Greater-Than-Class C Low-Level Radioactive Waste Characterization

Appendix I: Impact of Concentration Averaging Low-Level Radioactive Waste Volume Projections

*Greater-Than-Class C Low-Level Waste
Management Program*

August 1991

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GREATER-THAN-CLASS C LOW-LEVEL WASTE CHARACTERIZATION

Appendix I: Impact of Concentration Averaging Low-Level Radioactive Waste Volume Projections

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ABSTRACT

This study provides a quantitative framework for bounding unpackaged greater-than-Class C low-level radioactive waste types as a function of concentration averaging. The study defines the three concentration averaging scenarios that lead to base, high, and low volumetric projections; identifies those waste types that could be greater-than-Class C under the high volume, or worst case, concentration averaging scenario; and quantifies the impact of these scenarios on identified waste types relative to the base case scenario. The base volume scenario was assumed to reflect current requirements at the disposal sites as well as the regulatory views. The high volume scenario was assumed to reflect the most conservative criteria as incorporated in some compact host state requirements. The low volume scenario was assumed to reflect the 10 CFR Part 61 criteria as applicable to both shallow land burial facilities and to practices that could be employed to reduce the generation of Class C waste types.

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APPENDIX I: IMPACT OF CONCENTRATION AVERAGING LOW-LEVEL RADIOACTIVE WASTE VOLUME PROJECTIONS

1. INTRODUCTION

The requirements for low-level radioactive waste classification are defined in 10 CFR Part 61.¹ This regulation, specifically Paragraph 61.55, requires that waste suitable for disposal must fall into one of three classes: A, B, or C. Waste is determined to fall into one of these three classes by comparing radionuclide concentrations within the waste to limiting concentrations for particular radionuclides. The Class C designation is the most restrictive. Waste suitable for commercial disposal must not exceed those concentrations designated for Class C waste. Waste that exceeds these concentrations is referred to as greater-than-Class C (GTCC) low-level waste (LLW). The concentrations of radionuclides within a package are determined by dividing the estimated radioactivity by the volume of the waste material within the package. This calculation assumes that the waste material within the package is homogeneous, and the calculated concentrations are averaged over the packaged waste mass. In some cases, relatively high-concentration waste materials are combined with low-concentration waste materials in the same package, and the concentration calculations are based on the combined radioactivity divided by the combined waste volumes. This practice is referred to as concentration averaging. How this practice is applied to different types of waste affects the 10 CFR Part 61 Class C classification and the amounts of GTCC LLW that will be generated.

EG&G Idaho, Inc., has contracted with WMG, Inc., to provide a quantitative framework for bounding unpackaged GTCC low-level types as a function of the concentration averaging scenario. This information will be used as input to the U.S. Department of Energy (DOE) GTCC projection computer model. Three objectives were specified in order to perform this evaluation:

- Define the three concentration averaging scenarios that lead to base, high, and low volumetric projections.
- Identify those waste types that could be GTCC under the high volume, or worst case, concentration averaging scenario.
- Quantify the impact of these scenarios on identified waste types relative to the base case scenario.

To reasonably bound the volumes of GTCC LLW that could be generated over the 1990 to 2055 time span, both current and prospective LLW practices were considered. The base volume scenario was assumed to reflect current requirements at the LLW disposal sites as well as the current views of the DOE and the U.S. Nuclear Regulatory Commission (NRC) pertaining to the subject. The high volume scenario was assumed to reflect the most conservative criteria as incorporated in some compact host state requirements. The low volume scenario was assumed to reflect the 10 CFR Part 61 criteria as applicable to both shallow land burial facilities and to practices that could be employed to reduce the generation of Class C, hence GTCC, waste types.

A master list of potential GTCC low-level types was prepared under the high volume scenario. Those waste types are already included in the DOE data base; the current basis for their consideration was reviewed and revised to reflect current waste type characteristics and practices.

The basis for consideration of whether a waste type was to be included or excluded from the GTCC category was subsequently developed.

The master GTCC LLW type list provided the basis for consideration of volumetric variances as a function of concentration averaging scenarios. Initially, each waste type was evaluated to determine the extent to which it would be GTCC LLW under the different concentration averaging scenarios. The basis for these relative volumes was defined, and such volumes were normalized relative to the base volume case values. These normalized values could then be applied to the DOE model volumes to account for the various concentration averaging scenarios.

Section 2 presents the summary and conclusions of this evaluation. The three concentration averaging scenarios considered and their bases are described in Section 3. Those waste types identified as potential GTCC and the basis for such designation are presented in Section 4. The extent to which potential GTCC LLW types will be GTCC LLW for the three concentration averaging scenarios considered is presented in Section 5. The study conclusions are also presented in Section 5. Section 6 presents the study references.

2. EVALUATION SUMMARY AND CONCLUSIONS

To reflect current and prospective practices, wastes were divided into the following four categories before concentration averaging scenarios were defined:

- Activated Metals--Activated metals consist of the nonfuel-bearing components that are activated through exposure to neutron flux. Two types were considered: (a) components that are periodically replaced during routine operations, and (b) structural components in the reactor vessel that are removed at decommissioning.
- Process Wastes--Process wastes consist of the wet wastes generated from cleanup of liquids containing soluble and insoluble radioactive constituents.
- Contaminated Solids--Contaminated solids consist of plastic, paper, cloth, glass, wood, and metal that are contaminated.
- Sealed Sources--Sealed sources consist of small capsules, usually stainless steel, which encapsulate relatively high concentrations of a single radionuclide.

Three different concentration averaging scenarios were considered for these categories. The base volume case reflects current practices at the Barnwell, South Carolina, disposal site. The low volume case primarily reflects current practices at the Richland, Washington, disposal site since it will remain open beyond 1992. The high volume case is based on those compact regions that might prohibit any form of concentration averaging.

As expected, the results indicate that volumes of GTCC LLW will vary significantly with each concentration averaging scenario. However, even under the high volume scenario, the extent to which GTCC LLW could be generated is less than potential GTCC LLW types previously estimated. Thus, this evaluation showed fewer GTCC LLW types and does not support the implicit assumption in previous estimates that all wastes generated from a particular type of GTCC waste stream will be GTCC. In many cases, only a portion of a particular waste stream is potential GTCC, even under the high volume scenario.

Table I-1 lists the GTCC LLW types identified by this study and presents estimates of that portion, as a percentage age of the total amount generated, which could be GTCC for each concentration averaging scenario.

As shown in Table I-1, the relative variances between the high volume scenario and the base case scenario covered different ranges for each waste category and type. This range varied from unity, meaning no change between scenarios, to a factor of 100, meaning the high volume case would generate 100 times the volume of the base case. The relative variances between the low volume scenario and the base case scenario ranged from unity to zero. Except for some decommissioning activated metals and three types of Transuranic-bearing sealed sources, no GTCC LLW would be generated for the low volume case.

These results have varying degrees of confidence. The information used for routinely generated activated metals is based on a significant data base of actual components with a high confidence level. This is not the case for decommissioning activated metals. Few such components have been actually characterized and disposed of to date, yet some of this work is now being initiated at power reactors

Table I-1. Waste summary--relative GTCC waste volumes

WASTE TYPE SUMMARY RELATIVE GTCC WASTE VOLUMES			
	Percent GTCC For High Case	Percent GTCC For Base Case	Percent GTCC For Low Case
ACTIVATED METALS			
1.BWR Operations			
- Control Rod Blades--Control Cell	25	10	0
- Control Rod Blades--Normal	10	1	0
- LPRM Strings	75	10	0
- Dry Tubes	100	10	0
2. PWR Operations			
- Thimble Plug Assemblies	25	1	0
- Instrument Strings	75	10	0
- Primary Sources	100	100	100
3.BWR Decommissioning			
- Core Shroud	100	100	100
- Orificed Fuel Supports	10	1	0
4.PWR Decommissioning			
- Core Shroud	100	100	100
- Lower Core Barrel	25	1	0
- Thermal Shield	25	1	0
- Lower Grid Plate	100	100	75
5.Other Reactor internals			
-Research	100	100	0
-Test	100	1	0
PROCESS WASTES			
1. BWR & PWR Decon Resins			
- Full RCS with Fuel In	25	1	0
- Full RCS with Fuel Out	10	1	0
2.Cartridge Filters			
- BWR Control Rod Drive	50	10	0
- Other BWR & PWR	25	1	0
CONTAMINATED SOLIDS			
	25	10	1
SEALED SOURCES			
1.TRU Bearing Sources			
- Gamma Gauges	100	100	50
- X-Ray Fluorescent	100	100	0
- Well Logging	100	100	100
- Moisture Gauges	100	100	0
- Smoke Detectors	100	100	0
- Pacemakers	100	100	0
2.Other Sources			
- Med. Teletherapy	100	100	0
- Gamma Gauges	50	1	0
- Beta Gauges	50	1	0
- Well Logging	50	1	0
- Calibration	50	25	0
- Gamma Irradiators I,II,III,IV	100	100	0
- Gas Chromatography	100	1	0
- Beta Eye Applicators	100	1	0

and research facilities. While there are more extensive technical data sources available, detailed analyses of these data sources was beyond the scope of this study. Thus, the confidence level for the estimates on decommissioning activated metals is much lower than that for other metals.

The information used for spent resins and filter cartridges is also based on actual waste data. Except for the full reactor coolant system (RCS) decontamination resins that have not as yet been generated, this information has a high confidence level. The information used for contaminated solids has the lowest degree of confidence. The readily available DOE information was minimal.

For sealed sources, NRC reference materials were used almost exclusively. The information used to identify source characteristics has a high degree of confidence. However, data on the numbers of sources by type and the distribution of activities for source types is not readily available. Moreover, the assumption that sources would be encapsulated in 55-gal drum-size containers with approved stabilization media is overly simplistic. In addition to ignoring economic considerations, this also assumes that typical source users are aware of the approved stabilization methods and can readily employ them. Since sealed sources are the most widely used and likely GTCC LLW types, a more detailed evaluation of this waste category appears warranted.

The dependence of GTCC LLW generation on concentration averaging scenarios will also lead to some "orphan" wastes. In a compact-based regulatory environment, there is a high degree of certainty that waste could be GTCC in one compact region, meet Class C limits in another, and not meet the DOE definition of GTCC. Steps should be taken to address these types of issues to provide some degree of certainty to potential GTCC LLW type management practices.

3. CONCENTRATION AVERAGING

The concentrations of radionuclides within a package are determined by dividing the estimated radioactivity by the volume of the waste material within the package. This calculation assumes that the waste material within the package is homogeneous, and the calculated concentrations are averaged over the packaged waste mass. In some cases, relatively high concentration wastes are combined with low concentration wastes in the same package, and the related concentration calculations are based on the combined radioactivity divided by the combined waste volumes. This practice is referred to as concentration averaging. The application of this practice to different types of waste affects the 10 CFR Part 61 waste classification. For the purposes of this study, concentration averaging significantly affects which wastes will meet or exceed NRC waste form Class C limits.

To reflect current practices and disposal site criteria, potential GTCC LLW were divided into four major categories:

- **Activated Metals**--Activated metals consist of components comprised (primarily stainless steel) that are activated by neutrons within a reactor core. These wastes mostly contain activation product radionuclides.
- **Process Wastes**--Process wastes consist of wet wastes produced during cleanup of radioactive liquids in the form of ion-exchange resins and filter cartridges. These wastes primarily contain fission product and transuranic radionuclides.
- **Contaminated Solids**--Contaminated solids consist of dry wastes that are radioactive due to surface contamination. These wastes are produced during cleanup at special facilities and primarily contain transuranic radionuclides (TRU).
- **Sealed Sources**--Sealed sources consist of radioactive wastes with high radioactivity encapsulated in small volumes. Some of these wastes contain long-lived fission products, while others contain transuranic radionuclides.

To provide a framework for DOE volume projections, three concentration averaging scenarios were defined:

- **High Volume Case**--This covers disposal criteria that reflect prospective practices leading to high GTCC LLW volumes.
- **Base Volume Case**--This covers disposal criteria that reflect current practices leading to moderate GTCC LLW volumes.
- **Low Volume Case**--This covers disposal criteria that reflect reasonable practices leading to low GTCC LLW volumes.

This section describes the basis for integrating the disposal requirements with the different waste categories in order to define practicable and realistic concentration averaging scenarios. These scenarios would provide the concentration averaging bounding framework for DOE's GTCC volume projection model.

3.1 General NRC Guidelines

The documents published by the NRC allude to concentration averaging, but they do not specifically address the concept. The regulation in 10 CFR 61.55(a)(8) provides that "the concentration of a radionuclide may be averaged over the volume of the waste." When this statement is read in conjunction with the premise that 10 CFR Part 61 deals with Class A, B, and C packaged wastes, concentration averaging is permissible. The NRC Branch Technical Position (BTP)² on waste classification expands on 61.55(a)(8), indicating that the principal consideration is whether or not the distribution of radionuclides is reasonably homogeneous. In one example, the BTP indicates that a concentrated source being combined with trash can be averaged over the trash volume. In another example, the use of stabilization media as part of the concentration calculation for filters and sealed sources is discussed. Limits on concentration averaging are not defined, but the BTP recognizes that, for hard-to-detect radionuclides, which are the primary drivers of classification status, the concentration must be accurate to within a factor of 10.

Additional guidance is provided in a draft regulatory guide on waste classification^a that was never published. This draft indicates that concentration averaging, or blending, is acceptable provided the concentrations of the blended wastes are within several orders of magnitude.

While each of the commercial disposal sites has applied both these 10 FR Part 61 rules and the NRC guidelines differently, concentration averaging of packaged waste is routinely done.

3.2 Current Practices

Current practices arise from the requirements in 10 CFR Part 61, the NRC Branch Technical Position on waste classification (Reference 2), together with the currently licensed disposal site application of these requirements to specific commercial disposal sites. Current practices by waste category include:

- Activated Metals--Different types of components and different pieces from different types of components are usually packaged in the same disposal liner. In some cases, activated metals can also be encapsulated with a media like cement. The classification status of stabilized metal can sometimes be determined by dividing the metal activity by the total volume plus the stabilization media.
- Process Wastes--Different batches of resin are combined in the same package. Different types of filter cartridges are also combined in the same package. In some cases, spent filters and spent resins, or spent filters and activated metals, are combined in the same package. Both spent resins and filter cartridges can be stabilized with a media like cement. The classification status of the stabilized waste can usually be determined by dividing the waste activity by the total volume, including the stabilization media.
- Contaminated Solids--Current practices vary widely for these dry wastes and can include both incineration and compaction to reduce disposal volumes. Compaction can increase concentrations by a factor of 10, while incineration can increase concentrations by a factor of 100. Wastes are segregated primarily by physical form, with no differentiation between

a. U. S. Nuclear Regulatory Commission, "Regulatory Guide on Waste Classification and Manifest Reporting," draft, February 1986.

waste classes. Where these wastes are incinerated, the incinerator ash is sometimes stabilized. The classification status of the stabilized ash can usually be determined by dividing the ash activity by the total volume, including the stabilization media.

- **Sealed Sources**--By design, sealed sources contain high radioactivity in small volumes. This usually leads to very high concentrations of 10 CFR Part 61 radionuclides. Under NRC guidelines, these sealed sources can be stabilized or encapsulated in media like cement. When encapsulated, the classification status is determined by dividing the activity of the sources by the volume, including the stabilization media.

Practices vary with waste category. Moreover concentration averaging criteria, vary between both the waste categories and among the commercial disposal sites. Current criteria at the commercial disposal facilities are discussed below.

3.2.1 Barnwell Disposal Facility

The Barnwell Disposal Facility received about 68% of the commercial low-level radioactive waste disposed of in 1989.³ Hence, its application of 10 CFR Part 61 requirements to concentration averaging has a significant impact on how wastes are currently packaged for disposal. The criteria applied to commingling wastes varies with each waste category as follows:

- **Activated Metals**--Packages containing activated metals must satisfy what is commonly referred to as the "rule of 10." Application of this rule allows concentration averaging among the same types of components but limits concentration averaging to a factor of 10 among individual components. For example, local power range monitor (LPRM) strings with relatively high concentrations of 10 CFR Part 61 radionuclides cannot be combined with control rod blades of lower concentrations unless the concentrations of both 10 CFR Part 61 Table 1 and Table 2 radionuclides for the two components are within a factor of 10 of each other. Once the rule of 10 is satisfied, the classification status can be determined by dividing the total activity of all the components by the total volume.
- **Process Wastes**--Where different batches of resins or filters are placed in the same package, the classification status is determined by dividing the total activity of the waste by the total volume of the waste. Where different types of waste, (e.g., resins and filters) are combined in the same package, the classification status of each waste type is determined separately. The radioactivity of each waste type is divided by the volume for each waste type and documented separately.

The addition of cement increases the volume of the waste and correspondingly reduces the concentration of 10 CFR Part 61 radionuclides. Under NRC guidelines, the classification status of the stabilized waste can properly be determined by dividing the total activity by the total volume plus the stabilization media. Where spent resins are stabilized, the total volume can be applied. Where filter cartridges are stabilized, classification status must be determined by dividing the total activity by the volume of the filter cartridges only.

- **Contaminated Solids**--Packaged waste both with and without volume reduction is considered homogeneous, and the entire volume is used for classification determination. Incinerator ash may require stabilization, and the criteria applicable to resins would apply.

- Sealed Sources--Requests for disposal of encapsulated sources are addressed on a case-by-case basis. Generally, sources containing non-TRU radionuclides with activities up to 10 Ci and sources containing TRU radionuclides with activities up to 50 mCi are approved for encapsulation.

3.2.2 Richland Disposal Facility

The Richland Disposal Facility received about 25% of the commercial low level radioactive waste disposed in 1989 (Reference 3). Its application of 10 CFR Part 61 requirements to concentration averaging is similar to the NRC guidelines. The criteria applied to commingling waste varies with each waste category as follows:

- Activated Metals--The classification status of packages containing activated metals can be determined by dividing the total activity of all the components by the total volume of the components in the package.
- Process Wastes--In all cases of process wastes, the classification status of spent resins and filter cartridges is determined by dividing the total activity of the waste by its total volume.

Both spent resins and filter cartridges can also be stabilized. The classification status of the stabilized waste can be determined by dividing the total activity by the total volume, including the stabilization media.

- Contaminated Solids--The packaged wastes are considered homogeneous, and the entire volume is used for this classification determination.
- Sealed Sources--Non-TRU-bearing sources can be encapsulated, and the encapsulation media volume is included in the concentration calculation. Prior approval on the encapsulation media and method is required for sources containing TRU radionuclides.

3.2.3 Beatty Disposal Facility

The Beatty Disposal Facility in Nevada received about 7% of the commercial low-level radioactive waste disposed in 1989 (Reference 3). Its application of 10 CFR Part 61 requirements to concentration averaging is identical to that applied by the Richland facility, except that prior approval is not required for encapsulated TRU sources.

3.3 Prospective Practices

Beyond 1992, concentration averaging practices will be based on the criteria in effect within the different compact regions and sited states. Therefore, it is likely that disposal criteria will vary to a much greater extent than at present. The Richland site will continue to be the disposal site for the Northwest Compact, and, absent any new NRC criteria, current practices will remain essentially unchanged. However, the Appalachian Compact Region, hosted by Pennsylvania, intends to prohibit any form of concentration averaging. Some of the other compact regions and states that represent relatively large volumes of low-level radioactive waste, such as the Southeast, Midwest, and New York, have not yet stated their positions on concentration averaging. It is unlikely, however, that

these regulatory positions will differ from those already defined and bounded by the Northwest Compact Region and the Appalachian Compact Region.

The "no concentration averaging" position taken by Pennsylvania is the most restrictive. Applying this position to the different waste categories discussed above would lead to the following criteria:

- Activated Metals--Each activated metal component would be classified under 10 CFR Part 61 as if it were the only component in the disposal package. Radionuclide concentrations would be determined by dividing the component activity by the component volume.
- Process Solids--Where resins and filter cartridges are stabilized, the volume of the stabilization media would be excluded from the classification determination.
- Contaminated Solids--Commingling of contaminated solids would be prohibited. Use of the stabilization media volume to classify incinerator ash would probably be unacceptable.
- Sealed Sources--Encapsulation of sealed sources in a stabilization media practice would probably be acceptable. However, radionuclide concentrations would be determined by dividing the source activity by the source volume.

3.4 GTCC Projection Scenarios

The bounding of the volumes of GTCC LLW that could be generated requires some assumptions concerning prospective disposal criteria. For the purposes of determining the impact of alternative concentration averaging criteria, the following bounding conditions were assumed:

- Base Volume Case--The criteria currently in effect at the Barnwell site as described in Section 3.2.1 above represent the current practices for most waste (68% by volume in 1989) that could be GTCC. These criteria were selected to represent the base volume case. They provide for use of the rule of 10 for activated metals, use of the stabilization media volume for resins and incinerator ash, commingling of contaminated solids, and encapsulation of non-TRU-bearing sources with activities up to 10 Ci.
- Low Volume Case--The criteria currently in effect at the Richland site as described in Section 3.2.2 above are consistent with the current NRC reading of 10 CFR Part 61, representing current practices for some waste (25% by volume in 1989) that could be GTCC. These criteria were selected to represent the low volume case. They provide for determination of Class C status based on disposal liner activity and volume, including the stabilization media, and encapsulation of all sources.
- High Volume Case--The prospective criteria for compacts that are similar to the Appalachian Compact Region, as described in Section 3.3 above, represent a very restrictive reading of 10 CFR Part 61 requirements. These criteria were selected to represent the high volume case. They provide for no concentration averaging. Contaminated solid commingling, use of stabilization media volumes, and encapsulation would all be prohibited.

Table I-2 summarizes these cases and criteria as they apply to the four different categories of waste discussed.

Table I-2. GTCC volume projection scenarios

GTCC VOLUME PROJECTION SCENARIO S			
WASTE CATEGORY	LOW VOLUME CASE	BASE VOLUME CASE	HIGH VOLUME CASE
1.ACTIVATED METALS	Activity in liner divided by waste volume in liner Stabilization media volume INCLUDED	Activity in liner divided by waste volume in liner Concentrations of components/ types within a FACTOR of 10	Activity in component divided by component volume
2.PROCESS WASTE	Activity in liner divided by waste volume in liner Stabilization media volume INCLUDED for Resins and Filters	Activity in liner divided by waste volume in liner Stabilization media volume INCLUDED for Resins NOT for Filters	Activity in liner divided by waste volume in liner Stabilization media volume NOT INCLUDED
3.CONTAMINATED SOLIDS	Activity in liner divided by waste volume in liner Commingling with non TRU Solids	Activity in liner divided by waste volume in liner Commingling with lower activity TRU Solids	TRU bearing solids activity divided by solids volume No commingling
4.SEALED SOURCES	Activity in liner divided by waste volume in liner Encapsulation media volume INCLUDED for ALL	Activity in source divided by source volume Encapsulation media volume INCLUDED for non TRU sources<10Ci	Activity in source divided by source volume Encapsulation media volume EXCLUDED

4. POTENTIAL GTCC LLW TYPES AND BASIS FOR CLASSIFICATION

Any facility that produces LLW containing 10 CFR Part 61 Class C radionuclides can theoretically generate GTCC LLW. Fortunately, the types of facilities that routinely generate LLW containing these radionuclides also operate in environments that preclude or limit the potential to generate GTCC LLW. As discussed in Section 3, current and prospective disposal criteria have evolved to the extent that wastes can be divided into four main categories: (a) activated metals, (b) process wastes, (c) contaminated solids, and (d) sealed sources. Each of these categories has dominant 10 CFR Part 61 Class C radionuclides, the concentrations of which determine the extent to which wastes in the category approach or exceed Class C limits. The 10 CFR Part 61 Class C radionuclides of interest for each waste category are as follows:

- Activated Metals--The activation product radionuclides Ni-59, Ni-63, Nb-94, and C-14.
- Process Wastes--The fission product radionuclides Cs-137 and Sr-90, the activation product radionuclide Ni-63, and transuranics.
- Contaminated Solids--Transuranics.
- Sealed Sources--Two distinct groups, dependent on source type: the transuranics Am-241, CM-244, Pu-238, and Pu-239; and the radionuclides Cs-137, Sr-90, and Ni-63.

The DOE conducted a survey of LLW generators to identify waste types that could be GTCC LLW. The results of this survey are summarized in a draft DOE report.^b Table I-3 lists the wastes that the DOE indicated could exceed Class C limits and the radionuclide, or set of radionuclides, of interest. The listing in Table I-3 indicates that the waste could potential exceed Class C limits under the high volume, or most restrictive, concentration averaging case defined previously in Section 3.4. This table also indicates whether these wastes were considered GTCC for this evaluation.

The wastes identified on Table I-3 and the basis for their inclusion in this table as potential GTCC LLW are discussed by category in this section. These discussions also address the other wastes considered and the basis for their exclusion.

4.1 Activated Metals

Activated metals consist of the nonfuel-bearing components that are activated through exposure to neutron flux within light water, research, and test reactors. Emphasis is placed on light water reactors (LWR). Two sources were considered: (a) those components that are periodically replaced during normal operations, and (b) the structural components in the reactor vessel that are removed at decommissioning. These components are manufactured of stainless steels, high nickel bearing inconels, zircalloys, or a combination of all these materials. Some research reactors have aluminum components. Exposure to neutrons activates certain base metals that produce the 10 CFR Part 61 activation product radionuclides. Of particular interest in metals are nickel, which produces the Table 1 radionuclide Ni-59 and the Table 2 radionuclide Ni-63; niobium impurities in the base metals, which

b. U.S. Department of Energy, *Projected Volumes, Activities, and Other Waste Characteristics of Commercial Greater Than Class C Low-Level Radioactive Waste*, draft, Idaho National Engineering Laboratory, September 1989.

Table I-3. Potential GTCC LLW and radionuclides of interest

POTENTIALLY GTCC WASTES AND RADIONUCLIDES OF INTEREST		
Waste Category and Type	GTCC Potential	Part 61 Class C Nuclides of Interest
1. ACTIVATED METALS		
a. BWR Operations	YES	Ni-59,Nb-94,C-14,Ni-63
b. PWR Operations	YES	Ni-59,Nb-94,C-14,Ni-63
c. BWR Decommissioning	YES	Ni-59,Nb-94,C-14,Ni-63
d. PWR Decommissioning	YES	Ni-59,Nb-94,C-14,Ni-63
e. Other Reactor Internals	YES	Ni-59,Nb-94,C-14,Ni-63
2. PROCESS WASTES		
a. Spent Resins	YES	TRU,Cs-137,Sr-90
b. Cartridge Filters	YES	TRU,Cs-137,Sr-90,Ni-63
c. Aqueous Liquids	NO	TRU,Cs-137,Sr-90
d. Organic Liquids	NO	TRU
e. Zeolite Ion Exchange Media	NO	TRU
f. Sludge	NO	TRU,Cs-137,Sr-90
3. CONTAMINATED SOLIDS		
a. Non Metals	YES	TRU
b. Metals	YES	TRU
4. SEALED SOURCES		
a. TRU Bearing	YES	TRU
b. Other	YES	Cs-137,Sr-90,Ni-63

produce the Table 1 radionuclides C-14 from nitrogen impurities in stainless steel; and Nb-94. The Table 1 radionuclide Tc-99, from activation of molybdenum, is also present but yet insignificant. 10 CFR Part 61 classification is driven by either the sum of the Table 1 radionuclide concentrations Ni-59 plus Nb-94 plus C-14, or by the concentration of Ni-63 under Table 2. The Table 2 sum of the fractions drives the 10 CFR Part 61 Class C limits for most stainless steels and inconels, while the Table 1 radionuclide Nb-94 drives the Class C limits for zircalloys. For primary sources, the activation product radionuclides are secondary to the transuranic neutron source material in the component.

Type 304 stainless steels contain 8 to 11 wt% nickel plus trace ppm quantities of niobium. Zircalloys also contain trace quantities of niobium plus trace quantities of nickel. Inconels have the greatest potential for becoming GTCC LLW since they contain 52 to 72 wt% nickel plus 0.01 to 5.5 wt% niobium.

For routinely discharged components, the physical characteristics vary with LWR plant type and the component's application. The metal activation that produces 10 CFR Part 61 long-lived activation product radionuclides is directly proportional to the integrated neutron flux received by the component. Therefore, the extent to which a discharged component approaches Class C limits depends only on its initial materials composition, its axial and radial location in the core, and the duration for which it is exposed to the core neutron flux. Components that are fully inserted in the core and exposed to a relatively constant neutron flux will approach Class C limits with less incore time than those components that are only partially inserted in the same core. For example, a pressurized water reactor (PWR) instrument string will approach Class C limits after several fuel cycles since its hot end is fully inserted, while a PWR reactor control cluster assembly will never approach Class C limits since it is either fully or partially withdrawn during full power operation.

For decommissioning activated metals, the components consist of the structural components that support the fuel assemblies in the reactor vessel. Their axial and radial locations within the reactor vessel vary, and they are not exposed to the same neutron flux as fuel assemblies. Thus, while these components are exposed to a somewhat reduced neutron flux, this exposure takes place throughout the LWR operating lifetime. The physical characteristics of these structural components vary with LWR plant type and the component application. 10 CFR Part 61 activation product radionuclide content is directly proportional to the integrated neutron flux received by the component. Therefore, the extent to which a component approaches Class C limits depends only on its initial materials composition, its axial and radial location relative to the core, and the plant's operating history.

Table I-4 identifies the components considered. All component types identified as potential GTCC LLW are discussed below.

4.1.1 BWR Routine Components

The components of interest, except poison curtains, enter the core from the bottom. With the exception of control rod blades, these components are located in the active fuel region neutron flux. Potential GTCC components are discussed below.

Table I-4. Potential GTCC activated metals

POTENTIALLY GTCC ACTIVATED METALS		
	Waste Type Volume (Ft ³)	GTCC Potential
1. BWR Operations		
a. Control Rod Blades	0.6–0.64	YES
b. LPRM Strings	0.1	YES
c. Dry Tubes	0.08	YES
d. Poison Curtains	0.08	YES
e. Secondary Sources	0.03–0.05	NO
f. Fuel Channels	0.16–0.24	NO
2. PWR Operations		
a. Burnable Poison Rod Assemblies	0.06–0.24	NO
b. Thimble Plug Assemblies	0.02–0.03	YES
c. Instrument Strings	0.01–0.10	YES
d. Primary Sources	0.02–0.10	YES
e. Secondary Sources	0.01–0.10	NO
3. BWR Decommissioning		
a. Core Shroud	120–150	YES
b. Orificed Fuel Supports	14–18	YES
c. Control Rod Guide Tubes	70–95	NO
d. Top Fuel Guide	10–12	NO
e. Jet Pump Assemblies	25–30	NO
4. PWR Decommissioning		
a. Core Shroud	50–60	YES
b. Lower Core Barrel	150–200	YES
c. Thermal Shield	40–50	YES
d. Lower Grid Plate	15–20	YES
e. Upper Core Grid Plates	15–20	NO
f. Lower Support Columns	12–15	NO
5. Other Reactor Internals		
a. Research	Variable	YES
b. Test	Variable	YES

Control Rod Blades. Each core contains from 137 to 185 control rod blades (CRB) that are distributed radially throughout the core. A CRB consists of an upper handle, four blades containing neutron-absorbing material in a cruciform configuration, and a velocity limiter section. These units are attached to control rod drives at the velocity limiter end.

Typically, CRBs are comprised of B_4C absorber material in stainless steel tubing that is clad in a stainless steel sheath. Weights are model dependent and vary between 203 and 280 lb. Displaced volumes vary between 0.6 to 0.64 ft³.

Older models also contains eight stellite bearings. The top four stellite bearings are just below the handle and reside in the core. Due to the extremely high radiation levels from the cobalt in the stellite, the top four stellite bearings are usually removed prior to CRB shipment. Newer model CRBs have replaced the stellite bearings with inconel bearings, which perform the same function without the high cobalt content and attendant radiation levels.

CRBs are discharged based on boron depletion, which is proportional to the unit neutron exposure. Control patterns vary, with some CRBs full in, others full out, and others partially inserted. Some plants also run in what is referred to as the controlled cell mode. In this mode, CRB movement is restricted to a fixed group of 25 to 37 CRBs, with the rest of the CRBs completely withdrawn during full power operation.

Thus, the extent of boron depletion depends on radial location and mode of operation. Boron depletion also varies axially due to the partial insertion of the blade along its length. Some CRBs that remain incore for 10 to 15 years can have the same exposure as those run in the controlled cell mode, which remain for one to two fuel cycles.

Individual CRBs with extensive boron depletion (high neutron exposure) are potential GTCC LLW. Where stellites have been removed from the older model CRBs, the stellites alone are always GTCC LLW.

Local Power Range Monitor Strings. Each core contains 31 local power range monitor (LPRM) strings. These units are 0.7 in.-diameter and 0.03 in.-thick stainless tubing and are 38 to 42 ft in length. Each LPRM string contains four fission chambers that monitor neutron flux in the active core region. The units are inserted through the bottom of the reactor vessel. The uppermost 13 to 14 ft, which reside in the core itself, are commonly referred to as the hot end.

The metal volume of an intact LPRM string is 0.1 ft³, and the weight is about 50 lb. Each fission chamber, which is an integral part of the string, is about one in. long and weighs about 40 g.

LPRM strings are routinely discharged based on fission chamber depletion or when strings malfunction. Chamber depletion is proportional to the neutron exposure of the string which, for each fuel cycle, varies with the string radial location.

Individual LPRM strings with extensive neutron exposure of several fuel cycles are usually GTCC LLW. Where fission chambers have been removed and segregated from the string, the fission chambers alone are always GTCC LLW.

IRM/SRM Dry Tubes. Each core contains four source range monitors (SRM) and eight intermediate range monitors (IRM). These monitors are fission chambers that are inserted into the core region through stainless steel tubes referred to as dry tubes. These dry tubes are 0.69 in.

diameter and 0.012 in.-thick stainless tubing and are 42 to 44 ft in length. The units are inserted through the bottom of the reactor vessel. The uppermost 13 to 14 ft, which reside in the core itself, are commonly referred to as the hot end. The metal volume of an intact dry tube is 0.08 ft³, and the weight is about 39 lb.

Dry tubes are not routinely discharged. They are only replaced when damaged or embrittled. Individual dry tubes with extensive neutron exposure of several fuel cycles are usually GTCC LLW.

Poison Curtains. For the older plants, each core contained 140 to 170 poison curtains to shape flux during the first fuel cycle. These poison curtains are thin, about 0.06 in. thick, and have flat borated stainless steel plates 8.5 in. wide by 13 ft long. They were located between fuel assemblies and were exposed to the active fuel region neutron flux. These units receive one cycle of exposure before discharge, but, due to their axial location and small volume of about 0.08 ft³, they usually exceed Class C limits. Several of the older power plants still have poison curtains in their fuel pools.

4.1.2 PWR Routine Components

The components of interest enter the core from the top and, with the exception of instrument strings, are located above the active fuel region neutron flux.

Unlike boiling water reactors (BWRs), there are differences in materials compositions and physical characteristics among the components for the three PWR reactor manufacturers, Westinghouse, Babcock & Wilcox, and Combustion Engineering. Potential GTCC components are discussed below.

Thimble Plug Assemblies. These components are used to restrict water flow through fuel assemblies and are positioned in the tops of selected assemblies. For Westinghouse plants, they are stainless steel with an inconel spring and weigh 10 to 12 lb. They are only discharged when damaged. Although positioned above the active fuel region, their relatively long incore residence times can result in some units exceeding Class C limits.

For Babcock & Wilcox plants, orifice rod assemblies are very similar to Westinghouse thimble plugs. Orifice rod assemblies weigh about 15 lb and are made of stainless steel with an inconel spring. Like the thimble plugs, their long exposure times can result in some units exceeding Class C limits.

Incore Instrument Strings. Instrument strings consist of flux monitor probes and inconel or stainless steel flux wires. They are inserted through instrument tubes in the fuel assemblies. Their characteristics vary with reactor vendor.

Westinghouse plants use eight fixed and four movable incore detectors that contain fission chamber detectors housed in a stainless steel sheath. Each movable detector can be inserted into any one of 60 detector thimbles in the core. The fixed detectors have a total length of about 110 ft and a metal volume of about 0.06 ft³. The top 30 ft are activated due to neutron exposure. The 12 to 14 ft hot end section, which resides in the active core region, typically exceeds Class C limits. The fission chamber detectors themselves always exceed Class C limits.

Babcock & Wilcox plants have locations to accommodate 52 incore instrument assemblies. These instrument strings use rhodium emitters with inconel lead wires and stainless steel sheaths. They have a total length of about 100 ft and metal volumes in the 0.05 to 0.1 ft³ range. About 30 ft of the instrument string is neutron activated. The 12 to 14 ft hot end section typically exceeds Class C limits.

Combustion Engineering plants use between 28 and 61 incore instrument assemblies. These instrument strings use rhodium emitters attached to inconel lead wires, with the sheathing material being either inconel or stainless steel. They have a total length of 35 to 116 ft and weigh between 7 and 34 lb. Metal volumes are in the 0.01 to 0.07 ft³ range. The top 30 ft are activated due to neutron exposure. The 12 to 14 ft hot end section typically exceeds Class C limits. The inconel assemblies are the most restrictive from a classification standpoint.

Primary Sources. Westinghouse plants utilize one to two primary source assemblies. The primary source assemblies are thimble plug assemblies with one primary source rod, one to four secondary source rods, and 0 to 16 burnable poison rods. The remainder of the 24 guide tubes contain thimble plugs. The primary source assemblies have a total weight of 19 to 52 lb. The primary source rods weigh 2.7 to 3.6 lb. and are 110 to 152 in. long. The source materials are californium, plutonium-beryllium, or polonium-beryllium. The californium and plutonium-beryllium, source rods always exceed Class C limits due to the high transuranic content. Since the rods are not easily identifiable, the entire assembly is considered to exceed Class C limits.

Babcock & Wilcox plants use two primary neutron sources, which are stainless steel-clad americium beryllium sources. Each primary source is 146 in. long and 0.4 in. in diameter, with a total weight of about 1 lb. The primary sources are expected to exceed Class C limits due to the high transuranic content.

Each combustion engineering plant uses two primary neutron sources. The source assemblies are 99 to 117 in. long and weigh between 4.5 and 10.9 lb. The source assemblies are 316 stainless steel with inconel springs. Each source assembly contains one antimony-beryllium and two plutonium-beryllium sources. Due to the high transuranic content of the plutonium sources, these source assemblies will exceed Class C limits.

4.1.3 BWR Decommissioning Internals

The NRC has supported BWR decommissioning studies⁴ to identify the activated metals that could be GTCC LLW. Although these studies are dated, they are still used as reference materials on this subject. Activated metals in a BWR include the reactor vessel and its internal structural components. The low-alloy steel reactor vessel is cylindrical with hemispherical heads. Except for the top hemispherical head, the reactor vessel is clad internally with stainless steel. The vessel itself does not approach Class C limits. Other components include the core shroud, the top fuel guide, steam separators and dryers, jet pumps, control rod guide tubes, and orificed fuel supports. Except for the steam separators and dryers, these components are exposed to neutron fluxes that could lead to components, or parts thereof, that exceed Class C limits. These components are discussed below.

Core Shroud. The shroud is a large cylindrical type 304 stainless steel structure (about 90 to 180 ft³) that surrounds the core and provides a barrier to separate the upward flow through the core from the downward flow in the annulus. A flange at the top of the shroud mates with a flange on the steam separator assembly to form the core discharge plenum. This component can readily exceed Class C limits.

Orificed Fuel Supports. Each fuel assembly that makes up the core rests on an orificed fuel support (guide) mounted on top of the control rod guide tubes. Each fuel support is stainless steel and supports one to four fuel assemblies, dependent upon the radial location in the core. Each unit is about 1 ft² and has a metal volume of about 0.1 ft³ for a total metal volume of about 14 to 18 ft³. It is unlikely that these components will exceed Class C limits.

Control Rod Guide Tubes. Each core contains 137 to 185 type 304 stainless steel control rod blade guide tubes that extend from the top of the control rod drive housings up through holes in the core support plate. Besides serving as guides for control rods, the tubes also provide support for the fuel assemblies surrounding the control rods. Each guide tube has a metal volume of 0.5 ft³ for a total metal volume of about 70 to 95 ft³. It is unlikely that these components will exceed Class C limits.

Top Fuel Guide. The top fuel guide is a stainless steel structure that provides lateral support for the top section of the fuel assemblies. It is composed of about 10 to 12 ft³ of stainless steel beams that are joined at right angles, forming square openings for the fuel assemblies. The beams are fastened to a peripheral rim that rests on the core shroud. Dependent upon the core design, the beams that make up the top fuel guide can extend down into the active fuel region, which considerably increases their activation. Some portions of the top fuel guide that are toward the center of the core may exceed Class C limits, but the component as a whole is not expected to be GTCC.

Jet Pump Assemblies. Two semicircular groups of 10 jet pumps are located in the outer annulus between the core shroud and the reactor vessel wall. The jet pumps are type 304 stainless steel and have a total metal volume of 25 to 30 ft³. Each jet pump consists of an inlet riser pipe, a driving nozzle, a suction inlet, a throat or mixing section, and a diffuser with attachment braces. The driving nozzle, suction inlet, and throat are joined together as a removable unit. The diffuser, associated bracing, and riser pipe are permanently installed. This component should not exceed Class C limits.

4.1.4 PWR Decommissioning Internals

The NRC has also supported PWR decommissioning studies.⁵ These studies are dated but continue to be used as reference materials. Activated metals in a PWR include the reactor vessel and its internal structural components. The reactor vessel is cylindrical, with a hemispherical bottom head and a flanged and gasketed removable upper head. The body of the vessel is low alloy carbon steel. Inside surfaces in contact with coolant are clad with a minimum of 1/8 in. of stainless steel. The vessel itself does not approach Class C limits.

PWR internals include the core shroud and support structures, thermal shield, and coolant circulating channels. These components are exposed to neutron fluxes that could lead to components, or parts thereof, exceeding Class C limits. These components are discussed below.

Core Baffle (Shroud). The baffle, or shroud, is a type 304 stainless steel structure that surrounds the core and provides for a limited water flow between the baffle and the core barrel in order to provide additional cooling of the barrel. The core shroud has a metal volume of about 40 to 70 ft³. This component can readily exceed Class C limits.

Lower Core Barrel. The lower core barrel is a type 304 stainless steel cylinder that provides lateral support for the core and directs the flow of coolant water. The lower core barrel has a metal volume of about 80 to 130 ft³. The lower core barrel can exceed Class C limits.

Thermal Shield. The thermal shield is attached to the lower core barrel in the high flux region and protects the reactor vessel by attenuating gamma radiation and fast neutrons that escape the core. The heat energy deposited in the thermal shield is removed by the reactor coolant. The thermal shield is type 304 stainless steel and has a metal volume of about 50 to 110 ft³. It is unlikely that these components will exceed Class C limits.

Lower Grid Plate. The lower grid plate is type 304 stainless steel and has a metal volume of 15 to 20 ft³. It is positioned at the bottom level of the core and provides support and orientation for the fuel assemblies. The lower grid plate is perforated and contains the locating pins for the fuel assemblies. This component should not exceed Class C limits.

Upper Core Grid Plates. The upper core grid plate contains about 15 to 20 ft³ of 304 stainless steel. It is perforated and provides orientation for the upper core support assembly. Fuel assembly locating pins protrude from the bottom of the upper core grid plate and engage the fuel assemblies as the upper assembly is lowered into place. Some parts of the lower core barrel could exceed Class C limits. The component, as a whole, should not exceed Class C limits.

Lower Support Columns. Columns made from type 304 stainless steel are placed between the lower grid plate and the bottom support casting of the core barrel in order to provide stiffness to this plate and transmit the core load to the bottom support casting. The lower support columns have a metal volume of about 12 to 15 ft³. This component should not exceed Class C limits.

4.1.5 Research and Test Reactor Components

There is a diversity in types and sizes of nuclear research and test reactors and in their operating schedules and lifetimes. This significantly affects the generation of neutron activated materials that can potential exceed Class C limits. The neutron flux levels in these reactors are low compared to power reactors, and the irradiation histories are very different due to intermittent operation for relatively short lifetimes. The facilities considered are:

- TRIGA research reactor with a postulated 40-year operational lifetime at about 5% operating time utilization.
- 60 MWt Materials Test Reactor (MTR), light water moderated and cooled, used in testing materials for space flight applications. This reactor was operated over a 12-year period for a total of 4.476 effective full power years (EFPY).

These reactors do not use routinely replaced stainless steel components, as power reactors do. The relatively low fluxes mitigate against routine GTCC components, and, while isolated cases can be found, these are not a likely source of GTCC LLW.

At the decommissioning of these units, some GTCC LLW could be generated. The NRC studies⁶ on this subject, which are dated, indicate that these units generate small volumes of GTCC LLW at decommissioning.

The core assembly of the TRIGA reactor is a right-circular cylinder 3.6 ft in diameter and 2 ft high. It consists of a compact concentric array of cylindrical fuel elements with a central thimble, a neutron source, and control rods. The stainless components in the core include rotary specimen rack hardware, grid plate inserts and hardware, and three control rods. The aluminum components of the core do not approach Class C limits. The stainless steel components are located close to the core centerline and can potentially exceed Class C limits.

The MTR vessel is 31 ft tall and 8.8 ft O.D. It is fabricated of type A-201 steel with a type 304 stainless steel cladding. The major internal components are the core (including fuel, control rods, and in-core nuclear instrumentation), the core support structure (including the upper and lower flow guides, control rod drive box, and orifice plate), the thermal shields, the horizontal and vertical test holes, the horizontal beam holes, the thermal column, and the rabbit tubes. Some of these components are potential GTCC LLW.

4.2 Process Wastes

Process wastes consist of the wet wastes that are generated from cleanup of liquids containing soluble and insoluble radioactive constituents.

At power plants, these wastes are in the form of ion-exchange media, filter media, or cartridge filters. These waste forms are potential GTCC due to the concentrations of the Table 2 radionuclides Cs-137 and Sr-90, which have limits of 4600 and 7000 $\mu\text{Ci/cc}$ respectively. The Class C status of some cartridge filters is also affected by the presence of Ni-63, another Table 2 radionuclide with a Class C limit of 700 $\mu\text{Ci/cc}$. Where plants have operated with failed fuel, the concentrations of transuranics, with a Class C limit of 100 nCi/g, can also lead to GTCC LLW.

The other facilities originally considered by DOE included fuel development and fabrication facilities and academic institutions.

Table I-5 identifies the process wastes considered for LWRs, as well as the other types of facilities that could generate GTCC process wastes. Not all process wastes identified are potential GTCC LLW due to the facility type, specific activity, or Class C radionuclide content, or a combination of these factors. All process wastes shown as potential GTCC LLW are discussed below. Where a waste type is not potential GTCC, the basis for this conclusion is also discussed.

4.2.1 BWR Resins--Normal Operations

The BWR waste types of interest use deep bed resins, powdered resins, and other types of filter media. While these waste types can be Class C, in the absence of extensive fuel failures they will not exceed Class C limits.

- **Reactor Water Cleanup Resins (RWCU)**--These are generated by deep-bed demineralizers consisting of powdered resins. Beds of about 150 ft³ are depleted and transferred every 12 to 18 months.
- **Fuel Pool Cleanup Resins**--These are generated by relatively small ion-exchange vessels consisting of bead resins, usually two beds with 30 ft³ capacity. Beds are depleted and transferred every 12 to 18 months.

Table I-5. Potential GTCC process wastes

POTENTIALLY GTCC PROCESS WASTES		
	Waste Type Volume (Ft ³)	GTCC Potential
1.BWR Resins – Normal Operations		
a.Reactor Water Cleanup	150	NO
b.Fuel Pool Cleanup	30	NO
c.Fuel Pool Filter Precoat	20–30	NO
2.PWR Resins – Normal Operations		
a.Chemical and Volume Control System	30	NO
b.Fuel Pool Cleanup	30	NO
3.BWR Decontamination Resins		
a.Recirculation/RWCU	100–150	NO
b.Full System – Fuel Out	600–800	YES
c.Full System – Fuel In	1000–1200	YES
4.PWR Decontamination Resins		
a.Steam Generator Channel Head	200–300	NO
b.Full System – Fuel Out	500–4000	YES
c.Full System – Fuel In	600–4000	YES
5.BWR Cartridge Filters		
a.Control Rod Drive	0.01	YES
b.Fuel Pool	0.5	YES
c.Underwater Vacuum	0.5	YES
6.PWR Cartridge Filters		
a.Seal Water Injection	0.1–0.5	YES
b.Seal Water Return	0.5	YES
c.Reactor Coolant system	0.5	YES
d.Letdown	2	YES
e.Fuel Pool	0.5	YES
7.Aqueous Liquids		
	Variable	NO
8.Organic Liquids		
	Variable	NO
9.Zeolite Ion Exchange		
	Variable	NO
10.Sludge		
	Variable	NO

- Fuel Pool Filter Precoat (older BWRs only)--These are fuel pool filter septums (>200 micron elements) coated with a back-flushable mixture of powdered resin and cellulose. Volumes range from 20 to 30 ft³ per charge.

4.2.2 PWR Resins--Normal Operations

The PWR waste types of interest use deep bed cation and anion resins. While these waste types can be Class C, in the absence of extensive fuel failures, they will not exceed Class C limits.

- Chemical and Volume Control System Resins (CVCS)--These bead resins are generated from cation and mixed bed demineralizers with capacities of 30 ft³. Four beds are usually discharged after normal refueling cycles (prior to starting up again) every 12 to 18 months.
- Fuel Pool Cleanup Resins--These bead resins are generated from cation and mixed bed demineralizers with bed capacities of 30 ft³. Beds are discharged every 12 to 24 months.

4.2.3 Decontamination Resins

Two decontamination processes have been employed to date at BWRs, referred to as the LOMI and CANDECON processes. Although the primary systems differ, the same two decontamination processes have been employed at PWRs. A third process, referred to as CANDEREM, is also being evaluated for the full reactor coolant system decontamination at PWRs. These processes deposit the crud and scale removed from the reactor internal surfaces on deep bed resins.

Each of these decontamination processes involves several steps and uses different types of resin that include cation, mixed, and anion beds. The chelation step generates the cation resins, which can contain up to 75% of the total activity removed during the decontamination. The cation resins have the highest curie loading and could exceed Class C limits.

At BWRs, these processes have only been employed on the recirculation reactor water cleanup (RWCU) system, that represents less than 20% of a typical BWR system surface area with fuel out. At PWRs, these processes have only been employed on the steam generator channel heads. Channel heads represent less than 1% of the surface area of a PWR primary system.

The power industry is also considering what is referred to as a full RCS decontamination with and without fuel assemblies in the system. These decontamination operations are not routine operations and might be employed once per decade at a plant for as low as is reasonable achievable (ALARA) reasons.

A recent study⁷ examined the GTCC potential for the resins generated by the CANDECON and LOMI processes. The data were more recently supplemented by an ongoing evaluation of full RCS system decontamination^c for PWRs. Some of the results of these studies are summarized below.

BWR Recirculation/RWCU Piping System. This decontamination process covers a surface area of about 1800 m² and generates 100 to 150 ft³ of resin, dependent upon the decontamination process employed (Reference 5) It is highly unlikely that these resins will be GTCC LLW.

c. Westinghouse presentation to U. S. Nuclear Regulatory Commission, December 1990.

BWR Reactor Coolant System (Fuel Out). This decontamination process covers an RCS surface area of about 11,000 m². It can generate 600 to 800 ft³ of resin, dependent on the decontamination process employed (Reference 5). It is unlikely that these resins can be GTCC LLW.

BWR Reactor Coolant System (Fuel In). This decontamination process covers the same RCS surface area plus the fuel assemblies, which represent an additional 12000 m², (including fuel channels) for a total area of about 23,000 m². It can generate 1000 to 1200 ft³ of resin, dependent upon the decontamination process employed (Reference 5). Cation resin volumes could range from 200 to 275 ft³. Due to the presence of the fuel assemblies, a source of TRU radionuclides, about half of these cation resins can be GTCC LLW.

PWR Steam Generator Channel Head. This decontamination process covers a surface area of about 1.5 m² and generates 200 to 300 ft³ of resin (Reference 5), dependent upon the decontamination process employed. It is highly unlikely that these resins will be GTCC LLW.

PWR Reactor Coolant System (Fuel Out). This decontamination process covers an RCS surface area of about 200 m². One study (Reference 5) estimates it can generate 1500 to 1700 ft³ of resin, dependent upon the decontamination process employed. Other sources (Footnote a) indicated larger volumes, ranging from 3,000 to 4,000 ft³. About 75% of the activity is on 300 ft³ of cation resin. It is unlikely that these cation resins will be GTCC LLW.

PWR Reactor Coolant System (Fuel In). This decontamination process covers the same RCS surface area plus the fuel assemblies, which represent an additional 50 m², for a total area of about 250 m². One study (Reference 5) indicated 1600 to 1700 ft³ of resin, dependent upon the decontamination process employed. The other study (Footnote a) indicated volumes ranging from 3,000 to 4,000 ft³. About 75% of the activity is on 300 ft³ of cation resin. About half of these cation resins could be GTCC LLW.

4.2.4 BWR Cartridge Filters

The BWR filter cartridges of interest remove particulates from primary coolant and in the spent fuel pool. Due to their relatively small volumes and high activities, these filters are usually Class C. Individual filters can exceed Class C limits.

- **Control Rod Drive Strainers**--Each control rod drive contains three strainers that remove particulates. The volumes of these strainers are very small at 0.006 to 0.06 ft³, and individual strainers, particularly the small unit at the spud end, could be GTCC LLW. These strainers are replaced when the control rod drives are refurbished.
- **Fuel Pool Filters**--These units are located upstream or downstream of fuel pool purification demineralizers and consist of cartridge-type filter elements with metal retention screens. Their sizes vary but are usually about 6 in. in diameter and 30 in. long. The volume is about 0.5 ft³.
- **Underwater Vacuum Filters**--These units consist of large and small micron cartridge filters with metal retention screens. They are generated in the fuel pool during refueling. The volume is about 0.5 ft³.

4.2.5 PWR Cartridge Filters

PWRs use cartridge filters throughout the primary and secondary systems. Because of their relatively small volumes and high activities, these filters are usually Class C. Individual filters can exceed Class C limits.

- Seal Water Injection (SWI) Filters--These units consist of very small micron metal or fiber retention elements to purify water from the volume control tank. Reactor coolant pump SWI filters are normally changed during refueling operations and after major power transients. Filter cartridge sizes vary from 2 in. in diameter by 6 in. long to 6 in. in diameter by 30 in. long.
- Seal Water Return (SWR) Filters--These units consist of medium micron metal or fiber retention elements. Reactor coolant pump SWR filters are normally changed during refueling operations and after major power transients. Typically these units are about 0.5 ft³.
- Reactor Coolant System (RCS) Filters--These units consist of small to medium micron size cartridge filters with metal retention screens that purify water returning to the volume control or make-up tank. These filters are normally changed during normal refueling operations and after major power transients. Typically, these units are about 0.5 ft³.
- Letdown Filters--Some PWRs use back-flushable letdown filters downstream of the nonregenerative heat exchanger. When these filters are back-flushed, the liquids and solids pass through medium to large micron cartridge filters (crud filters) with metal retention screens prior to being transferred to a waste holdup tank. These units could be as large as 12 in. in diameter and 30 in. long, or about 2 ft³.
- Fuel Pool Filters--These units are located upstream or downstream of fuel pool purification demineralizers and have cartridge type-filter elements with metal retention screens. Their sizes vary but are usually about 6 in. in diameter and 30 in. long, or about 0.5 ft³.

4.2.6 Aqueous Liquids

The DOE survey (Footnote b) indicated that one respondent, an academic institution, had TRU-bearing aqueous liquids that were GTCC LLW. These wastes must be stabilized for disposal, and it is unlikely that the stabilized liquids will exceed Class C limits.

4.2.7 Organic Liquids

The DOE survey (Footnote b) indicated that three respondents, all industrial firms, had organic liquids that were GTCC LLW. These wastes are mixed wastes and are thus excluded from consideration.

4.2.8 Zeolite Ion-Exchange Media

The DOE survey (Footnote b) indicated that some utility respondents had zeolite ion-exchange media that were GTCC LLW. Most of these wastes were produced during cleanup of Three-Mile Island reactor TMI-2, and were disposed of at a DOE facility. A form of zeolites is currently used

in the power industry, but the liquid waste types processed are not those that could lead to GTCC LLW.

4.2.9 Filter Sludge

The DOE survey (Footnote b) indicated that a utility respondent had TRU-bearing sludge in the fuel pool that was GTCC LLW. TRU-bearing sludges from fuel pools are usually deposited on cartridge filters. They do not warrant a separate waste type designation since they are addressed under cartridge filters.

4.3 Dry Contaminated Solids

Dry wastes are routinely generated at most facilities in the nuclear power industry and by other commercial users of radioactive materials that produce LLW. In fact, these dry materials, which are in the form of contaminated plastic, paper, cloth, glass, metals, and wood, have historically represented the largest volume of LLW generated.

Since these materials become LLW due to contamination, their specific activity is usually very low, and they rarely exceed Class A limits, much less Class C limits. Accordingly, the routine generation of GTCC LLW based on exceeding the Class C limits for Table 2 radionuclides like Cs-137, Sr-90 and Ni-63 is highly unlikely. For most facilities, it is also unlikely that the Class C Table 1 limits for transuranics will be exceeded. There are, however, some fuel development and hot cell facilities that could generate GTCC LLW due to TRU contamination. These waste types are discussed below.

4.3.1 Contaminated Nonmetals

These wastes are compactible and, in most cases, combustible. Dry wastes that are produced in areas that contain TRU radionuclides are usually segregated and evaluated separately before commingling with other dry wastes or volume reduction processing. The DOE survey (Footnote b) indicated volumes for these wastes. They are unique to a few facilities.

4.3.2 Contaminated Metals

These wastes are generated by the same types of facilities as the nonmetals, but the metals are neither readily compactible nor combustible. The DOE survey (Footnote b) indicated volumes for these wastes. They are limited to a few facilities.

4.4 Sealed Sources

Sealed sources consist of small capsules, usually stainless steel, which encapsulate relatively high concentrations of a single radionuclide. Sources are used for a wide range of industrial and medical applications and become waste when they are no longer usable. The NRC has conducted a survey on sealed sources.^d

Criteria for disposal of sealed sources has evolved to the point where the sources can be divided into two distinct groups: (a) those containing transuranics, and (b) other radionuclides. As noted

d. U. S. Nuclear Regulatory Commission, Sealed Source Data Survey, December 1990.

in Section 3, the current and prospective criteria for disposal of TRU sources is more stringent than that for non-TRU sources.

Transuranics are 10 CFR Part 61 Table 1 radionuclides with a Class C limit of 100 nCi/g. The transuranic radionuclides of interest include Am-241, Cm-244, Pu-238, and Pu-239. For other sealed sources, the radionuclides of interest are Cs-137, Sr-90, and Ni-63. These are all 10 CFR Part 61 Table 2 radionuclides with Class C concentration limits of 4600, 7000, and 700 μ Ci/cc, respectively.

Table I-6 identifies the types of sealed sources considered, their volumes and activity ranges, and radionuclides of interest. All source types identified are discussed below by group.

4.4.1 Transuranic-Bearing Sources

As shown in Table I-6, most TRU sealed sources have activities in the millicurie to curie range and volumes in the 1 cc to 1000 cc range. Assuming the density for stainless steel, most sealed source TRU concentrations are orders of magnitude above the 100 nCi/g, which is the Class C limit. A description of these sources and their characteristics is presented below.

TRU Gamma Gauges. These are used throughout industry to measure or control processes, component thickness, density, and other industrial parameters. Both Am-241 and Cm-244 sources are used. For Am-241 gauges, source strength may vary from 0.1 μ Ci to 10 Ci. For Cm-244 gauges, the strength may vary from 1 mCi to 1 Ci.

Typically the volumes of these sources are less than 1 cc and, assuming a stainless steel density, weigh about 8 g. All sources with strengths above 1 μ Ci exceed Class C limits.

X-Ray Fluorescent Sources. These are used to determine material composition. Both Am-241 and Cm-244 sources are used. For Am-241 sources, source strength may vary from 2 to 200 mCi. For Cm-244 sources, the strength may vary from 10 to 100 mCi. Typically, the volumes of these sources are less than 1 cc and, assuming a stainless steel density, weigh about 8 g. All these sources exceed Class C limits.

TRU Well Logging Sources. These are used to determine geological properties of rock formations. Each licensee uses both a gamma source and a neutron source. The neutron sources are either Am-241/Be or Pu-239/Be. Source strengths can vary from 5 to 20 Ci. Typically, the volumes of these sources are less than 1 cc and, assuming a stainless steel density, weigh about 8 g. All these sources exceed Class C limits.

TRU Moisture Density Gauges. These are portable devices used to measure the moisture content of soils and other materials. The TRU type primarily consists of 50 mCi Am-241 sources with a source volume of about 500 cc. Assuming a stainless steel density, these sources weigh about 4000 g for a concentration of 12,500 nCi/g. All these sources exceed Class C limits.

Smoke Detectors. These devices are used in homes to detect combustion gases and particles. They employ Am-241 sources in the 1 to 180 μ Ci range. The sources themselves are very small, about 0.1 cc, and even at the 1 μ Ci level, they exceed Class C limits. Since they are consumer products, they are not regulated as LLW. However, the manufacturers of these devices are regulated and do produce them as LLW.

Table I-6. Potential GTCC sealed sources

POTENTIALLY GTCC SEALED SOURCES					
	Part 61 Nuclide Of Interest	Typical Volume cc	Minimum Activity Ci	Maximum Activity Ci	GTCC Potential
TRU Bearing Sources					
1. Gamma Gauges	Am-241	1	1.00E-07	1.00E+01	YES
	Cm-244	1	1.00E-03	1.00E+00	YES
2. X-Ray Fluorescent	Am-241	1	2.00E-03	2.00E-01	YES
	Cm-244	1	1.00E-03	1.00E-01	YES
3. Well Logging	Am-241	1	5.00E+00	2.00E+01	YES
	Pu-239	1	5.00E+00	5.00E+00	YES
4. Moisture Gauges	Am-241	500	5.00E-02	5.00E-02	YES
5. Smoke Detectors	Am-241	1	1.00E-06	1.80E-04	YES
6. Pacemakers	Pu-238	100	4.00E+00	4.00E+00	YES
Other Sources					
1. Med. Teletherapy	Cs-137	50	1.00E+02	1.50E+03	YES
2. Gamma Gauges	Cs-137	1	1.00E-07	1.00E+01	YES
3. Beta Gauges	Sr-90	3	1.00E-08	1.00E-01	YES
4. Well Logging	Cs-137	50	2.00E+00	2.00E+00	YES
5. Moisture Gauges	Cs-137	100	1.00E-02	1.00E-02	NO
6. Calibration	Cs-137	2	1.00E-04	3.00E+01	YES
7. Gamma Irradiators I	Cs-137	50	3.00E+01	3.00E+04	YES
8. Gamma Irradiators II-IV	Cs-137	2000	1.00E+03	1.00E+04	YES
9. Gas Chromatography	Ni-63	0.02	1.00E-02	2.00E-02	YES
10. Beta Eye Applicators	Sr-90	1	7.50E-02	1.50E-01	YES

Heart Pacemakers. These devices are implanted in humans to regulate heartbeat. These devices contain about 4 Ci of Pu-238 and contain about 50 g of material. All these sources exceed Class C limits.

4.4.2 Nontransuranic Sealed Sources

As shown in Table I-6, other sealed sources have activities from microcuries to thousands of curies and volumes that vary from less than 1 cc to 2000 cc. While some of these sources do not exceed Class C limits, most of them do. A description of these sources and their characteristics is presented below.

Medical Teletherapy Sources. These sources are used to directly treat diseases with gamma radiation. Most are Co-60 sources that cannot exceed Class C limits, but some are also Cs-137 sources. Due to their applications, these are high activity sources containing up to 1500 Ci. They also have relatively small volumes in the 30-50 cc range. At a limit of 4600 $\mu\text{Ci/cc}$, all these Cs-137 sources exceed Class C limits.

Other Gamma Gauges. These are used throughout industry to measure or control processes, component thickness, density, and other industrial parameters. Cs-137 sources are used with source strengths in the 0.1 μCi to 10 Ci range. Typically, the volumes of these sources are less than 1 cc. Accordingly, at a limit of 4600 $\mu\text{Ci/cc}$, all Cs-137 sources with strengths above 4.6 mCi exceed Class C limits.

Well Logging Sources. These are used to determine geological properties of rock formations. Each licensee uses both a gamma source and a neutron source. The gamma source is usually 2 Ci of Cs-137. Typically, the volumes of these sources are 30 to 50 cc. At a limit of 4600 $\mu\text{Ci/cc}$, all these Cs-137 sources exceed Class C limits.

Beta Gauges. Beta-emitting sources are also used throughout industry to measure or control processes, component thickness, density, and other industrial parameters. Sr-90 sources are used with source strengths in the 0.01 μCi to 100 mCi range. Typically, the volumes of these sources are less than 5 cc. At a limit of 7000 $\mu\text{Ci/cc}$, all Sr-90 sources with strengths above 30 mCi exceed Class C limits.

Moisture Density Gauges. These are portable devices used to measure the moisture content of soils and other materials. The non-TRU type primarily consists of 10 mCi Cs-137 sources, with a source volume of about 100 cc. At a limit of 4600 $\mu\text{Ci/cc}$, all these Cs-137 sources are below Class C limits.

Calibration Sources. These are used to determine the accuracy of instruments. These are typically Cs-137 sources with strengths in the 100 μCi to 30 Ci range. The volumes are relatively small, about 2 cc. At a limit of 4600 $\mu\text{Ci/cc}$, all Cs-137 sources with strengths of about 70 mCi exceed Class C limits.

Category I Gamma Irradiators. These are self-shielded devices used for food and materials irradiation. They are Cs-137 sources with activities in the 30 to 30,000 Ci range, with volumes in the 30-50 cc range. At a limit of 4600 $\mu\text{Ci/cc}$, all these Cs-137 sources exceed Class C limits.

Category II, III, and IV Gamma Irradiators. These are very high activity irradiators that are themselves composed of multiple sources. They are Cs-137 sources with activities up to 15 million Ci.

Source volumes are relatively large, about 2000 cc. Assuming individual source strengths in the 10,000 Ci range, all these Cs-137 sources exceed Class C limits.

Gas Chromatography Sources. These are used in the chemical analysis of materials. These sources are primarily Ni-63 and have strengths in the 10-20 mCi range. Volumes are very small, less than 0.1 cc. At a limit of 700 $\mu\text{Ci/cc}$, all these Ni-63 sources exceed Class C limits.

Beta Eye Applicators. These are Sr-90 sources used to treat eye cancers. Typically, source strengths are in the 75 to 150 mCi range, and volumes are small, about 1 cc. At a limit of 7000 $\mu\text{Ci/cc}$, all these Sr-90 sources exceed Class C limits.

5. CONCENTRATION AVERAGING AND RELATIVE VOLUME PROJECTIONS

Section 4 identified the waste types that could potential exceed Class C limits under the most conservative concentration averaging scenario--the high volume case. This section analyzes each potential GTCC LLW type and quantifies its volume relative to the base and low volume scenarios defined in Section 3. These relative volume factors can be incorporated into the DOE projection model to project volumes as a function of concentration averaging scenario.

5.1 Methods of Analysis

For discussion purposes, the concentration averaging scenarios defined in Section 3 were redefined. The high volume case is referred to as worst, the base volume case is referred to as average, and the low volume case is referred to as best.

As described in Section 4, a wide range of routinely generated waste types could exceed Class C limits and become GTCC LLW. In some cases, the waste type clearly exceeds the limits, and all the waste produced is GTCC. This applies to some sealed sources. In other cases the waste type only exceeds the limits under worst case assumptions, the high volume scenario. This applies to activated metals in the form of BWR dry tubes. In still other cases, while the waste type exceeds the limits under the worst case scenario, only a portion of the amount generated does so. This applies to activated metals in the form of BWR control rod blades where position and mode of operation impact classification status relative to Class C limits.

To analyze the impact of the various concentration averaging scenarios on volume projections, the high volume case was used as the baseline. Each potential GTCC LLW type under this scenario was reviewed, and the amounts of GTCC LLW in the waste type were estimated. To quantify these amounts as percentages, current practices were used in conjunction with the following qualitative descriptors.

- 100%--Essentially all of the waste generated by the waste type will be GTCC.
- 75%--Most of the waste generated by the waste type will be GTCC.
- 50%--About half of the waste generated by the waste type will be GTCC.
- 25%--Some of the waste generated by the waste type will be GTCC.
- 10%--A small portion of the waste generated by the waste type will be GTCC.
- 1%--Essentially none of the waste generated by the waste type will be GTCC. The minimum used for the base case.

Once these estimates were applied to the high volume case by waste type, they were either left intact or adjusted downward to reflect the estimated volumes generated under the less conservative average and best cases. After each waste type in each waste category was quantified as to relative volume in this manner, all quantitative estimates were normalized to the average volume case.

5.2 Activated Metals

The concentration averaging criteria used for both routinely generated and decommissioning activated metals were assumed to be the same. These included:

- Worst Case--No concentration averaging.
- Average Case--Concentration averaging within a factor of 10 among components in the same disposal liner.
- Best Case--Concentration averaging of all activated metals in the disposal liner.

Table I-7 presents the estimates of the portion of each waste type that could be GTCC. The basis for these estimates is discussed below.

The routinely discharged irradiated components described below may exceed Class C limits. However, these irradiated component types, as well as others, may be included in the standard DOE fuels agreement and accompany spent fuel to the DOE repository.

5.2.1 BWR Components

Control rod blades are the largest volume component and are typically discharged in batches when boron is almost depleted. Their characteristics at discharge depend on their position in the core, their irradiation history, and the mode of operation. Records for over 600 control rod blades shipped for disposal were reviewed. About 80 of these blades were run in the controlled cell mode. Most blades that have not been operated in the controlled cell mode are not GTCC at discharge, although at times some of these blades have occupied several different positions and have been in cores for 10 to 15 years. Generally, control rod blades that received over seven cycles of exposure tended to exceed Class C limits. These were a small portion of the blades operated in the normal mode and are GTCC under the worst case conditions.

Blades operated in the controlled cell mode are discharged after one to two fuel cycles and have been operated almost fully inserted. Some of these blades, particularly the two cycle blades, can be GTCC at discharge. In neither case do these blades exceed Class C limits by factors of more than 2. Thus, the concentrations of these and others discharged are usually within a factor of 10, permitting disposal under the average case. Occasionally, a controlled cell mode blade can fall outside the factor of 10 relative to other blades available and be GTCC under the average case. Thus a small portion of the controlled cell mode blades can be GTCC under average conditions. Under best case conditions, there is always another activated metal that can be packaged with GTCC blades.

Both LPRM strings and dry tubes are typically installed for several fuel cycles. Over 1000 LPRM string and about 80 dry tube records were reviewed. Dry tubes are almost always GTCC, and most LPRM strings are GTCC under the worst case. Generally, only those LPRM strings removed early, after one or two cycles, did not exceed Class C limits. Both types of components have very low volumes, which makes it relatively easy to blend these components with the larger volume control rod blades. LPRM strings and dry tubes can usually meet the factor of 10 criteria. Occasionally, some units cannot meet the factor of 10 criteria and become GTCC LLW under the average case. Under best case conditions, there is always another activated metal that can be packaged with GTCC LPRMs and dry tubes.

Table I-7. Relative impact assessment--activated metals

RELATIVE IMPACT ASSESSMENT ACTIVATED METALS			
	Percent GTCC High Case	Percent GTCC Base Case	Percent GTCC Low Case
1.BWR Operations			
a.Control Rod Blades			
–Not Control Cell	25	10	0
–Control Cell	10	1	0
b.LPRM Strings	75	10	0
c.Dry Tubes	100	10	0
2. PWR Operations			
a.Thimble Plug Assemblies	25	0	0
b.Instrument Strings	75	10	0
c.Primary Sources	100	100	100
3.BWR Decommissioning			
a.Core Shroud	100	100	100
b.Orificed Fuel Supports	10	1	0
4.PWR Decommissioning			
a.Core Shroud	100	100	100
b.Lower Core Barrel	25	1	0
c.Thermal Shield	25	1	0
d.Lower Grid Plate	100	100	75
5.Other Reactor Internals			
a.Research	100	100	0
b.Test	100	1	0

Poison curtains are limited to early BWRs and all in existence were discharged in the 1970s. Several hundred poison curtain records were reviewed. At discharge, essentially all these units were GTCC due to their locations and low volumes. Some units still remain in several fuel pools. While they met the factor of 10 for the average case, there wasn't enough other hardware to blend with them for shipment. These units should be disposed before the 1993 deadline, and this component type should not be included in the DOE projection model.

5.2.2 PWR Components

Thimble plug assemblies are not routinely discharged. About 180 records from both Westinghouse and Babcock & Wilcox plants were reviewed. Of the Babcock & Wilcox components, none exceeded Class C limits. The Westinghouse units generally had lower volumes and had seen more fuel cycles than the Babcock & Wilcox units. Some of these Westinghouse units exceeded Class C limits. A small portion of Westinghouse thimble plug assemblies are GTCC at discharge, primarily due to their low volume and the presence of the inconel spring. Under average case conditions, they can be readily combined with other PWR components like burnable poison rod assemblies and meet the factor of 10 criteria for disposal. Hence, these units are not GTCC under average or best case conditions.

Instrument strings vary by manufacturer. Over 800 instrument string records from all three manufacturers were reviewed. About 85% of these units were from combustion engineering plants that regularly replace the strings. About 50% of these units just exceeded Class C limits. A similar situation existed for the Babcock & Wilcox instrument strings. The records reviewed for the Westinghouse plants were for thimble tubes, the stainless tubes into which instrument strings are inserted. All of these units exceeded Class C limits. Although the thimble tubes are removed infrequently, all these units could exceed Class C limits under worst case conditions.

5.2.3 BWR Decommissioning

The core shroud in a BWR should greatly exceed Class C limits due to its proximity to the active fuel region and the long exposure time over the lifetime of a BWR. All of the core shroud will be GTCC even under best case conditions.

5.2.4 PWR Decommissioning

The core baffle (shroud) in a PWR will greatly exceed Class C limits due to its proximity to the active fuel region and the long exposure time. All core shrouds will be GTCC, even under best case conditions.

The lower core barrel will also be GTCC under worst case conditions. However, blending these parts with other internals reduces this to the point where only some core barrels will exceed Class C limits under average case conditions.

There should be no core barrels above Class C limits under best case conditions.

5.2.5 Research and Test Reactor Components

For the TRIGA research reactor, the control rods and the grid plate inserts and hardware will be GTCC under worst case conditions. A small portion of the rotary specimen rack hardware will be GTCC. Blending is limited for the base or average case as there is not much stainless in the core

that can be used for blending. However, the best or low volume case includes aluminum for blending, which reduces the GTCC LLW to essentially zero for the TRIGA research reactor.

For the test reactor, the stainless components that will be GTCC under the worst case include the control rod (upper rollers), miscellaneous bolts, instrumentation thimbles, and shim rod section. Some of the stainless metering plate and flow guide will also be GTCC. Blending these wastes with other activated metals will result in essentially no GTCC LLW from these components for the average case.

5.3 Process Wastes

The concentration averaging criteria used for process wastes included:

- Worst Case--No concentration averaging.
- Average Case--Concentration averaging in that stabilization media volume can be included for resins but not filters.
- Best Case--Concentration averaging in that stabilization media volume can be included for resins and filters.

Table I-8 presents the estimates of the portion of each waste type that could be GTCC. The basis for these estimates is discussed below.

5.3.1 Decontamination Resins

Decontamination resins generated from BWR and PWR full reactor coolant system decontaminations performed about every 10 years could exceed Class C limits. Full RCS decontaminations have not yet been performed, but it is likely that about half of the resins generated with fuel in could exceed Class C limits under worst case conditions. Under average conditions, when these resins are stabilized, essentially none of these resins should be GTCC LLW. The same applies to these resins under the best case conditions.

5.3.2 Cartridge Filters

Operationally, filters can be changed out on radiation level to preclude generation of GTCC LLW in most cases. However, routine practices that rely on pressure differential for filter change-out were assumed for this evaluation.

Filter cartridges are expected to exceed Class C limits when characterized as individual units under the worst case conditions. For PWRs, some filters would be GTCC. For BWRs, some for the fuel pool and vacuum filters would be GTCC, and about half of the control rod drive (CRD) filters would be GTCC under the worst case. When these filters are commingled with other filters and characterized and classified as a group, all filter types except the CRD units should meet Class C limits. In the average case, some CRD units could still exceed the limits due to low volumes and TRU content. Under best case conditions with encapsulation, all cartridge filters should be below Class C limits.

Table I-8. Relative impact assessment--process wastes

RELATIVE IMPACT ASSESSMENT PROCESS WASTES			
	Percent GTCC High Case	Percent GTCC Base Case	Percent GTCC Low Case
1.BWR Decontamination Resins			
a. Full System – Fuel In	25	1	0
b. Full RCS System – Fuel Out	10	1	0
2.PWR Decontamination Resins			
a. Full System – Fuel In	25	1	0
b. Full RCS System – Fuel Out	10	1	0
3.BWR Cartridge Filters			
a.Control Rod Drive	50	10	0
b.Fuel Pool	25	1	0
c.Underwater Vacuum	25	1	0
4.PWR Cartridge Filters			
a.Seal Water Injection	25	1	0
b.Seal Water Return	25	1	0
c.Reactor Coolant System	25	1	0
d.Letdown	25	1	0
e.Fuel Pool	25	1	0

5.4 Contaminated Solids

The basis for consideration of these wastes as GTCC is the presence of TRU radionuclides from a select group of industrial facilities. The concentration averaging scenarios and criteria used for contaminated solids included:

- Worst Case --No concentration averaging or commingling with other lower activity TRU-bearing dry solids and no use of stabilization media volume for incinerator ash.
- Average Case--Commingling with other lower activity TRU-bearing dry solids plus inclusion of the stabilization media volume for incinerator ash.
- Best Case--Commingling with non-TRU-bearing dry solids.

For some unique fuel development and evaluation facilities, some of the contaminated solids generated could exceed Class C limits under the worst case. With commingling under the average case, a small portion of these materials could still be GTCC. With extensive commingling with other contaminated solids under the best case, essentially none of these wastes would be GTCC.

5.5 Sealed Sources

Sealed sources were considered in two groups: TRU-bearing and other. The concentration averaging criteria used for both groups included:

- Worst Case --No encapsulation to reduce concentrations.
- Average Case--Encapsulation allowed for non-TRU sources with activities below 10 curies, no encapsulation for TRU sources.
- Best Case--Encapsulation allowed for TRU and non-TRU sources.

Table I-9 presents the range of radionuclide concentrations for each source type and compares them to the 10 CFR Part 61 Class C limit for the relevant radionuclide. These values represent conditions for the worst case scenario.

Table I-10 takes the values in Table I-9 and considers encapsulation. It was assumed that sealed sources would be encapsulated in a 55-gal drum-size container with a volume of 200,000 cc. It was further assumed that the encapsulation media would be cement at a density of 1.5 g/cc for a weight of 300,000 g. Accordingly, encapsulation will reduce TRU source concentrations by a factor of 300,000 and non-TRU source concentrations by a factor of 200,000. When TRU sources are encapsulated, they still exceed Class C limits for both the average and best cases. When non-TRU sources are encapsulated, most of them meet Class C limits under both the average and the best cases. However, some of these source types could not be encapsulated under the average case because their activity exceeds 10 Ci. Thus, some non-TRU sources would also be GTCC under the average case. Under best case conditions, TRU-bearing gamma gauges (Item 1) and TRU-bearing well logging sources (Item 3) still exceed Class C limits.

Table I-11 presents estimates for the portion of each source type that could be GTCC under each scenario where the source activity ranges varied significantly and resultant concentrations were both above and below the Class C limit. It was assumed that half of the sources were GTCC.

Table I-9. Sealed sources--10 CFR Part 61 radionuclide concentrations

SEALED SOURCES PART 61 RADIONUCLIDE CONCENTRATIONS				
	Part 61 Nuclide	Part 61 Class C Limit	Minimum Specific Activity	Maximum Specific Activity
TRU Bearing Sources		nCi/gm	nCi/gm	nCi/gm
1. Gamma Gauges	Am-241	1.00E+02	1.25E+01	1.25E+09
	Cm-244	1.00E+02	1.25E+05	1.25E+08
2. X-Ray Fluorescent	Am-241	1.00E+02	2.50E+05	2.50E+07
	Cm-244	1.00E+02	1.25E+05	1.25E+07
3. Well Logging	Am-241	1.00E+02	1.04E+09	4.17E+09
	Pu-239	1.00E+02	1.04E+09	1.04E+09
4. Moisture Gauges	Am-241	1.00E+02	1.25E+04	1.25E+04
5. Smoke Detectors	Am-241	1.00E+02	1.25E+02	2.25E+04
6. Pacemakers	Pu-238	1.00E+02	5.00E+06	5.00E+06
Other Sources		uCi/cc	uCi/cc	uCi/cc
1. Med. Teletherapy	Cs-137	4.60E+03	2.00E+06	3.00E+07
2. Gamma Gauges	Cs-137	4.60E+03	1.67E-01	1.67E+07
3. Beta Gauges	Sr-90	9.00E+03	2.94E-03	2.94E+04
4. Well Logging	Cs-137	4.60E+03	4.00E+04	4.00E+04
5. Calibration	Cs-137	4.60E+03	6.25E+01	1.88E+07
6. Gamma Irradiators I	Cs-137	4.60E+03	6.00E+05	6.00E+08
7. Gamma Irradiators II-IV	Cs-137	4.60E+03	5.00E+05	5.00E+06
8. Gas Chromatography	Ni-63	7.00E+02	6.67E+05	1.33E+06
9. Beta Eye Applicators	Sr-90	7.00E+03	7.89E+04	1.58E+05

Table I-10. Sealed sources--10 CFR part 61 radionuclide concentrations after encapsulation

SEALED SOURCES PART 61 RADIONUCLIDE CONCENTRATIONS AFTER ENCAPSULATION				
	Part 61 Nuclide	Part 61 Class C Limit	Minimum Specific Activity	Maximum Specific Activity
TRU Bearing Sources		nCi/gm	nCi/gm	nCi/gm
1. Gamma Gauges	Am-241	1.00E+02	4.17E-05	4.17E+03
	Cm-244	1.00E+02	4.17E-01	4.17E+02
2. X-Ray Fluorescent	Am-241	1.00E+02	8.33E-01	8.33E+01
	Cm-244	1.00E+02	4.17E-01	4.17E+01
3. Well Logging	Am-241	1.00E+02	3.47E+03	1.39E+04
	Pu-239	1.00E+02	3.47E+03	3.47E+03
4. Moisture Gauges	Am-241	1.00E+02	4.17E-02	4.17E-02
5. Smoke Detectors	Am-241	1.00E+02	4.17E-04	7.50E-02
6. Pacemakers	Pu-238	1.00E+02	1.67E+01	1.67E+01
Other Sources		uCi/cc	uCi/cc	uCi/cc
1. Med. Teletherapy	Cs-137	4.60E+03	1.00E+01	1.50E+02
2. Gamma Gauges	Cs-137	4.60E+03	8.33E-07	8.33E+01
3. Beta Gauges	Sr-90	9.00E+03	1.47E-08	1.47E-01
4. Well Logging	Cs-137	4.60E+03	2.00E-01	2.00E-01
5. Calibration	Cs-137	4.60E+03	3.13E-04	9.38E+01
6. Gamma Irradiators I	Cs-137	4.60E+03	3.00E+00	3.00E+03
7. Gamma Irradiators II-IV	Cs-137	4.60E+03	2.50E+00	2.50E+01
8. Gas Chromatography	Ni-63	7.00E+02	3.33E+00	6.67E+00
9. Beta Eye Applicators	Sr-90	7.00E+03	0.00E+00	7.89E-01

Table I-11. Sealed sources--relative GTCC waste volumes

SEALED SOURCES RELATIVE GTCC WASTE VOLUMES			
	Percent GTCC For High Case	Percent GTCC For Base Case	Percent GTCC For Low Case
TRU Bearing Sources			
1. Gamma Gauges	100	100	50
2. X-Ray Fluorescent	100	100	0
3. Well Logging	100	100	100
4. Moisture Gauges	100	100	0
5. Smoke Detectors	100	100	0
6. Pacemakers	100	100	0
Other Sources			
1. Med. Teletherapy	100	100	0
2. Gamma Gauges	50	1	0
3. Beta Gauges	50	1	0
4. Well Logging	50	1	0
5. Calibration	50	25	0
6. Gamma Irradiators I	100	100	0
7. Gamma Irradiators II-IV	100	100	0
8. Gas Chromatography	100	1	0
9. Beta Eye Applicators	100	1	0

5.6 Summary and Conclusions

As expected, the different concentration averaging scenarios have a significant impact on GTCC LLW volumes. Table I-12 presents the estimated portions of each waste type that are GTCC, as presented in Tables I-7, I-8 and I-11, normalized to the base volume case. Note that the minimum allocated to the base or average case was 1%, or essentially none. This enables normalization of the high and low volume estimates to the base volume case.

The results indicate that the extent to which GTCC LLW could be generated, even under the worst case high volume scenario, is less than previous estimates of the types of LLW waste that are potential GTCC. Thus, this evaluation showed fewer potential GTCC LLW types. Additionally, the implicit assumption in previous estimates that if a waste type is GTCC, all wastes generated for that particular type will be GTCC, is not supported. In many cases, only a portion of a particular waste type is potential GTCC, even under the worst case scenario. Accordingly, when these factors are included in the DOE projection model, projections of GTCC volumes will be lower than previous estimates, regardless of the scenario.

The portions of activated metals that could be GTCC under the three scenarios were presented in Table I-7. For routinely generated activated metals, the high volume case varies from 2.5 to 10 times the base case amount for BWR components and up to 10 times the base case amount for PWR components. Except for the PWR primary sources that contain TRU, these amounts are reduced to zero for the low volume or best case. The information used for routinely generated activated metals is based on a significant data base of actual components and has a high confidence level. For decommissioning activated metals, the high volume case for BWR is unity and up to four times the base case amount for PWR components. However, unlike routinely generated components, these amounts are not reduced to zero for the low volume case. This is due to the size of the components and their activity at discharge. The same applies to research and test reactor decommissioning components. The confidence level for the estimates on decommissioning activated metals is much lower than those for other metals. Few components have been actually characterized and disposed. Some of this work is just now being initiated at power reactors and research facilities. Additionally, while there are more extensive technical data sources available than those used, detailed analyses of these data were not performed.

The portions of process wastes that could be GTCC under the three scenarios were presented in Table I-7. For RCS decontamination resins, the high volume case is 50 times the base case amount and is reduced to zero for the low volume case. The use of the stabilization media volume effectively precludes the generation of GTCC resins in the absence of economic factors. For cartridge filters, the high volume case varies from 5 to 25 times the base case amount and is also reduced to zero for the low volume case. Again, the use of the stabilization media volume effectively precludes the generation of GTCC cartridge filters. The information used for spent resins and filter cartridges is based on actual waste data. Except for the full RCS decontamination resins, which have not yet been generated, this information has a high confidence level.

The estimates for contaminated solids are not well-founded since the information available on the few facilities that can reasonably be expected to generate these wastes is limited. However, it was assumed that even under best case conditions there will always be some of these wastes that are GTCC. The readily available DOE information was minimal. As shown, the high volume case is estimated at 25 times the base case amount, and the low volume case is 10% of the base case

Table I-12. Relative GTCC waste volumes normalized to base volume case

RELATIVE GTCC WASTE VOLUMES NORMALIZED TO BASE VOLUME CASE		
	High Volume Scenario	Low Volume Scenario
ACTIVATED METALS		
1.BWR Operations		
- Control Rod Blades-Control Cell	2.5	0
- Control Rod Blades-Normal	10	0
- LPRM Strings	7.5	0
- Dry Tubes	10	0
2. PWR Operations		
- Thimble Plug Assemblies	25	0
- Instrument Strings	7.5	0
- Primary Sources	1	1
3.BWR Decommissioning		
- Core Shroud	1	1
- Orificed Fuel Supports	10	0
4.PWR Decommissioning		
- Core Shroud	1	1
- Lower Core Barrel	25	0
- Thermal Shield	25	0
- Lower Grid Plate	1	0.75
5.Other Reactor internals		
-Research	1	0
-Test	100	0
PROCESS WASTES		
1. BWR & PWR Decon Resins		
- Full RCS with Fuel In	25	0
- Full RCS with Fuel Out	10	0
2.Cartridge Filters		
- BWR Control Rod Drive	5	0
- Other BWR & PWR	25	0
CONTAMINATED SOLIDS		
	2.5	0.1
SEALED SOURCES		
1.TRU Bearing Sources		
- Gamma Gauges	1	0.5
- X-Ray Fluorescent	1	0
- Well Logging	1	1
- Moisture Gauges	1	0
- Smoke Detectors	1	0
- Pacemakers	1	0
2.Other Sources		
- Med. Teletherapy	1	0
- Gamma Gauges	50	0
- Beta Gauges	50	0
- Well Logging	50	0
- Calibration	2	0
- Gamma Irradiators I,II,III,IV	1	0
- Gas Chromatography	100	0
- Beta Eye Applicators	100	0

amount. The absolute volumes of these waste categories, although not considered here, are expected to be relatively small. The information used for contaminated solids had perhaps the lowest degree of confidence.

Sealed sources have the greatest GTCC potential other than activated metals from LWR decommissioning. The portions of sealed source waste that could be GTCC under the three scenarios were presented in Table I-11. As shown on that table, almost all of the TRU-bearing sources and most of the non-TRU-bearing sources were GTCC for the high volume case. Encapsulation of the non-TRU sources for the average case reduced the base case amounts for these sources, but the TRU sources, which could not be encapsulated, remained unchanged for the base case. Removing the limits on curie content for non-TRU sources and the encapsulation of TRU sources had a significant impact on the relative quantities of GTCC LLW. This impact is reflected in Table I-12, where the high volume case is either equal to or 100 times greater than the base case amount. Conversely, the low volume case essentially eliminates all sealed sources as GTCC LLW except for high activity non-TRU gamma gauges and TRU-based well logging sources.

For sealed sources, NRC reference materials were used almost exclusively. Thus, the information used to identify source characteristics has a high degree of confidence. However, data on the numbers of sources by type and the distribution of activities for source types is not readily available. Moreover, the assumption that sources would be encapsulated in 55-gal drum-size containers with approved stabilization media was overly simplistic. In addition to ignoring economic considerations, it assumes that typical source users are aware of the approved stabilization methods and can readily employ them. Since sealed sources are the most widely used and likely GTCC LLW category, a more detailed evaluation appears warranted.

Finally, the dependence of GTCC LLW generation on the concentration averaging scenarios may lead to some orphan wastes. In a compact based regulatory environment, there is a high degree of certainty that waste could be GTCC in one compact region, meet Class C limits in another, and not meet the DOE definition of GTCC. Steps should be taken to address these types of issues to provide some degree of certainty to potential GTCC LLW type management practices.

6. REFERENCES

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