimated and are shown in Table 4.1.

Table 4.1. Estimated Inventory of Other Generators GTCC LLW (DOE, 1994a).

Year	Volume (m^3)	Activity (Ci)
1993	74.2	$2.738 \times 10^{+3}$
2035	465	$1.268 \times 10^{+4}$

4.3. CURRENT STUDY

Potential other generators in the current study were identified from a variety of available sources including:

- DOE Manifest Information Management System (MIMS) and other databases,
- Barnwell Approved Waste Brokers list,
- Washington State Permit-holders list, and
- Potential other generators identified in DOE (1994a)

[4] Formerly the Idaho National Engineering and Environmental Laboratory

Potential other generators were contacted to obtain information on waste volumes for their stored and projected inventories. The method is outlined in Figure 4.1.

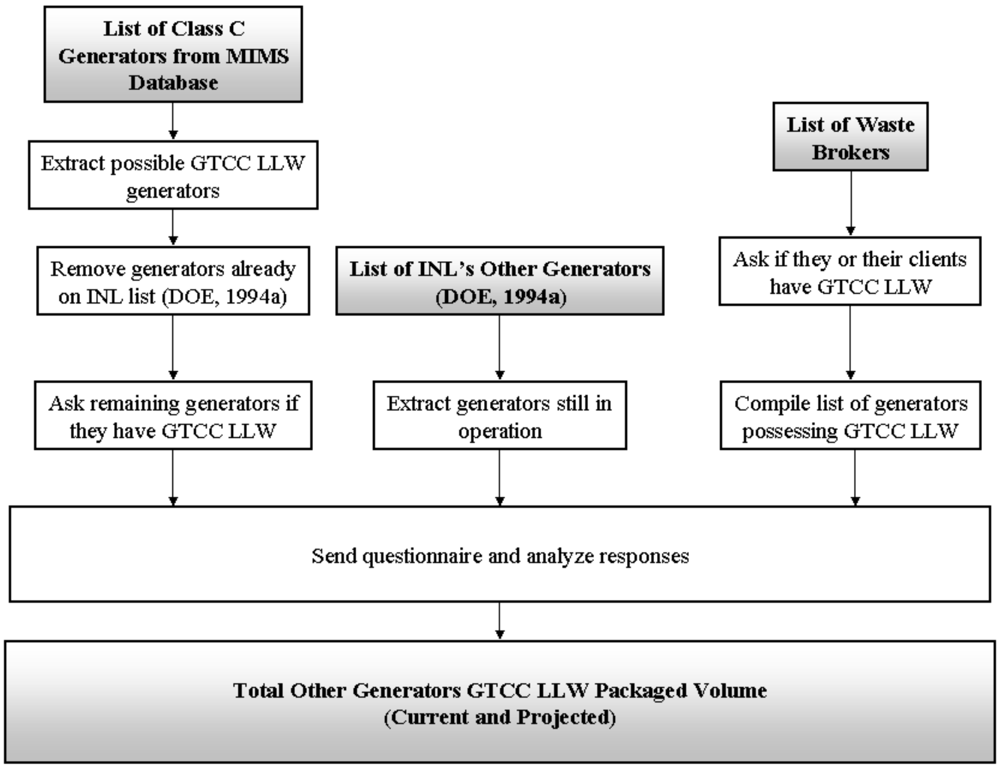

Figure 4.1. Method Used to Identify Other Generators

4.3.1. ESTIMATING THE STORED INVENTORY

The DOE Office of Environmental Management (DOE/EM) contacted INL in June 2005 to obtain the names of the thirteen other generators identified in reference DOE 1994a. These generators were then contacted to determine if they still possessed GTCC LLW. DOE also reviewed the MIMS Database for information on Class C LLW generators. The MIMS Database, created in 1996, categorizes LLW shipments that have been sent to operating LLW disposal sites. A waste generators list was compiled using the MIMS Database by identifying registered shipments of Class C waste to the Barnwell LLW disposal facility. This approach assumed that generators of waste shipments with high activities and/or large volumes of Class C waste could be potential GTCC LLW generators.

Eleven waste brokers were identified from the Barnwell Approved Waste Brokers list, and sixteen waste brokers were identified from the Washington State Permit-holders list obtained from US Ecology, Inc. Waste brokers are companies that are called upon by waste generators to remove waste from their site, and typically either recycle this waste or send it to a disposal site or a storage site. Contact information for seven other waste brokers was acquired using the internet.

Waste brokers were contacted and asked if they had any GTCC LLW or if they could identify clients that were producing GTCC LLW. A list of potential GTCC LLW generators was prepared and each generator was contacted to determine if they possessed any GTCC LLW. Several waste brokers were contacted and none reported having GTCC LLW, nor could they identify any customers that had GTCC LLW. Other waste brokers reported being contacted by customers who wished to dispose of GTCC LLW, but no records were available.

Table 4.2 describes the types of GTCC LLW produced by other generators.

Table 4.2. Description of GTCC LLW Produced by Other Generators.

Generator ID	Business Type	Waste Description	Note
1	Industrial research and development firm	Sealed sources, contaminated solids	No future GTCC generation anticipated
2	Site remediation waste from a sealed source manufacturer in Harris County, Texas	Contaminated debris from hot cell and glove box	May generate additional GTCC waste prior to 2035

4.3.2. ASSUMPTIONS

- The current study assumed that no new other generators will begin to generate GTCC LLW by 2035.

4.3.3. RESULTS AND UNCERTAINTIES

<u>Stored Inventory</u>

Table 4.3 summarizes the inventory of stored GTCC LLW from other generators.

Table 4.3. Stored Inventory of GTCC LLW from Other Generators.

Generator ID	Isotope	Number of Drums	Activity (Ci)	Volume (m^3)	Details
1	Misc TRU[a]	163	7,570	33[b]	Miscellaneous TRU
2	Am-241 Cs-137	N/A [8-120 DOT Liner]	0.05 0.1	7	Sealed source waste
2	Am-241 Cs-137 Co-60	N/A [8-120 DOT Liner]	0.075 0.1	32	Am-241 and Beryllium contaminated dry active waste
2	Am-241 Cs-137	N/A [8-120 DOT Liner]	5 8	4	Radioactively contaminated lead waste (mixed waste)
	Total	163	7,583	76	

[a] No further details on isotope or activity were available for this waste stream as it is impractical to remove the waste from its storage facility for characterization; average RH-TRU concentration assumed.
[b] Assumes 55-gallon drum equivalents.

Projected Inventory

Table 4.4 shows the projected 2035 GTCC LLW inventory from other generators.

Table 4.4. Projected Inventory of GTCC LLW from Other Generators.

Generator ID	Isotope	Number of Drums	Activity (Ci)	Volume (m^3)	Details
1	Misc TRU[a]	5	229	1	Miscellaneous TRU
	Total	5	229	1	

[a] No further details on isotope or activity were available for this waste stream; average RH-TRU concentration assumed.

5. DOE GTCC-LIKE WASTE

5.1. WASTE DESCRIPTION

GTCC LLW exceeds NRC concentration limits for Class C LLW. Because DOE waste is not regulated by NRC, it is not required to use the NRC LLW classification system for LLW disposed at DOE facilities. However, DOE does generate and own waste that has similar characteristics to GTCC LLW and which may not have a path to disposal. This waste is referred to as "DOE GTCC-like waste" throughout this report.

> **DOE GTCC-like Waste**
>
> Waste generated or owned by DOE that has characteristics similar to GTCC LLW and which may not have a path to disposal. Such waste may include LLW or transuranic waste.

In the May 11, 2005, "Advance Notice of Intent to Prepare an Environmental Impact Statement for the Disposal of Greater-Than-Class-C Low-Level Radioactive Waste," DOE announced that it "plans to review its waste inventories with a view toward including those wastes with characteristics similar to GTCC LLW and which may not have a path to disposal in the scope of the EIS, as appropriate." (70 FR 24755). This chapter documents the results of DOE's inventory review of DOE GTCC-like waste. For the purposes of this inventory, DOE sealed sources are discussed in Chapter 3, Sealed Sources.

5.2. SUMMARY OF PREVIOUS STUDIES

DOE/LLW-114 did not specifically review the inventory of DOE GTCC-like waste (DOE, 1994a).

5.3. CURRENT STUDY

5.3.1. METHODOLOGY OVERVIEW

DOE databases and other documented information sources were reviewed to obtain information on DOE GTCC-like waste. In addition, DOE issued a complex-wide data call in August 2005 to obtain additional information on GTCC-like waste that was not included or sufficiently described in available databases and information sources. The data call requested information on stored and projected DOE GTCC-like waste through 2035 and beyond, if available. This data was updated in 2007.

5.3.2. ASSUMPTIONS

The following assumptions were applied in the current study:

- The August 2005 DOE data call assumes no disposal path for the reported DOE GTCC-like waste.
- Where different activities were provided for several waste components in a single reported volume, the maximum value was used for conservatism.
- In cases where activities were not available, activity values were assumed based on similar waste streams with known activities.

5.3.3. RESULTS/UNCERTAINTIES

The following lists include DOE sites with either stored DOE GTCC-like waste or DOE GTCC-like waste projected through 2035.

DOE sites with stored DOE GTCC-like waste:

- Idaho National Laboratory,
- Oak Ridge National Laboratory,
- Oak Ridge (Bechtel Jacobs-managed waste)
- BWXT-Lynchburg VA (DOE waste at commercial facility), and
- West Valley Demonstration Project

DOE sites with projected DOE GTCC-like waste through 2035 or later:

- Idaho National Laboratory,
- BWXT-Lynchburg VA (DOE waste at commercial facility)
- West Valley Demonstration Project, and
- Proposed Radioisotope Power Systems (RPS) Project

Based on responses from the DOE data call and other documented DOE information sources, the DOE GTCC-like total volume for the stored inventory is 864 m^3, not including 9 m^3 of stored sealed sources addressed in Chapter 3 (See Table 5.1.). Although activities are uncertain, the West Valley wastes dominate the activity and are estimated as having an activity of approximately 11 MCi.

The total volume for the projected inventory of DOE GTCC-like waste is 2,050 m^3, not including 25 m^3 of projected sealed sources addressed in Chapter 3 (See Table 5.2). This includes 1,260 m^3 of contact-handled (CH) and RH-TRU from proposed operations required to produce radioisotope power systems, as described in the "Draft

Environmental Impact Statement for the Proposed Consolidation of Nuclear Operations Related to Production of Radioisotope Power Systems (DOE/EIS-0373D, June 2005)[5]. For conservatism, DOE is including the projected waste from the proposed operations required to produce RPS in the DOE GTCC-like waste inventories even though this waste may be determined to be defense TRU waste based on circumstances and determinations made at the time the waste is generated. The 2035 projected inventory also includes waste that has not been formally identified by DOE as defense-related. The activity of the projected inventory is also uncertain, but is estimated as approximately 19 MCi, with the proposed RPS project accounting for 16 MCi of the total.

Table 5.1. Stored Inventory of DOE GTCC-like Waste, Sorted by Waste Type.

DOE Site	Waste Type	Volume (m^3)	Activity (Ci)	Mixed Waste
ACTIVATED METAL				
Oak Ridge National Laboratory	Activated Metal (3 items, solid)	1.6[a]	$6.80x10^{+3}$	No
Oak Ridge National Laboratory	Activated Metal (solid)	0.6[a]	$1.76x10^{+3}$	No
Idaho National Laboratory	Activated Metal Parts from Reactor (solid)	0.25[a]	$9.74x10^{+4}$	No
Idaho National Laboratory	RH Activated Metal Parts from Reactor (beryllium containing components)	2.5[a]	$9.17x10^{+2}$	No
OTHER WASTE				
BWXT-Lynchburg VA (DOE waste at commercial facility)	Transuranic-contaminated waste	17.9	$3.42x10^{+3}$	No
Idaho National Laboratory	Other (31 mixed transuranic items)	19.4	$5.73x10^{+1}$	Yes
Idaho National Laboratory	Other (remote handled transuranic)	8	$8.72x10^{+1}$	No
Idaho National Laboratory	Other (transuranic)	0.4	$1.60x10^{+2}$	No
Idaho National Laboratory	Other (10 radioactive only waste items)	39.9	Not available	Further analysis required
Oak Ridge (BJC-managed waste)	RH Fuel flush salts from Molten Salt Reactor Experiment (MSRE) (10 salt cans)	4	$3.07x10^{+4}$	No
Oak Ridge (BJC-managed waste)	Uranium laden charcoal canister from MSRE	0.03	$1.74x10^{-2}$	Further analysis required
Oak Ridge National Laboratory	RH waste	8.4[a]	(b)	No
Oak Ridge National Laboratory	Scrap metal (RH)	14.1[a]	(b)	No
Oak Ridge National Laboratory	Scrap metal (RH)	1.3[a]	(b)	Yes
Oak Ridge National Laboratory	Process waste (RH)	70.2[a]	(b)	No

[5] CH-TRU waste currently generated at LANL for operations required to produce RPS has been determined to be eligible for disposal at WIPP and would not be considered as part of the inventory of DOE GTCC-like waste as long as those operations continue at LANL.

DOE Site	Waste Type	Volume (m^3)	Activity (Ci)	Mixed Waste
Oak Ridge National Laboratory	Process waste (RH)	5.4[a]	(b)	Yes
Oak Ridge National Laboratory	Irradiators (RH)	0.6[a]	(b)	Yes
West Valley	TRU waste	632	$9.11x10^{+6}$	No
West Valley	Mixed TRU waste	37.2	$2.08x10^{+6}$	Yes
TOTAL		**864**	**$1.14x10^{+7}$**	

[a]Unpackaged volume; all other volumes are packaged volumes
[b]Activity for the Oak Ridge National Laboratory RH waste totals $1.62x10^{+5}$ Ci

Table 5.2. Projected Inventory of DOE GTCC-Like Waste, Sorted by Waste Type.

DOE Site	Waste Type	Volume (m^3)	Activity (Ci)	Mixed Waste
ACTIVATED METAL				
Idaho National Laboratory	Activated Metal Parts from Reactors (5 items, solid)	2.38[a]	$1.7x10^{+5}$	No
Idaho National Laboratory	Activated Metal Parts from Reactors (2 items, Solid)	21.9[a]	$6.4x10^{+5}$	Yes
Idaho National Laboratory	RH Activated Metal Parts from Reactor (beryllium containing components)	4.9[a]	$4.9x10^{+3}$	No
OTHER WASTE				
BWXT-Lynchburg VA (DOE waste at commercial facility)	Potentially non-defense TRU from maintenance activities	0.6	$1.67x10^{+1}$	Further analysis required
Idaho National Laboratory	Other [Various] – (Solid)	0.21[a]	$1.9x10^{+3}$	Yes
Proposed Radioisotope Power Systems (RPS) Project	Contact handled and remote handled TRU from proposed RPS operations, including target fabrication and plutonium purification	1,260	$1.6x10^{+7}$	No
West Valley	Transuranic waste (various D&D projects)	66.4[b]	$3.0x10^{+6}$	Further analysis required
West Valley	Process Plant Demolition	33[a]	2.48	No
West Valley	Specific D&D Project: SDS Columns, 8D-1	384.52	$2.51x10^{+5}$	No
West Valley	Specific D&D Project: 8D-2 & 8D-4 (Waste Tank Farm – TRU)	195.18	$1.24x10^{+5}$	No
West Valley	Remote Handled Waste Facility Operations	80.7	242	No
TOTAL		**2,050**	**$1.94x10^{+7}$**	

[a]Unpackaged volume; all other volumes are packaged volumes.
[b]Reported as 147.1 m^3, but includes 80.7 m^3 of waste from Remote Handled Waste Facility Operations, which is reported as a separate item in this table.

5.4. SUMMARY OF RESULTS

The current study identified 864 m^3 (11.4 MCi) of DOE GTCC-like waste in storage and estimated that by 2035 there would be, in addition, approximately 2,050 m^3 (19.4 MCi) of projected DOE GTCC-like waste. The above volume and activity estimates do not include the DOE GTCC-like sealed sources that are addressed in Chapter 3.

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6. MIXED WASTE CONSIDERATIONS

6.1. WASTE DESCRIPTION

Mixed GTCC LLW is GTCC LLW that is also a hazardous waste under Subtitle C of the Resource Conservation and Recovery Act (RCRA) (Public Law 94-580). Similarly, DOE GTCC-like waste can be mixed waste.

6.2. SUMMARY OF PREVIOUS STUDIES

The "Greater-Than-Class C Low-Level Radioactive Waste Characterization: Estimated Volumes, Radionuclide Activities, and Other Characteristics" (DOE/LLW-114) report provided waste volume projections of mixed GTCC LLW through the year 2035 for sealed sources and other generators, and through the year 2055 for the nuclear utilities. Table 6.1 below presents the expected future mixed GTCC LLW waste volume estimates from Appendix E-2 of DOE/LLW-114 (DOE, 1994a).

Table 6.1. Projected Volumes of Mixed GTCC LLW (DOE/LLW-114).

Generator Category	Waste Type	Volume (m^3)
Nuclear Utility	Fuel-in decontamination resins[a]	0
Other Generators	Organic liquids	176
	Process waste	<1
Total		177

[a] It is highly speculative that any mixed GTCC LLW will ever be generated, as it is unlikely the Nuclear Utility industry will use this decontamination technique.

Although DOE/LLW-114 projected estimates for mixed GTCC LLW waste volumes from the nuclear utilities for several different scenarios, operating practices can be modified to eliminate the production of mixed GTCC LLW in this category. DOE/LLW-114 also emphasized that only two C-14 users in the Other Generators category were responsible for the production of mixed GTCC LLW in the form of organic liquids and "they generate essentially all the mixed GTCC LLW that can reasonably be expected to be generated in the future" (DOE, 1994a).

6.3. CURRENT STUDY

Mixed waste in the current study could only come from Other Generators and DOE based on the following assumptions originating from DOE/LLW-114:

- Only sealed sources with more than 5% by weight silver could become mixed waste, and none of the sealed sources exceeded this limit.

- The nuclear utility industry will not employ the fuel-in decontamination resin procedure. However, if nuclear utilities began to use this technique, no mixed waste would be generated because the resins would be taken out of service before they became GTCC LLW.
- It is assumed that all of the mixed waste identified in this study can be treated prior to disposal.

6.4. RESULTS/UNCERTAINTIES

As shown in Chapter 4, only 4 m^3 of mixed GTCC LLW was identified for the Other Generator category for the stored inventory and none for the projected inventory. This waste consists of radioactively contaminated lead waste from a remediation site. Similarly, as shown in Chapter 5, 64 m^3 of mixed radioactive waste was identified for the DOE GTCC-like category for the stored inventory and an additional 22 m^3 for the projected inventory. All of the mixed GTCC-like waste in the 2035 projected inventory is anticipated to be generated at INL and consists primarily of activated metal reactor parts. Table 6.2 gives a summary of the mixed waste inventory.

Table 6.2 Mixed Waste Inventory Summary

Origin	Volume (m^3)		
	Stored	**Projected**	**Total**
Other Generator GTCC Waste	4	0	4
DOE GTCC-like Waste	64	22	86
Total	**68**	**22**	**90**

7. INVENTORY SUMMARY

This chapter provides an overall summary of the information presented in this document. Four categories of waste are discussed. These include

- nuclear utilities, which will generate the majority of the activity of GTCC LLW;
- sealed sources, which includes both NRC-licensed GTCC LLW and DOE GTCC-like waste;
- other generators of GTCC LLW in the NRC-licensed sector; and
- DOE GTCC-like waste, which includes items similar to GTCC LLW under DOE regulation, which may not have a path to disposal.

The estimates presented in this document are based on the best available information compiled in 2005 and updated appropriately from the results of data calls, interviews, and other sources of information. NRC sealed source information compiled in 2006 was also used for this document. A degree of uncertainty in the results exists due to limitations in the availability of information and the assumptions applied in the analysis. These estimates, however, provide reasonable values for the volumes and activities of GTCC LLW and DOE GTCC-like wastes.

Summary information on the volumes and activities for these four categories, which are discussed in more detail in their respective chapters, is provided in Table 7.1. Figures 7.1 through 7.4 provide graphical representations of the same information.

Table 7.1 Summary Estimates of GTCC LLW and DOE GTCC-like Waste Volume and Activity[a]

Waste type	In storage		Projected		Total stored and projected	
	Volume (m^3)	**Activity (MCi)**	**Volume m^3**	**Activity (MCi)**	**Volume (m^3)**	**Activity (MCi)**
GTCC LLW						
Activated metal[a]	58	3.5	810	110	870	110
Sealed sources[b]	(d)	(d)	1,700	2.4	1,700	2.4
Other waste	76	0.0076	1.0	0.00023	77	0.0078
Total GTCC LLW	130	3.5	2,500	110	2,600	110
DOE GTCC-like waste						
Activated metal	5.0	0.11	29	0.82	34	0.93
Sealed sources[b]	8.7	0.013	25	0.030	34	0.043
Other	860	11	2,000	19	2,900	30
Total DOE GTCC-like waste	870	11	2,100	20	3,000	31
Total GTCC and GTCC-like waste	1,000	15	4,600	130	5,600	140

[a]Values have been rounded to two significant figures.

[b]Activities for the projected inventory estimated at six years following reactor shutdown. Activities for the stored inventory have been decayed to 2007. The year 2062 was used for the overall nuclear utility GTCC LLW projections in order to include the 20-year license renewal that a number of commercial nuclear reactors are likely to receive and a minimum six-year cooling period before the waste would be available for disposal. Waste from operating reactors is assumed to start becoming available in 2035; waste from six reactors, accounting for 51.9 m^3 and $6.7 \times 10^{+6}$ Ci, will become available after 2055.

[c]Sealed source activities estimated as of January 1, 2007.

[d]NRC licensees currently possess sealed sources that may become GTCC LLW when no longer needed by the licensee; the estimated volume and activity of those sources are included in the projected inventory.

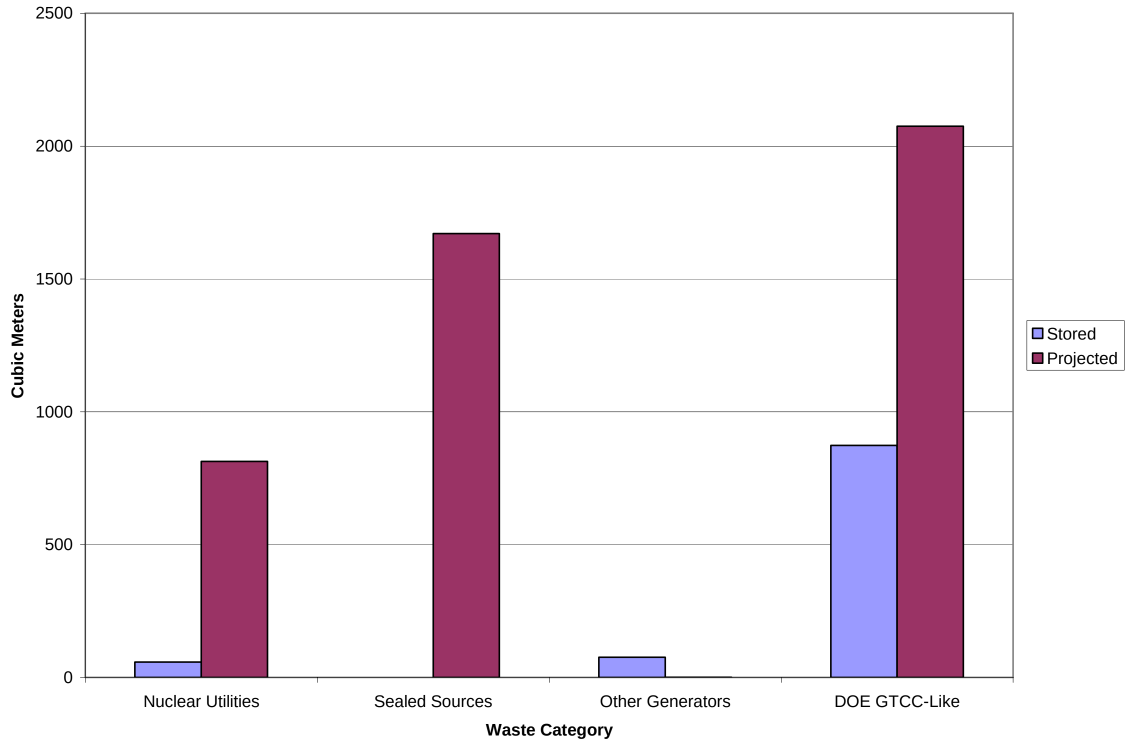

Figure 7.1 GTCC LLW and GTCC-like Waste Volume Estimates (Stored and Projected)

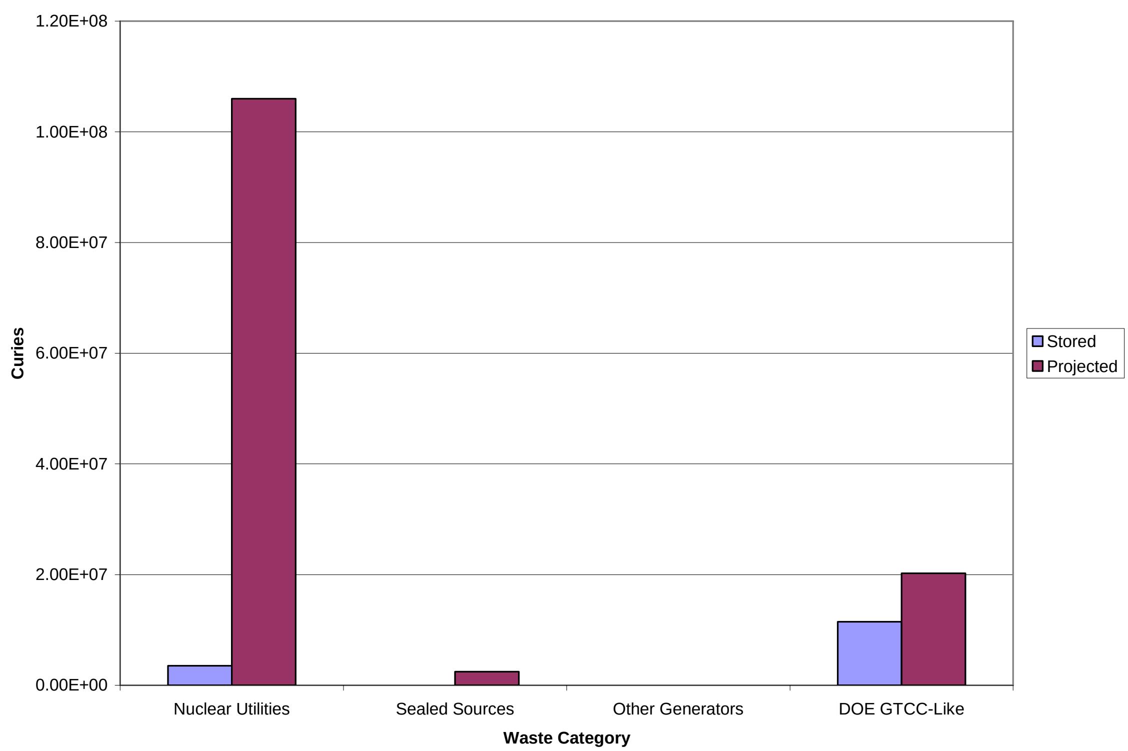

Figure 7.2 GTCC LLW and GTCC-like Waste Activity Estimates (Stored and Projected)

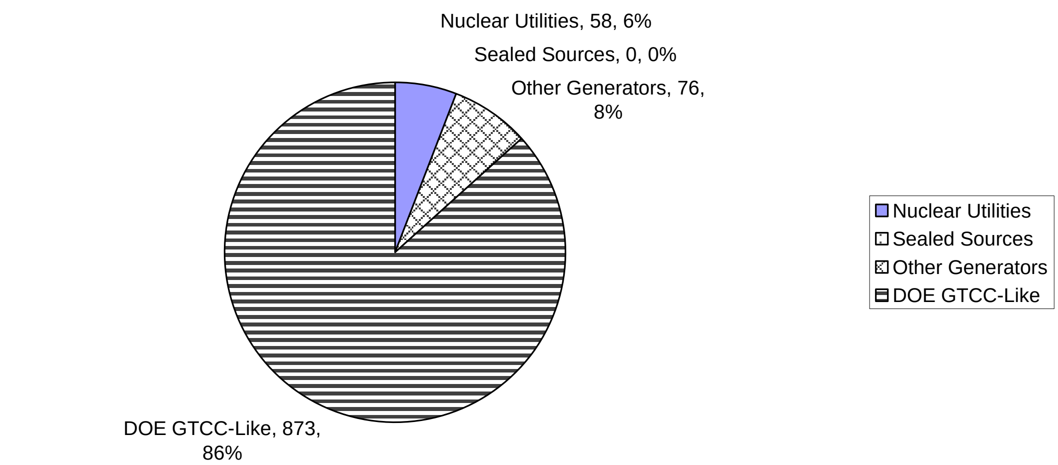

Figure 7.3 Stored Volume Estimates in Cubic Meters

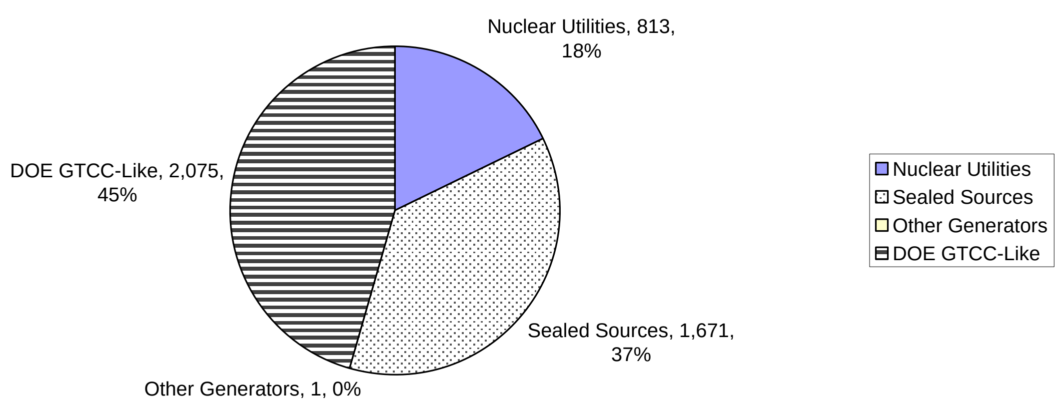

Figure 7.4 Projected Volume Estimates in Cubic Meters

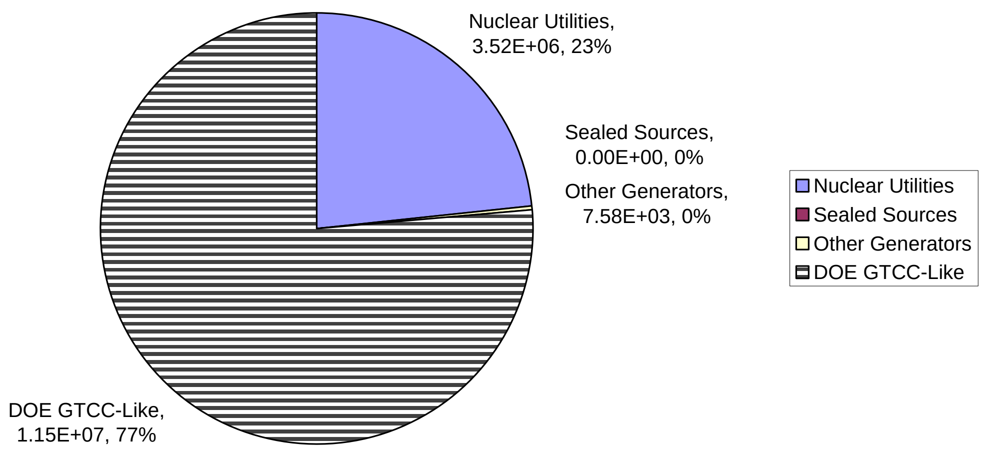

Figure 7.5 Stored Activity Estimates in Curies

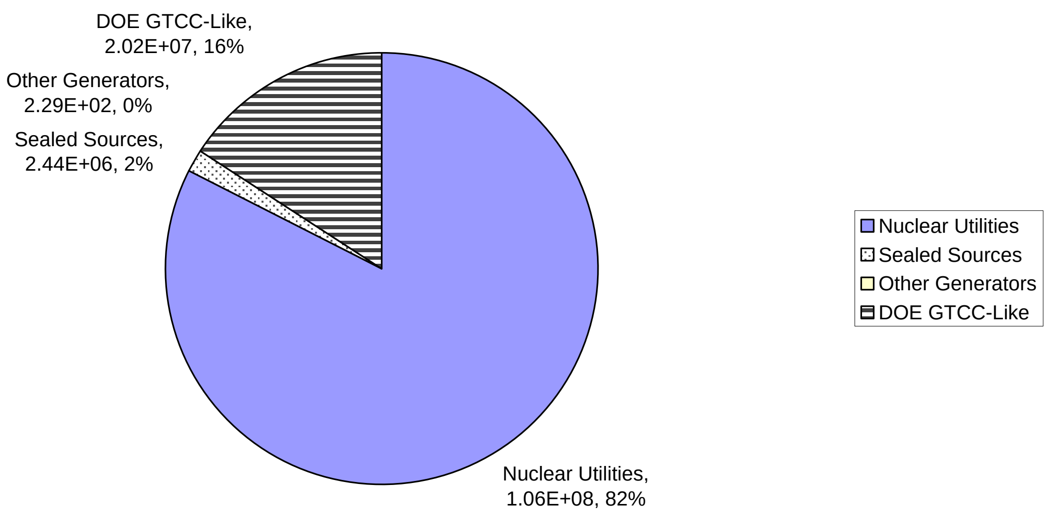

Figure 7.6 Projected Activity Estimates in Curies

In addition to estimates of the total volumes and activities for the stored and projected (2035) inventories, the estimated volumes of GTCC and GTCC-like mixed waste, which may require treatment prior to disposal, are addressed in Chapter 6 and summarized in Table 7.2. The mixed waste volume is uncertain, but likely relatively small in relation to the overall inventory.

Table 7.2 Mixed Waste Volume Estimates

	Volume (m^3)		
	Other Generators GTCC Waste	***DOE GTCC-like Waste***	***Total***
Stored	4	64	68
Projected	0	22	22
Total	**4**	**86**	**90**

In order to better appreciate the magnitude of GTCC LLW and DOE GTCC-like waste requiring disposal by 2062, a comparison was made to NRC GTCC Class A, B, and C LLW volumes disposed of in fiscal year 2006 (see Figure 7.7) (DOE, 2007). As can be seen from this figure, the total volume of GTCC LLW and GTCC-like waste requiring disposal by 2062 (5,567 cubic meters) is less than 5% of the volume disposed of at the three NRC-licensed disposal facilities (117,282 cubic meters) in fiscal year 2006.

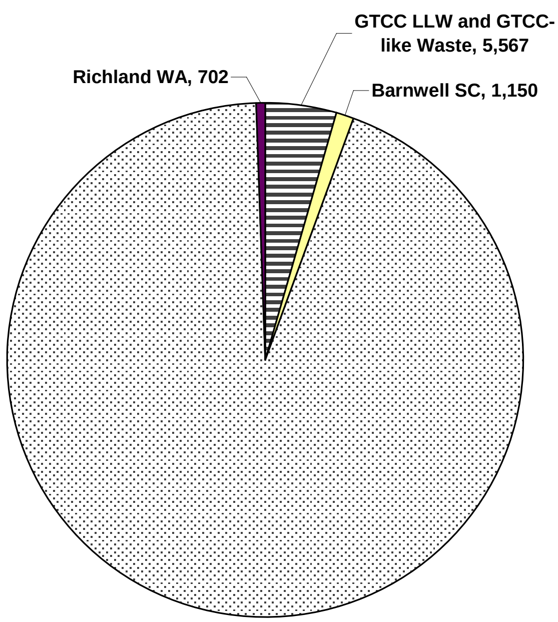

Figure 7.7. Comparison of GTCC LLW and GTCC-like Waste Volume (Cubic Meters) with Fiscal Year 2006 Disposal Volumes (Cubic Meters) from Operating LLW Disposal Facilities

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