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Evaluation of the Capabilities of the Hanford Reservation and Envirocare of Utah for Disposal of Potentially Problematic Mixed Low-Level Waste Streams

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Evaluation of the Capabilities of the Hanford Reservation and Envirocare of Utah for Disposal of Potentially Problematic Mixed Low-Level Waste Streams

Prepared for the
U.S. Department of Energy Mixed Waste Focus Area
Waste Form Initiative

by

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Abstract

The U.S. Department of Energy's (DOE) Mixed Waste Focus Area is developing a program to address and resolve issues associated with final waste form performance in treating and disposing of DOE's mixed low-level waste (MLLW) inventory. A key issue for the program is identifying MLLW streams that may be problematic for disposal. Previous reports have quantified and qualified the capabilities of fifteen DOE sites for MLLW disposal and provided volume and radionuclide concentration estimates for treated MLLW based on the DOE inventory. Scoping-level analyses indicated that 101 waste streams identified in this report (approximately 6250 m^3 of the estimated total treated MLLW) had radionuclide concentrations that may make their disposal problematic. The radionuclide concentrations of these waste streams were compared with the waste acceptance criteria (WAC) for a DOE disposal facility at Hanford and for Envirocare's commercial disposal facility for MLLW in Utah. Of the treated MLLW volume identified as potentially problematic, about 100 m^3 exceeds the WAC for disposal at Hanford, and about 4500 m^3 exceeds the WAC for disposal at Envirocare. Approximately 7% of DOE's total MLLW inventory has not been sufficiently characterized to identify a treatment process for the waste and was not included in the analysis. In addition, of the total treated MLLW volume, about 30% was associated with waste streams that did not have radionuclide concentration data and could not be included in the determination of potentially problematic waste streams.

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Executive Summary

In March 1996, the U. S. Department of Energy's (DOE) Office of Science and Technology (EM-50) asked the DOE Mixed Waste Focus Area to develop and lead a program that would address and resolve issues associated with final waste form performance in treating and disposing of the DOE mixed low-level waste (MLLW) inventory. This program, named the Waste Form Initiative, has the primary goal of ensuring that the MLLW treatment technologies being developed, currently used, or planned for use by DOE will produce final waste forms that will satisfy the waste acceptance criteria (WAC) of the existing and/or planned MLLW disposal facilities. A key issue for the program and the subject of this report is identifying MLLW streams that may be problematic for disposal. The selected treatment processes and waste forms for these waste streams will be reexamined to determine areas for improvement in terms of acceptance for disposal.

The Federal Facilities Compliance Act (FFCAct) Disposal Workgroup has conducted previous work on disposal issues. The DOE established the group in 1993 to work with the States in identifying, from among the sites currently storing or expected to generate MLLW, those that might be suitable for MLLW disposal. The disposal capabilities of the fifteen sites selected through this process were quantified and qualified in the scoping-level performance evaluation (PE) project completed in early 1996. An additional scoping-level residuals analysis (RA) provided volume and radionuclide concentration estimates for treated MLLW that were based on DOE's current and five-year projected inventory of approximately 130,000 m^3. The RA provided a means for identifying MLLW streams that may be potentially problematic for disposal.

The 101 waste streams (approximately 6250 m^3 of treated MLLW) that were considered in this analysis as potentially problematic had total radionuclide concentrations, based on the scoping-level estimates used in the RA project, that were greater than 10 times the concentration limits derived from the PE project for the Hanford Reservation. In the analysis described in this report, the radionuclide concentrations of these waste streams were compared with the WAC for DOE's low-level waste (LLW) disposal facility at Hanford (the WAC for a MLLW facility at Hanford are not yet complete) and with the WAC for Envirocare's commercial disposal facility for MLLW in Utah. At Hanford, the WAC are based on the LLW performance assessment recently completed for its currently operating, shallow land burial site. The WAC provide limiting activity concentrations for Category 1 and Category 3 wastes, which correspond to the performance-assessment results of the homesteader and post-drilling scenarios, respectively. Envirocare of Utah is a commercial site, and details about the development of their WAC are not available.

The analysis provided a substantiated estimate of the capability of the Hanford and Envirocare sites for disposal of treated MLLW. The following conclusions were derived from the analysis results:

- One hundred-one waste streams associated with approximately 6250 m^3 of treated MLLW were identified as potentially problematic based on the PE-derived

concentration limits for Hanford. Of this volume, all but 96 m^3 meets the WAC for either Category 1 or Category 3 disposal at Hanford. Additional documented justification for disposal of the 96 m^3 may allow its disposal at Hanford. Containment of this waste in concrete boxes (as is the current practice for waste that has a SOF less than or equal to 1 based on Category 3 limits) may be sufficient to allow disposal.

- Of the approximately 6250 m^3 of treated MLLW that was identified as potentially problematic for disposal at Hanford, about 4500 m^3 has a SOF of greater than 1 based on the WAC for commercial disposal at the Envirocare MLLW disposal facility in Utah.

- Compatibility of wastes and waste forms was not evaluated because this issue is a site responsibility.

Recommendations based on the analysis are the following:

- The majority of the MLLW acceptable for disposal at Hanford has a SOF of 1 or less based on Category 3 limits. However, the cost for disposal of Category 3 waste is approximately three times higher than for Category 1 waste. A cost/benefit analysis should be conducted to determine if the use of different or additional treatment processes or waste forms will result in MLLW that can be disposed of as Category 1 waste.

- Adequate data appear to be available to estimate waste form performance for both grouted and vitrified wastes. However, the data suitable for estimating performance of both polyethylene microencapsulated and macroencapsulated waste are sparse. If this waste form is expected to be used extensively for MLLW disposal, additional performance data should be collected for the polyethylene waste form.

- Only a portion of DOE's MLLW inventory was included in the analysis. At the time of the analysis, approximately 8700 m^3 of MLLW was insufficiently characterized to allow the sites to determine a treatment process for the associated waste streams. In addition, approximately 27,000 m^3 of MLLW included in the total estimate of after-treatment MLLW volume was not characterized with respect to radionuclides and their concentrations at the time of the analysis. Neither of these volumes was analyzed for disposal at any site. Further analysis of MLLW streams that do not have assigned treatment processes should be conducted; data on radionuclides and concentrations should be collected for waste streams that are lacking these data.

Nomenclature

ALT	accelerated leach test
DOE	Department of Energy
EM	environmental management
ER	environmental restoration
FFCAct	Federal Facility Compliance Act
INEL	Idaho National Engineering Laboratory
LLW	low-level waste
MLLW	mixed low-level waste
MPC	matrix parameter category
MWFA	Mixed Waste Focus Area
MWIR	Mixed Waste Inventory Report
NRC	Nuclear Regulatory Commission
NTS	Nevada Test Site
ORNL	Oak Ridge National Laboratory
PA	performance assessment
PE	performance evaluation
QA	quality assurance
RA	residuals analysis
RCRA	Resource Conservation and Recovery Act
SOF	sum-of-fractions
SRS	Savannah River Site
STP	site treatment plan
TRU	transuranic
TSP	Technical Support Program
WAC	waste acceptance criteria
WFI	waste form initiative

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1. INTRODUCTION

The Federal Facility Compliance Act (FFCAct) of 1992 (FFCAct, 1992) requires the U.S. Department of Energy (DOE) to work with state and federal regulators and with members of the public to establish plans for the treatment of DOE's mixed low-level waste (MLLW). Along with other radioactive and hazardous waste, wastes that are now considered MLLW have been generated for more than 50 years through DOE activities related to the production of materials for nuclear weapons and research with nuclear materials. The FFCAct does not specifically address disposal of treated MLLW. However, both DOE and the States recognize that disposal issues are an integral part of treatment discussions.

The DOE established the FFCAct Disposal Workgroup in 1993 to work with the States in identifying, from among the sites currently storing or expected to generate MLLW, those that might be suitable for the disposal of MLLW. The technical capabilities of the fifteen sites selected through this process were quantified and qualified in the performance evaluation (PE) project completed in early 1996 (DOE, 1996). An additional residuals analysis (RA) provided estimates of volumes and radionuclide concentrations for treated MLLW considered under the FFCAct. The estimates were based on DOE's current and five-year projected inventory of approximately 130,000 m^3 (DOE, 1997).

1.1 Purpose of This Report

This report builds on the results of the RA project (DOE, 1997). In that study, the radionuclide concentrations of all waste streams that had sufficient characterization to permit evaluation were compared to the permissible concentrations in waste derived from the PE project. The PE-derived concentration limits for disposal were determined by using a set of modeling assumptions that included sufficient detail to capture major site-specific characteristics but were general enough to allow consistent application at all sites. Thus, the PE-derived concentration limits were used in the RA project to identify waste streams that are not likely to present significant issues for disposal and to focus attention on the waste streams that require more analysis.

In this report, the waste streams that were identified in the RA project as potentially problematic are examined. The radionuclide concentrations of these waste streams are compared to the waste acceptance criteria (WAC) developed for one DOE site, the Hanford Reservation, and one commercial site, Envirocare of Utah, for disposal of MLLW residuals in their facilities. Because these WAC were developed specifically for each site, they serve as realistic screening tools in determining those waste streams for which disposal considerations should be given closer attention. The RA project considered only the radiological content of the waste streams in evaluating disposability; however, the sites must consider all of the WAC in the final disposal decision. The WAC for Hanford is for the low-level waste (LLW) disposal facility at that site because the WAC for the MLLW disposal facility is not completed. However, the WAC for the MLLW disposal facility at Hanford is expected to be similar, in terms of radiological limits, to the LLW disposal facility.

This report provides the results of a more refined analysis of the disposability of the residuals from treatment of MLLW than those provided by the RA project. Specific waste streams requiring additional evaluation and research are identified. By identifying the waste streams that may still pose problems for disposal, research and development can be funded in the needed areas. This report provides input to documents prepared by DOE's Mixed Waste Focus Area (MWFA) for DOE Environmental Management (EM) customers, including Waste Management (EM-30), Environmental Restoration (EM-40), and Facility Transition (EM-60) divisions.

In March 1996, the DOE Office of Science and Technology (EM-50) asked the DOE MWFA to develop and lead a program that would address and resolve issues associated with final waste form performance with respect to treatment and disposal of the DOE MLLW inventory. This program, named the Waste Form Initiative (WFI), has the primary goal of ensuring that the MLLW treatment technologies being developed, currently used, or planned for use by DOE will produce final waste forms that will satisfy the WAC of the existing and/or planned MLLW disposal facilities. The potentially problematic waste streams identified in the RA project are one of the focal points of the WFI in furthering the completion of MLLW disposal plans.

The focus of the current analysis is on disposal at Hanford and Envirocare of Utah because these sites currently have capacity for MLLW disposal. Disposal capacity for MLLW also exists at the Nevada Test Site (NTS); however, based on results of performance assessments at Hanford and NTS, wastes that can be disposed of at Hanford can be disposed of at NTS. Thus, this analysis provides a bounding analysis for the two sites. Other DOE and commercial sites can be evaluated with this type of analysis if deemed necessary.

1.2 Background

The following figures show the results of the RA project. Figure 1-1 shows that of the 130,300 m^3 of MLLW evaluated in the RA, approximately 89,000 m^3 of treated waste will require disposal as MLLW; 5,000 m^3 of treated waste will require disposal as transuranic (TRU) waste; and 6,000 m^3 of treated waste will require disposal as LLW. The net volume reduction from treatment of all MLLW is approximately 21,000 m^3. Approximately 8,700 m^3 of MLLW was not considered in the RA because the sites had not assigned a treatment process for these wastes.

Figure 1-2 shows that of the 89,160 m^3 to be disposed of as MLLW, approximately 62,000 m^3 had sufficient radiological characterization (i.e., characterization for radionuclides and their concentrations) to allow comparisons with the PE-derived limits for disposal. The remaining 27,000 m^3 of MLLW were not characterized for either the radionuclides in the waste or their concentrations. When these characterizations are complete, the disposability of these waste streams can be analyzed.

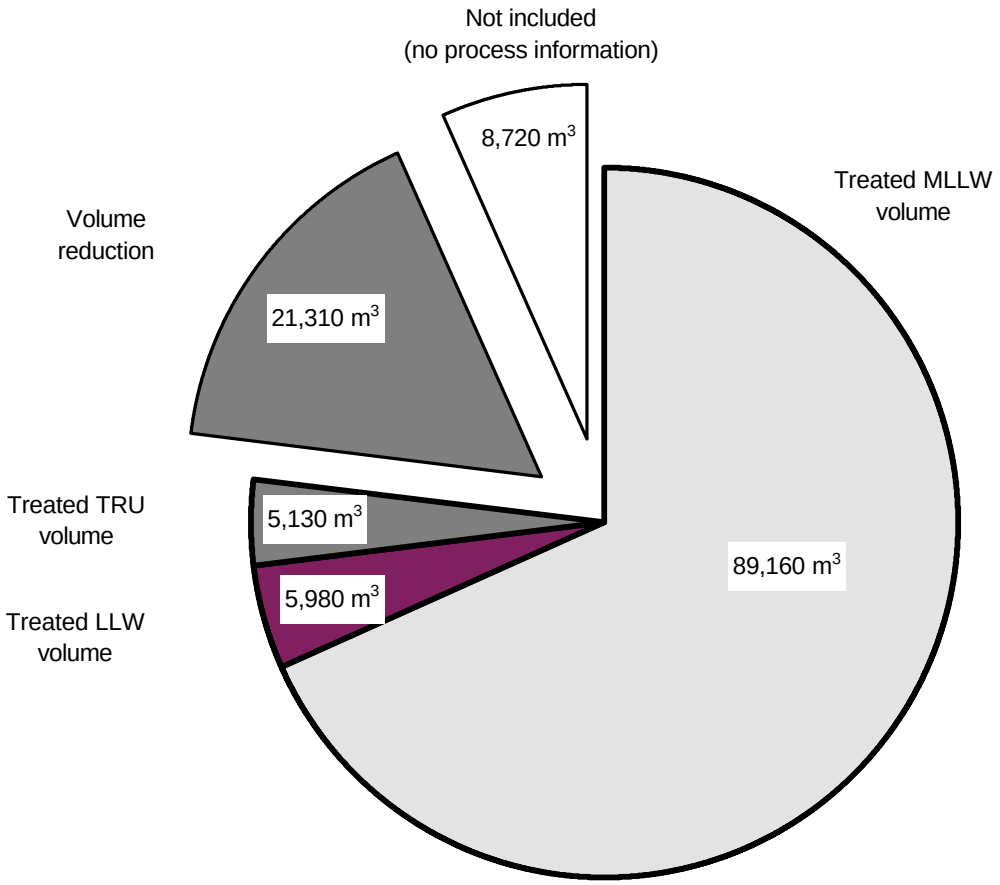

Figure 1-1. Categorization of the initial total volume of MLLW (DOE, 1997).

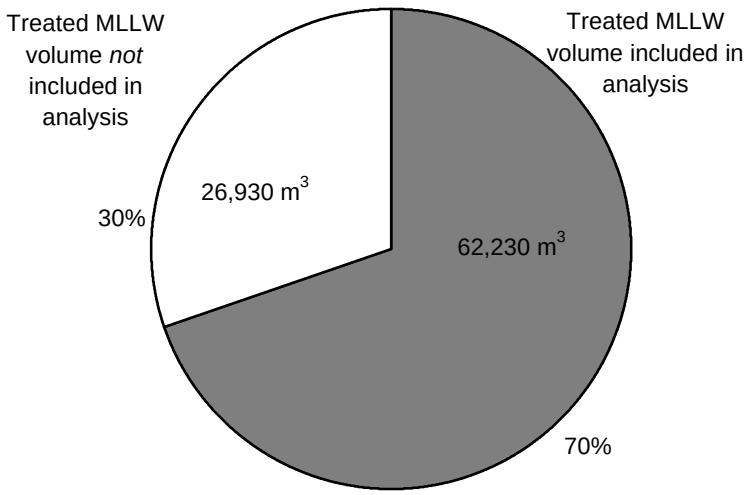

Figure 1-2. Treated MLLW volume included in the analysis of radionuclide concentrations (DOE, 1997).

The 62,000 m^3 of MLLW considered in the comparison of radionuclide concentrations with the PE-derived disposal limits were placed into one of four categories depending on the outcome of a sum-of-fractions (SOF) analysis of the combined effect of the radionuclides (Table 1-1).

Table 1-1. Categories for Comparison of Radionuclide Concentrations in Waste Streams with the PE-Derived Limits.

Categories	Sum of Fractions (SOF)	Description
○	SOF ≤ 0.1	Concentrations in waste are one or more than one orders of magnitude below the PE-derived limits. These wastes are highly likely to be technically suitable for disposal at that site.
□	0.1 < SOF ≤1.0	Concentrations in waste are equal to or less than one order of magnitude below the PE-derived limits. These wastes are also likely to be technically suitable for disposal at that site but by a smaller margin than the category described above.
■	1.0 < SOF ≤ 10.	Concentrations in waste are less than or equal to one order of magnitude above the PE-derived limits. Although the combined concentrations of radionuclides in waste are greater than the PE-derived limits for these streams, many conservative assumptions were used to develop the PE and the RA, and more detailed analyses (i.e., site-specific performance assessments) may be needed to show that these waste streams will also be technically suitable for disposal.
●	SOF > 10	Concentrations in waste are more than one order of magnitude above the PE-derived limits. As with the wastes in the previous classification, more detailed analyses (i.e., site-specific performance assessments) may be needed to show that these waste streams will also be technically suitable for disposal. However, a revised treatment plan, disposal design, or disposal location may also be required for some of these wastes.

Figure 1-3 shows the volume distribution of waste streams associated with four SOF categories based on comparing the radionuclide concentrations in waste with the PE-derived concentration disposal limits at Hanford. In the RA, the waste volumes associated with the ○ and □ symbols were considered likely to be acceptable for disposal. Due to the conservative nature of the PE project compared to site-specific performance assessments (PAs), the wastes associated with the ■ symbol were also considered likely to be acceptable for disposal after more rigorous analysis (DOE, 1997). The more rigorous analysis summarized in this report indicates that these waste streams will likely be acceptable for disposal. In the RA, the waste streams associated with the ● symbol were considered potentially problematic and are the primary focus of this analysis because one or more of the radionuclide concentrations in these waste streams exceed the PE-derived disposal limits at Hanford by more than an order of magnitude.

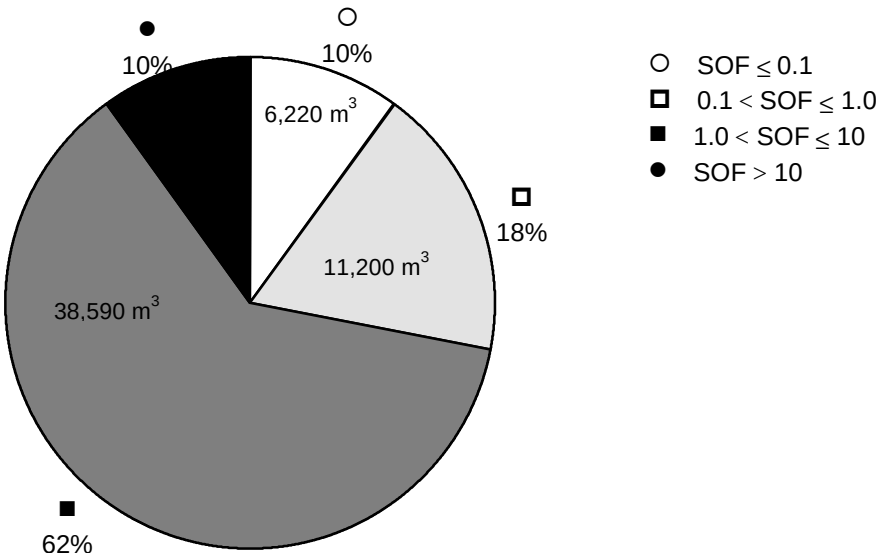

Figure 1-3. Distribution of the 62,230 m^3 of characterized MLLW for disposal associated with four sum-of-fractions (SOF) categories at Hanford (DOE, 1997).

1.3 Quality of Data

The analyses described in this report were based on data collected for the RA project. The analyses described in the RA report (DOE, 1997) were based on characterization data collected by the DOE in 1995 for the Mixed Waste Inventory Report (MWIR) (INEL, 1995) and on site-specific treatment plans compiled into a site treatment plan (STP) database. These data were updated by the sites to reflect the status as of mid-1996. The MWIR contains characterization data for MLLW streams managed under agreements resulting from implementation of the FFCAct. Other activities may also generate MLLW, including environmental restoration and decontamination and decommissioning. The quality of the data used in the RA analysis is a function of the quality of both the initial input data from the MWIR and STP databases and the efforts used in the RA to process the data.

The National Low-Level Waste Management Technical Support Program (TSP) located at Idaho National Engineering and Environmental Laboratory (INEEL) conducted the data collection for the 1995 version of DOE's MWIR. The data quality program for the MWIR database developed by the TSP staff is summarized in the RA report (DOE, 1997).

For the STP database, development consisted of electronically incorporating data from the site treatment plans. The quality assurance (QA) efforts for that project were directed at ensuring that the data were incorporated correctly (e.g., review of input data). Little formal interaction with the site contacts was required or conducted.

For the RA project, the site contacts reviewed the input data and results of the calculations on two separate occasions. Comments received during these reviews and resolution of these comments were entered into a QA catalog for the project. For each waste

stream considered in the analysis, this QA catalog contains a record of all comments from the site and disposition of the comments by the project staff. In addition, it contains the basis for inclusion or exclusion of the waste stream in the concentration analysis.

For both the RA and this analysis, technical staff at Sandia National Laboratories provided quality assurance of the electronic database and calculations used in the project. When required data were missing or not available for a waste stream, that waste stream was identified as lacking data and not analyzed.

While the input data used in the RA and this analysis contain many gaps and uncertainties, the MWIR and STP databases represent the best available source of data for DOE MLLW. Used with circumspection, these data appear to be adequate for use in the analyses described here.

1.4 Limitations of the Analysis

As with the RA report, the comparison of radionuclide concentrations in treated wastes with the WAC for Hanford and Envirocare was a scoping-level analysis. The method used to estimate post-treatment concentrations was a simplified approach to quantifying the effects of treatment processes: estimates were made of initial and post-treatment bulk densities of the waste and of the volume changes that would occur in using the preferred treatment processes. Thus, the analysis described in this report was a scoping-level analysis to identify those waste streams for which disposal considerations should be given closer attention. Waste streams identified in this analysis as continuing to be potentially problematic should not be considered as wastes that cannot be disposed of at Hanford or Envirocare; instead, they should be viewed as wastes that need more careful scrutiny. All other waste streams evaluated in this analysis are not expected to present significant issues for disposal. In this sense, the scoping-level nature serves to eliminate from further analysis those waste streams that appear to present no significant issues for disposal and to focus attention on the wastes that require more analysis.

2. METHODOLOGY

The RA project provided estimates of post-treatment volumes and radionuclide concentrations of MLLW considered under the FFCAct based on DOE's current and five-year projected inventory of approximately 130,000 m^3 (DOE, 1997). A summary is provided in this section of the methodology used to evaluate the 105 waste streams identified in the RA report as potentially problematic for disposal at the Hanford site.

The 105 waste streams identified in the RA report as potentially problematic comprise 6390 m^3 of treated MLLW. The waste streams are those from all DOE sites that store or generate MLLW that are in the ● SOF category as defined in Table 1-1 for disposal at the Hanford site. However, because of the conservative nature of the PE-derived disposal limits (DOE, 1996), these waste streams were evaluated to determine if they would fall into a more favorable SOF category when their radionuclide concentrations were compared to site-specific WAC.

Some waste streams recognized by the sites as potentially problematic are not in the list of 105 waste streams. Some sites may consider waste streams as problematic if they have not yet been characterized. Waste streams that are currently classified as MLLW may become LLW after treatment and be potentially problematic LLW streams. These waste streams are not included in the list derived from the RA report.

In the analysis described in this report, the radionuclide concentrations of the potentially problematic waste streams were compared with the WAC for the Hanford LLW facility and for the Envirocare of Utah facility, a commercial disposal site for MLLW. The results of these comparisons are presented and discussed in the next section. The results of the comparison of radionuclide concentrations with the Hanford WAC were reviewed for accuracy by performance assessment specialists at that site.

In addition, waste streams comprising 38,700 m^3 of treated MLLW are associated with the ■ SOF symbol at Hanford; this waste was identified in the RA report as likely to be acceptable for disposal with more refined analyses. These waste streams were compared with the WAC from Hanford and Envirocare to verify this assumption.

2.1 Determining Radionuclide Concentrations of MLLW Streams

The concentration in each waste stream after treatment for each radionuclide *i*, C_{Fi}, was estimated using Equation 2-1:

$$C_{Fi} = C_{Ii} \times \frac{1}{AMR} \times \frac{r_{b-final}}{r_{b-initial}} \tag{2-1}$$

where

C_{Ii} is the initial concentration of radionuclide *i* (μCi/m^3);

AMR is the activity-per-unit-mass ratio (the ratio of the activity per unit mass before treatment to the activity per unit mass after treatment) (dimensionless);
$r_{b\text{-}final}$ is the final bulk density of the treated waste (g/cm^3); and
$r_{b\text{-}initial}$ is the initial bulk density of the waste (g/cm^3).

The preliminary estimates for $r_{b\text{-}initial}$ for the waste streams were based on the matrix parameter categories (MPC) associated with each waste stream in the MWIR database (Kirkpatrick, 1995). The AMR values (Table 2-1) were based on work done at the Savannah River Site (SRS) (WSRC, 1995). The sites reviewed and updated the estimates for all parameter values for each waste stream.

Radionuclides with half-lives less than 5 years were not included in the analysis because of their limited effect on the long-term risks from disposal.

The assumed values for C_{Ii} were the mean concentration values for a particular waste stream given in the MWIR database or were based on a given range. Mean values were used because (1) treatment processes tend to provide a homogenization that results in radionuclide concentrations near their mean, and (2) the range of radionuclide concentrations was generally based on a smaller scale (e.g., drums), which generally results in a wider range of values than when aggregated to a larger scale (e.g., waste stream).

Radionuclide distributions were assumed for waste streams in which radionuclides were identified as mixed fission products, mixed activity products, depleted uranium, and natural uranium. These distributions were based on an average of 20 years decay (an estimate of the average time between waste characterization and disposal). For waste streams that had one or more radionuclides without concentrations, the listed radionuclide concentrations were evaluated and the missing data noted.

2.2 Comparing Waste Stream Concentrations with the WAC at Hanford and Envirocare

The WAC for Hanford and Envirocare of Utah are determined by the waste disposal facility owners and generally have higher concentration limits than the PE-derived concentration limits used in the RA because of the additional conservatism in these latter analyses. At Envirocare, the waste acceptance criteria are set as limiting concentrations for each radionuclide. Envirocare is a commercial site, and the details of their WAC development are not available.

Table 2-1. Activity Per Unit Mass Ratio (AMR) for Selected Waste Types (from DOE,1997, based on Ades, 1996)

Waste Type	Treatment Process	AMR $(A_1/m_1)/(A_2/m_2)$[a]	Range or Value Used by Sites
Wastewater	Thermal	0.01	0.01 - 0.1
	Non-Thermal	0.25	0.001 - 0.25
	Direct Stabilization	2	0.2
Combustible Organics	Thermal	<0.01	0.01 - 2
	Non-Thermal	2	0.01 - 2
Inorganic Homogeneous Soils and Solids	Thermal	2	0.01 - 2
	Thermal Desorption	2	1 - 2
	Non-Thermal	2	1 - 2
	Non-Thermal Extraction Oxidation	2	2
Debris	Thermal	0.05	0.01 - 2
	Non-Thermal	2	2
	Stabilization	2	1 - 2
	Thermal Desorption	2	--[b]
Lab Packs	Thermal Oxidation	0.05	0.01 - 1
	Chemical Oxidation	2	2 - 100
	Chemical Precipitation	Variable	--[b]
Elemental Mercury	Amalgamation	10-20	2 - 15
Hazardous Metals (Pb, Cd, Be)	Surface Decontamination	0.05	0.05 - 0.5
Batteries	Surface Decontamination Liquid/Solid Separation Neutralization	2	--[b]
Reactive Metals	Deactivation	2	--[b]
Explosives/Propellants	Thermal Oxidation/Incineration	0.05 (solids) 0.01 (liquids)	--[b] --[b]
	Chemical Deactivation	2	2
Compressed Gases/Aerosols	Thermal Oxidation/Incineration	0.01	1
	Chemical Redox	2	1

[a] A_1/m_1 is the radioactivity per unit mass ratio before treatment; A_2/m_2 is the radioactivity per unit mass ratio after treatment; the radioactivity is assumed to be the same before and after treatment. Except for amalgamation and surface decontamination of hazardous metals, values include a factor of 2.0 to account for stabilization of residual wastes. For example, the AMR of 1/100 for thermal treatment of wastewater is the product of 1/200 for thermal treatment and 2 for stabilization of the residuals.

[b] Not used in the analysis

At Hanford, the WAC are based on the LLW performance assessment (PA) recently completed for the currently operating, shallow land burial site. The WAC provide limiting radionuclide concentrations based on two intruder scenarios—homesteader and post-drilling cases that correspond to Category 1 and Category 3 wastes, respectively. As such, if a waste stream has a SOF below 1 based on Category 1 limits, then the Hanford disposal facility will take the waste and dispose of it with few additional measures. If the SOF is greater than 1 using Category 1 limits but less than 1 using Category 3 limits, then proposed disposal measures include concrete encasement of the waste to protect against inadvertent intrusion by the post-drilling scenario. If the SOF is greater than 1 using Category 3 limits, then additional documented justification for disposal of these wastes and possibly additional disposal requirements would be needed.

In addition to the concentration limits based on intrusion scenarios, the Hanford WAC specifies reporting limits for radionuclides that are potentially mobile: H-3, C-14, Cl-36, Se-79, Tc-99, I-129, Re-187, all U, and Np-237. The limits for these mobile radionuclides are determined from a very conservative groundwater pathway analysis that does not take credit for a waste form. Therefore, these values are not limits in the sense that wastes exceeding these concentrations cannot be disposed of at Hanford but that additional measures such as waste forms may be required to allow disposal. In many cases, disposal of these wastes in concrete boxes (as is the practice for Category 3 waste) is sufficient, thus removing the need for additional measures. The current analyses include information about whether a specific waste stream has radionuclides exceeding these reporting limits. The radionuclide limits in the Envirocare and Hanford WAC are given in Appendix A.

The comparisons of radionuclide concentrations in the potentially problematic waste streams to the WAC at Hanford and Envirocare were made using the SOF method described in 10 CFR Part 61.55:

$$SOF = \sum_i \frac{C_{i-waste}}{C_i} \qquad (2\text{-}2)$$

where

$C_{i\text{-}waste}$ is the concentration of radionuclide i in the treated waste (μCi/m^3); and
C_i is the concentration limit from the WAC for radionuclide i in waste (μCi/m^3).

Depending on the calculation results from Equation 2-2, each waste stream was placed into one of the four SOF categories summarized in Table 1-1. The results are provided in Chapter 3.

3. RESULTS

Specific MLLW streams were identified in the RA project as being potentially problematic for disposal at any of the 15 DOE sites being considered for MLLW disposal. In this analysis, potentially problematic wastes are defined as those for which the Hanford SOF value is greater than 10 based on the PE analysis. These waste streams are represented by the ● symbol.

3.1 Evaluation of Potentially Problematic Waste Streams at Hanford

Comparisons of the radionuclide concentrations in the potentially problematic waste streams at Hanford with the WAC concentration limits at Hanford and Envirocare are shown in Table 3-1. The SOF values for Hanford and Envirocare are based on Equation 2-2, the radionuclide concentrations for the waste stream, and the WAC concentration limits for these sites. The information in Table 3-1 is based on the Hanford SOF results in the RA project. However, while the analysis described in this report was being reviewed, the Savannah River Site (SRS) indicated that several of the listed waste streams had been combined and would be disposed of at Envirocare. These waste streams have been removed from Table 3-1 and the volume total adjusted accordingly.

The SOF values for most of the waste streams are greater than 10 based on Hanford's WAC Category 1 and on the Envirocare WAC. However, most of the waste streams are acceptable for disposal based on the Hanford Category 3 limits. Eighty-three waste streams contain mobile radionuclides with concentrations that exceed the Hanford reporting limits, indicating that more information about waste form performance would be required prior to determining the acceptability for disposal at that site.

The distribution of waste stream volumes in Table 3-1 based on the resulting SOF categories is summarized in Figure 3-1 for Hanford and in Figure 3-2 for Envirocare. For Hanford, of the 6245 m^3 of potentially problematic MLLW analyzed, 52 m^3 (0.8%) has a SOF of 1 or less based on the Category 1 limits, 6097 m^3 (97.6%) has a SOF of 1 or less based on the Category 3 limits, and 96 m^3 (1.6%) has a SOF greater than 1 based on the Category 3 limits.

Table 3-1. SOF of Potentially Problematic MLLW Streams at Hanford Based on the Hanford and Envirocare WAC Concentration Limits (Part 1 of 2)

MWIR Survey ID	Treated Volume (m^3)	Hanford PE SOF	Hanford WAC SOF			Envirocare WAC SOF
			Category 1	Category 3	Mobile Nuclide Exceeding Reporting Limit?	
AE-W035	5.6	2E+02 ●	9.2E+01 ●	2.7E-01 □	Yes	6.9E+00 ■
BT-W007	0.002	6E+02 ●	2.4E-01 □	1.1E-03 ○	No	2.6E+00 ■
BT-W013	1.1	4E+03 ●	5.3E+02 ●	2.6E+00 ■	Yes	1.5E+02 ●
BT-W031	0.02	1E+01 ●	5.3E+00 ■	2.4E-02 ○	Yes	1.8E+00 ■
DP-W002	93.9	3E+01 ●	5.6E+00 ■	3.1E-02 ○	Yes	8.3E+00 ■
DP-W140	927.8	4E+02 ●	4.6E+01 ●	2.3E-01 □	Yes	1.3E+01 ●
DP-W147	245.2	1E+01 ●	2.9E+00 ■	1.6E-02 ○	Yes	4.4E+00 ■
DP-W148	82	3E+01 ●	6.5E+00 ■	3.6E-02 ○	Yes	9.0E+00 ■
FM-W114	0.02	2E+01 ●	1.7E+01 ●	8.3E-02 ○	Yes	1.5E+00 ■
FM-W117	0.03	1E+01 ●	6.2E+00 ■	3.0E-02 ○	Yes	2.3E+00 ■
FM-W125	2.4	2E+01 ●	3.9E+00 ■	2.2E-02 ○	Yes	5.7E+00 ■
FM-W130	0.003	6E+01 ●	4.3E+01 ●	2.1E-01 □	Yes	9.8E+00 ■
FM-W132	0.4	2E+01 ●	1.2E+01 ●	5.8E-02 ○	Yes	1.7E+00 ■
FM-W147	0.01	4E+02 ●	2.5E+02 ●	1.2E+00 ■	Yes	6.1E+01 ●
FM-W154	0.2	1E+01 ●	7.0E+00 ■	3.4E-02 ○	Yes	1.8E+00 ■
FM-W162	0.01	1E+01 ●	7.2E+00 ■	3.5E-02 ○	Yes	2.4E+00 ■
FM-W165	0.8	7E+01 ●	4.3E+01 ●	2.1E-01 □	Yes	1.0E+01 ●
FM-W168	0.002	3E+02 ●	2.3E+02 ●	1.1E+00 ■	Yes	5.4E+01 ●
FM-W172	0.001	1E+01 ●	8.6E+00 ■	4.1E-02 ○	Yes	1.3E+00 ■
FM-W173	0.001	1E+02 ●	8.7E+01 ●	4.2E-01 □	Yes	2.1E+01 ●
FM-W181	0.001	3E+02 ●	2.0E+02 ●	9.8E-01 □	Yes	4.9E+01 ●
FM-W191	0.01	3E+01 ●	1.9E+01 ●	9.0E-02 ○	Yes	4.6E+00 ■
FM-W197	0.003	3E+03 ●	2.2E+03 ●	1.0E+01 ●	Yes	2.6E+02 ●
FM-W217	0.01	2E+01 ●	1.8E+01 ●	8.7E-02 ○	Yes	3.0E+00 ■
FM-W221	1.8	1E+01 ●	8.2E+00 ■	4.0E-02 ○	Yes	2.2E+00 ■
FM-W224	1.6	5E+01 ●	3.3E+01 ●	1.6E-01 □	Yes	8.1E+00 ■
FM-W225	0.1	2E+01 ●	1.7E+01 ●	8.1E-02 ○	Yes	3.8E+00 ■
FM-W226	0.4	2E+01 ●	1.5E+01 ●	7.2E-02 ○	Yes	3.6E+00 ■
FM-W227	0.003	6E+01 ●	4.7E+01 ●	2.3E-01 □	Yes	8.5E+00 ■
FM-W233	0.001	5E+01 ●	3.2E+01 ●	1.5E-01 □	Yes	7.5E+00 ■
FM-W240	8.9	7E+01 ●	5.2E+01 ●	2.5E-01 □	Yes	7.5E+00 ■
FM-W241	1.2	9E+01 ●	6.4E+01 ●	3.1E-01 □	Yes	1.4E+01 ●
FM-W243	9.8	7E+01 ●	5.8E+01 ●	2.7E-01 □	Yes	7.1E+00 ■
FM-W247	0.9	3E+01 ●	1.8E+01 ●	8.8E-02 ○	Yes	4.5E+00 ■
FM-W253	0.4	6E+01 ●	4.0E+01 ●	1.9E-01 □	Yes	8.4E+00 ■
FM-W258	0.3	1E+01 ●	8.8E+00 ■	4.3E-02 ○	Yes	1.9E+00 ■
FM-W262	0.01	6E+02 ●	4.6E+02 ●	2.2E+00 ■	Yes	6.0E+01 ●
FM-W282	81	6E+01 ●	5.4E+01 ●	2.6E-01 □	Yes	5.1E+00 ■
FM-W341	0.5	8E+01 ●	4.9E+01 ●	2.4E-01 □	Yes	1.2E+01 ●
FM-W358	0.01	4E+01 ●	2.7E+01 ●	1.3E-01 □	Yes	4.4E+00 ■
FM-W365	0.002	2E+03 ●	1.1E+03 ●	5.2E+00 ■	Yes	2.5E+02 ●
FM-W370	0.001	2E+02 ●	1.2E+02 ●	5.8E-01 □	Yes	1.9E+01 ●
FM-W403	0.001	5E+02 ●	3.6E+02 ●	1.7E+00 ■	Yes	7.6E+01 ●
FM-W409	0.001	2E+03 ●	1.5E+03 ●	7.1E+00 ■	Yes	3.1E+02 ●
IN-W007	0.01	3E+01 ●	2.2E+01 ●	8.2E-02 ○	Yes	1.1E+01 ●
IN-W038	0.03	2E+03 ●	4.9E+03 ●	1.4E+01 ●	Yes	3.8E+03 ●
IN-W057	0.001	3E+02 ●	1.5E+04 ●	6.8E-03 ○	No	2.2E+06 ●
IN-W062	0.001	1E+05 ●	5.7E+06 ●	2.6E+00 ■	No	2.3E+07 ●
LA-W074	0.2	5E+01 ●	1.5E+02 ●	5.0E-01 □	Yes	1.2E+02 ●
LA-W075	0.1	1E+04 ●	4.7E+02 ●	1.5E+00 ■	Yes	1.1E+03 ●
LA-W077	0.03	2E+03 ●	9.6E+00 ■	4.2E-02 ○	Yes	1.2E+05 ●

Table 3-1. SOF of Potentially Problematic MLLW Streams at Hanford Based on the Hanford and Envirocare WAC Concentration Limits (Part 2 of 2)

MWIR Survey ID	Treated Volume (m^3)	Hanford PE SOF	Hanford WAC SOF			Envirocare WAC SOF
			Category 1	Category 3	Mobile Nuclide Exceeding Reporting Limit?	
LA-W083	0.02	1E+05 ●	2.1E+03 ●	9.5E+00 ■	Yes	2.0E+03 ●
LA-W084	3.1	2E+02 ●	5.6E+00 ■	2.4E-02 ○	Yes	6.2E+00 ■
LL-W001	15.5	5E+01 ●	8.8E-01 □	3.2E-03 ○	Yes	1.8E+03 ●
LL-W002	254.4	2E+01 ●	3.5E+01 ●	2.9E-02 ○	Yes	2.1E+01 ●
LL-W004	88.9	6E+03 ●	2.8E+04 ●	4.6E-01 □	Yes	8.9E+04 ●
LL-W006	79.3	9E+02 ●	8.6E+02 ●	2.0E+00 ■	Yes	4.1E+04 ●
LL-W007	12.5	4E+04 ●	1.9E+04 ●	7.5E+01 ●	Yes	5.2E+04 ●
LL-W008	0.1	1E+04 ●	1.1E+02 ●	5.3E-01 □	Yes	6.1E+05 ●
LL-W010	29.6	6E+01 ●	2.0E+02 ●	2.8E-01 □	Yes	9.7E+01 ●
LL-W014	0.1	1E+02 ●	4.8E+02 ●	5.6E-01 □	Yes	4.0E+03 ●
LL-W015	15.4	5E+02 ●	5.3E-01 □	1.8E-03 ○	Yes	3.3E+04 ●
LL-W016	0.01	5E+06 ●	1.8E+03 ●	1.2E+00 ■	Yes	3.1E+08 ●
LL-W017	1.4	4E+03 ●	6.4E+02 ●	3.3E+00 ■	Yes	3.8E+02 ●
LL-W025	399.5	7E+01 ●	2.2E+02 ●	9.7E-01 □	Yes	1.7E+02 ●
PO-W018	60.8	4E+03 ●	8.9E+01 ●	4.1E-01 □	Yes	8.5E+01 ●
PO-W019	0.6	9E+02 ●	2.2E+02 ●	1.1E+00 ■	Yes	3.8E+01 ●
PO-W022	0.1	9E+04 ●	2.0E+04 ●	1.1E+02 ●	Yes	2.7E+04 ●
PO-W027	1.7	7E+02 ●	2.0E+01 ●	9.3E-02 ○	Yes	1.6E+01 ●
PO-W028	0.01	3E+02 ●	7.6E+00 ■	3.5E-02 ○	Yes	6.4E+00 ■
PO-W053	0.01	5E+01 ●	2.9E+00 ■	1.4E-02 ○	Yes	1.2E+00 ■
PO-W058	0.8	6E+02 ●	1.3E+01 ●	6.2E-02 ○	Yes	1.2E+01 ●
PO-W072	0.01	2E+02 ●	2.5E+01 ●	1.2E-01 □	Yes	5.5E+00 ■
RF-W017	0.1	4E+01 ●	1.3E+02 ●	5.6E-01 □	No	1.0E+02 ●
RF-W024	36.4	1E+01 ●	3.4E+01 ●	1.5E-01 □	No	3.2E+01 ●
RF-W025	0.2	1E+01 ●	4.0E+01 ●	1.8E-01 □	No	3.2E+01 ●
RF-W027	1.5	1E+01 ●	4.0E+01 ●	1.8E-01 □	No	3.2E+01 ●
RF-W030	46.9	1E+01 ●	4.0E+01 ●	1.8E-01 □	No	3.2E+01 ●
RF-W031	17	1E+01 ●	4.0E+01 ●	1.8E-01 □	No	3.2E+01 ●
RF-W035	2	1E+01 ●	4.0E+01 ●	1.8E-01 □	No	3.2E+01 ●
RF-W042	3.8	1E+01 ●	4.0E+01 ●	1.8E-01 □	No	3.2E+01 ●
RF-W043	29.9	1E+01 ●	4.0E+01 ●	1.8E-01 □	No	3.2E+01 ●
RF-W045	7.6	1E+01 ●	4.0E+01 ●	1.8E-01 □	No	3.2E+01 ●
RF-W046	0.2	3E+03 ●	8.1E+03 ●	3.6E+01 ●	No	6.4E+03 ●
RF-W047	0.5	1E+02 ●	3.2E+02 ●	1.4E+00 ■	No	2.6E+02 ●
RF-W049	0.1	3E+03 ●	8.1E+03 ●	3.6E+01 ●	No	6.4E+03 ●
RF-W050	1267.3	1E+01 ●	3.4E+01 ●	1.5E-01 □	No	3.2E+01 ●
RF-W062	0.6	1E+01 ●	4.0E+01 ●	1.8E-01 □	No	3.2E+01 ●
RF-W071	253.6	1E+01 ●	4.0E+01 ●	1.8E-01 □	No	3.2E+01 ●
RF-W074	10	1E+01 ●	4.0E+01 ●	1.8E-01 □	No	3.2E+01 ●
RL-W062	1.9	5E+01 ●	3.7E+00 ■	2.3E-03 ○	Yes	4.4E+00 ■
RL-W068	589	2E+01 ●	2.0E+00 ■	9.7E-03 ○	Yes	9.1E-01 □
RL-W069	1190.9	2E+01 ●	2.0E+00 ■	9.7E-03 ○	Yes	9.1E-01 □
RL-W095	204.1	1E+02 ●	8.5E+02 ●	3.4E-04 ○	No	2.3E+03 ●
RL-W152	0.8	5E+01 ●	3.7E+00 ■	2.3E-03 ○	Yes	4.4E+00 ■
RL-W234	72.3	2E+01 ●	2.4E+01 ●	8.6E-03 ○	Yes	4.5E+04 ●
SR-W009	13.3	1E+03 ●	3.7E+02 ●	3.8E-02 ○	Yes	5.7E+03 ●
SR-W015	21.3	3E+02 ●	1.8E-01 □	NL ○	Yes	1.1E+04 ●
SR-W046	6.2	1E+01 ●	8.0E+02 ●	3.7E-04 ○	No	3.9E+03 ●
SR-W047	36.7	2E+01 ●	8.7E+02 ●	4.0E-04 ○	No	4.3E+03 ●
SR-W060	0.1	3E+03 ●	2.2E+00 ■	NL ○	Yes	5.2E+05 ●
Total	**6245**					

NL means that no upper limit exists for H-3, the only radionuclide in the waste stream.

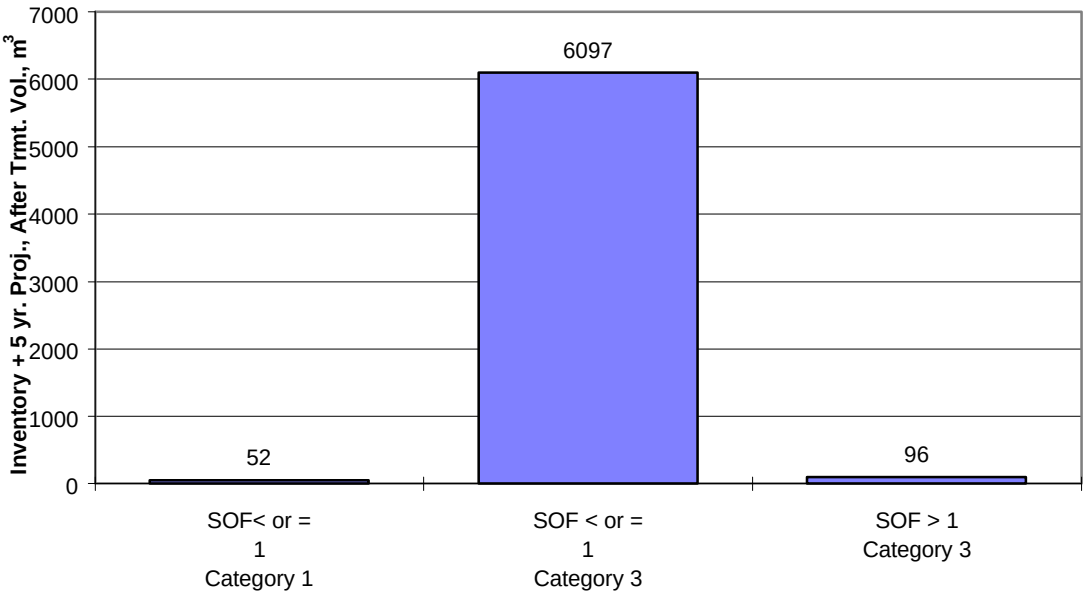

Figure 3-1. Classification of potentially problematic waste streams at Hanford based on Hanford WAC categories.

For Envirocare, of the 6245 m^3 of potentially problematic MLLW analyzed, 1780 m^3 (29%) meets the WAC limits, while 4465 m^3 (71%) exceeds the limits in the WAC. This result confirms that Envirocare has relatively restrictive disposal limits compared to DOE facilities.

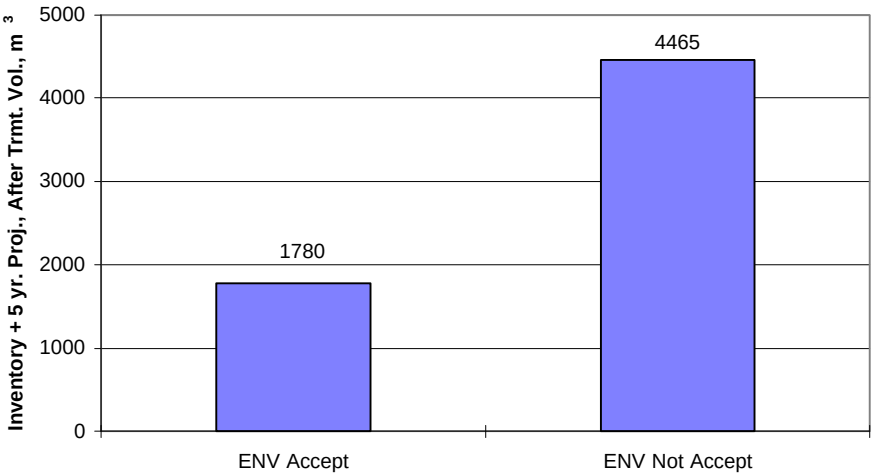

Figure 3-2. Classification of potentially problematic waste streams at Hanford based on the Envirocare WAC.

The potentially problematic waste streams that have a SOF of 1 or more based on Hanford's Category 3 limits are summarized in Table 3-2. All of these wastes are in the ● SOF category based on the Envirocare WAC. The treated volume of these wastes is about 100 m^3. The radionuclides that individually exceed the Category 3 limiting concentrations are also shown. Based on the Category 3 limits, eight waste streams have SOFs that exceed 1 by one order of magnitude or more. Only one waste stream has a SOF that exceeds 1 by more than two orders of magnitude, and it has an estimated treated volume of 0.1 m^3.

Table 3-2. Potentially Problematic Waste Streams at Hanford with SOF of 1 or Greater Based on Hanford WAC Category 3 Limits

MWIR Survey ID	Treated Volume (m^3)	SOF Based on Category 3	Controlling Radionuclide(s)
BT-W013	1.1	3 ■	U-234
FM-W147	0.01	1 ■	U-238
FM-W168	0.002	1 ■	(U-235 + U-238)
FM-W197	0.003	10 ●	U-238
FM-W262	0.01	2 ■	U-238
FM-W365	0.002	5 ■	U-238
FM-W403	0.001	2 ■	U-238
FM-W409	0.001	7 ■	U-238
IN-W038	0.03	14 ●	Pu-239, Am-241
IN-W062	0.001	3 ■	Cs-137
LA-W075	0.1	1 ■	Th-232
LA-W083	0.02	10 ■	Tc-99
LL-W006	79.3	2 ■	Am-241
LL-W007	12.5	75 ●	Ra-226
LL-W016	0.01	1 ■	C-14
LL-W017	1.4	3 ■	Pu-239, U-233
PO-W019	0.6	1 ■	(U-234 + U-238)
PO-W022	0.1	112 ●	U-234, U-235, U-238
RF-W046	0.2	36 ●	Pu-239, Pu-240
RF-W047	0.5	1 ■	(Pu-239 + Pu-240)
RF-W049	0.1	36 ●	Pu-239, Pu-240
Total	**96.0**		

3.2 Waste Streams Associated with the ■ SOF Category in the RA Report

An analysis similar to that performed for the potentially problematic waste streams at Hanford was conducted for the waste streams in the RA project that resulted in the ■ SOF category. The analysis was conducted to evaluate the assumption in the RA report that these wastes would be acceptable for disposal based on more detailed analysis. The results of this analysis, which are provided in Appendix B, indicate that all of these waste streams are acceptable for disposal at Hanford. Of the 38,660 m^3 of waste analyzed, waste streams associated with 32,260 m^3 (83%) had SOFs of 1 or less based on Hanford Category 1 limits, and waste streams associated with 6,400 m^3 (17%) had SOFs of 1 or less based on Hanford Category 3 limits. These results validate the assumption made in the RA report about the disposability of ■ category waste. At Envirocare, waste streams associated with 33,680 m^3 (87%) of the ■ category at Hanford would be acceptable for disposal.

4. DISCUSSION

The results presented in this report are based on a scoping-level analysis, and many simplifying assumptions have been made. Additionally, many uncertainties exist in the waste stream characterization data, the plans for treatment of waste streams, and treatment effects on waste stream volumes and radionuclide concentrations. The effects of these assumptions and uncertainties on the analysis results are discussed in this section.

4.1 Assumptions and Uncertainties

The assumptions and uncertainties discussed in this section are those related to waste form performance, potential changes in DOE Orders, and estimates of volumes and radionuclide concentrations of the waste streams.

4.1.1 Models and Data for Waste Form Performance

Basic Information about the Waste Forms

The waste forms evaluated in the RA project (DOE, 1997) were based on data in site-specific STPs and on treatment assumptions used by the MWFA and reviewed by several sites (MWFA, 1996). The volume percentages of residual MLLW associated with the site-selected waste forms for the potentially problematic waste streams listed in Chapter 3 of this report are shown in Figure 4-1. Grouted residuals represent the largest amount of waste: approximately 60% of the total volume. The waste forms designated as “soil,” “clay,” and “grout or polymer” were modeled as a grouted waste form. Thus, effectively, over 95% of the waste stream volume discussed in Chapter 3 was modeled on the grouted waste form. Eight waste streams modeled as a polymer waste form account for 0.9% of the total volume; six of the polymer waste forms were macro-encapsulated. Five waste streams modeled as a vitrified waste form account for about 3.6% of the total volume for the waste streams included in Chapter 3 of this report.

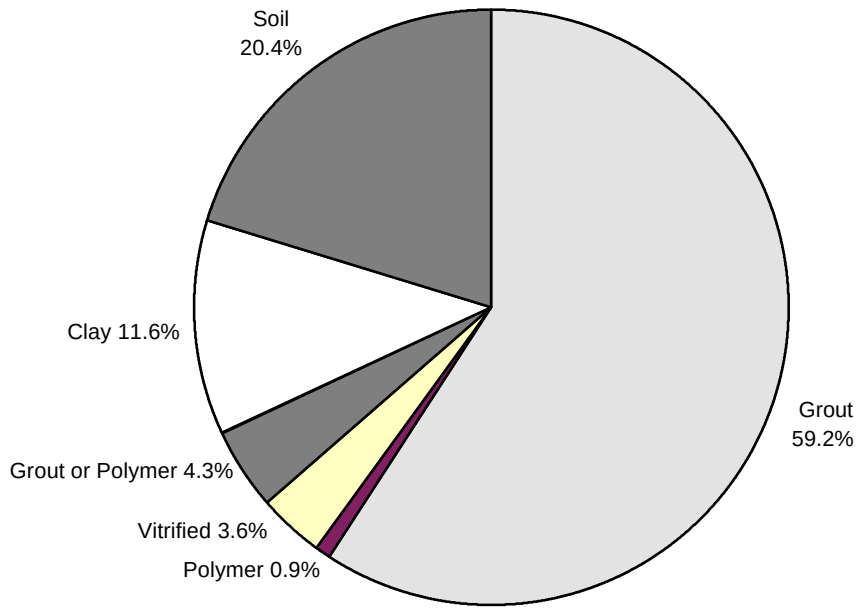

Figure 4-1. Volume percentages of potentially problematic, treated MLLW streams associated with various waste forms.

The grouted waste form model was described in the PE report (DOE, 1996). The other waste form models are based on work completed by Sandia for EM-50 (SNL, 1996). These models are described in this section.

The source term model used in the PE provided a correlation between radionuclide concentrations in the waste form and the resulting radionuclide concentrations in the leachate that exits the bottom of the disposal facility. The source model is used to formulate the source concentration reduction factor, CRF_{Source}:

$$CRF_{Source} = C_{Waste} / C_{Leachate} \tag{4-1}$$

where

C_{Waste} is the concentration in the waste form for each radionuclide averaged over the entire waste volume in the disposal facility (µCi/L), and

$C_{Leachate}$ is the corresponding individual radionuclide concentration in the leachate as it exits the bottom of the disposal facility (µCi/L).

Grouted Waste Form

For the grouted waste form, the partitioning of radionuclides between the solid phase (i.e., radionuclides sorbed onto the grout) and the liquid phase (i.e., radionuclides dissolved in the pore water) was assumed to be determined by the equilibrium sorption phenomenon. This

assumption is consistent with analyses in the three LLW performance assessments that have evaluated grouted waste forms (ORNL, 1994; MMES et al., 1994; Kincaid et al., 1993). With this assumption, the radionuclide concentration in the leachate based on desorption in infiltrating water can be described (ORNL, 1994) by

$$C_{Leachate} = \frac{C_{Waste} f_m}{q_G + K_d^G r_G} \tag{4-2}$$

where

f_m is the mixing fraction, defined as the ratio of the volume of waste disposed in a unit volume of the facility and assumed to be 2/3 for a trench design and 1/3 for a tumulus design;

θ_G is the volumetric water content of the grouted waste form, which has a value of approximately 0.3 mL/mL;

K_d^G is the distribution coefficient (i.e., solid/liquid partition coefficient) of the radionuclide in the grout (mL/g); and

ρ_G is the dry bulk density of the grouted waste form, which has a value of approximately 1.8 g/cm^3.

Combining Equations 4-1 and 4-2 derives a relationship for CRF_{Source} in terms of the grout distribution coefficient (K_d^G) and the properties of the stabilized waste (θ_G, ρ_G, and f_m):

$$CRF_{Source} = \frac{(q_G + K_d^G r_G)}{f_m} . \tag{4-3}$$

There are a wide variety of methods for determining radionuclide distribution coefficients in grout (K_d^G). For example, the EPA (1989) identified nine extraction procedures and three different leaching tests. Because of the wide range of values resulting from different procedures, conservative K_d^G values are used in the analyses. These values are based largely on the analysis in the Oak Ridge SWSA 6 performance assessment (ORNL, 1994).

The grouted waste form considered in the formulation of K_d^G values in the Oak Ridge performance assessment was based on mixing dry waste with pumpable grout. Conversely, K_d^G values in the Hanford vault performance assessment (Kincaid et al., 1993) and the Savannah River Z-Area vaults performance assessment (MMES et al., 1992) are based on grout formulations in which the radionuclides are contained in water mixed into the grout material. Much higher K_d^G values were used in the performance assessments for the Savannah River and Hanford sites than for Oak Ridge. The lower values used in the Oak Ridge performance assessment are more conservative because smaller values are obtained for CRF_{Source}; thus, these K_d values are used as the primary basis for estimating the values used in the analyses.

Although there are uncertainties in determining the appropriate K_d^G value to use in these analyses, grout has been widely studied (e.g., Bradbury and Sarett [1995] and Walton et al. [1990]). Further study is not expected to yield lower K_d^G values than those used in these analyses. Additionally, most of the waste can be disposed of in existing facilities. Further study of grouted waste forms is not expected to change this conclusion.

Encapsulated Polyethylene Waste Form

The source model for encapsulated polyethylene was assumed to be limited by radionuclide diffusion through pore channels in the waste. The model is a function of waste form size and waste loading. In these calculations, the waste form was assumed to be a 1 × 1-m cylinder (i.e., roughly the size of a 55-gallon drum) with a waste loading of 50% at 20°C. For use in the source term model, the dependent variable was represented by leachate concentrations rather than by fraction leached. This translation was accomplished by using a mass balance (i.e., what leaves the waste form goes into the infiltrating water):

$$C_{Leachate} = \frac{1}{Q}\frac{dF}{dt}Vf_m C_{Waste} \tag{4-4}$$

where

Q is the water flow rate through the waste site (m^3/yr);
F is the fraction of waste leached based on the diffusion model used (unitless);
t is time (yr); and
V is the volume of the waste form (m^3).

As a conservative, simplifying assumption, the release rate was held constant at the initial rate, and the effects of a depleting source were not accounted for. Hence, from Equations 4-1 and 4-4, the concentration reduction factor for waste stored in polyethylene is:

$$CRF_{Source} = \frac{Q}{\frac{dF}{dt}Vf_m} \tag{4-5}$$

where dF/dt is assumed to be constant throughout the period of performance.

This source model was also used for macroencapsulated waste, with no releases assumed for the first 100 years after disposal. The polyethylene surrounding the waste was assumed to start to crack after 100 years, allowing the radionuclides to begin to diffuse from the waste form. The source concentration factors were determined at 20°C.

Little information is available about radionuclide release mechanisms for macroencapsulated polyethylene. The diffusion models used to determine dF/dt for polyethylene are primarily based on the Accelerated Leach Test (ALT). More study is needed for polyethylene encapsulated waste using the ALT or a similar test to determine radionuclide specific diffusivities under various conditions. Degradation of physical properties of polyethylene by gamma irradiation, in combination with oxidation, has been

observed (Kalb, 1996). The irradiation effect on a polyethylene waste form could be significant for higher dose rate MLLW because the Nuclear Regulatory Commission (NRC) Class C limits on low-level waste activity (10 CFR Part 61) are presently about two orders of magnitude greater than the dose rates predicted to create radiation damage in polyethylene wire coatings (Fuhrmann and Zhou, 1994). Also, there are few experimental data that compare the leaching of different contaminants from polyethylene. Although the pore dimensions in the waste form are expected to be much larger (about a micrometer) than the molecule size of solubilized radionuclides in waste, further study is needed to confirm radionuclide-specific diffusivities in polyethylene waste forms.

Vitreous Waste Form

In the glass leach model, radionuclides were assumed to be released from properly formulated waste glass because of breakdown of the glass network. A corrosion model (Cunnane and Allison, 1994) was adopted. The fraction (F) of a canistered waste glass that corrodes per year after exposure to repository groundwater environment is

$$\frac{dF}{dt} = \frac{RA}{W} \tag{4-6}$$

where

R is the glass corrosion rate (g/m^2-yr);
A is the surface area (m^2) of the glass contacted by water; and
W is the mass (g) of the glass in a canister.
.

The term A/W can be replaced by the specific surface area, A_{sp}, which is a function of the degree of cracking. Hence, the CRF_{Source} is computed as

$$CRF_{Source} = \frac{Q}{RA_{sp}Vf_m} \tag{4-7}$$

The glass corrosion rate is determined similarly to the ALT (Brown and Lu, 1993): the water used in solution is exchanged frequently, producing the greatest possible leaching conditions. Several studies attempted to determine glass corrosion rates for high level waste. Fuhrmann and Zhou (1994) have recorded a cumulative fraction of calcium leached from glass of 6.2×10^{-7} using the ALT, equating to a forward rate of 4×10^{-4} g/m^2-day. Mazer and Walther (1994) computed the linear dissolution rate for pure silica glass to be 7.6×10^{-6} g/m^2-day at pH 4 and 40°C (6×10^{-7} g/m^2-day corrected to 20°C). The data show that this value is approximately constant to pH 7 and should represent a lower bound on this parameter because pure silica is the most durable of the borosilicate glasses. Cunnane and Allison (1994) evaluated the performance of high level waste borosilicate glass. They used a corrosion rate of 2.5×10^{-3} g/m^2-day that considered the forward rate and saturation conditions at 90°C; a comparable value for low level waste would be 3×10^{-6} g/m^2-day at 20°C assuming 20 kcal/mol activation energy.

McGrail et al. (1996) recently completed corrosion rate studies for some of Hanford's low level waste. For the glass LD6-5412, the forward leach rate is 1.0×10^{-4} g/m^2-day at 20°C and pH 7, with pH and temperature dependence described by exponential and Arrhenius functions, respectively. The glass corrosion rate for the current analysis was based on these data. Because the source term model was intended to provide a conservative analysis, the forward dissolution rate at 20°C was used as the release rate. Effects of crystallization and solution pH on the glass release rate were neglected. The forward dissolution rate for the borosilicate glass waste form was assumed to be 0.0001 g/m^2-d at a loading of 30 wt% waste.

The large amount of information available on vitreous waste forms is based on studies to determine corrosion rates for high-level waste. Because the release rates for vitreous waste forms are generally much lower than for other low-level waste forms, these numerous studies indicate that, even with the variability in the data, vitreous waste forms exceed the leach requirements for MLLW disposal.

In addition, as shown by the Hanford WAC, the concentration limits for most radionuclides are based on inadvertent intrusion scenarios. The primary methods of minimizing inadvertent intrusion effects are (1) packaging the wastes in containers that minimize the intrusion potential and (2) burying wastes with higher radioactivity at deeper depths.

4.1.2 Potential Changes to DOE Orders

In developing its PA, Hanford was required to follow DOE Order 5820.2A (DOE, 1988). This order requires DOE disposal facilities to develop site-specific performance assessments and other performance analyses to ensure that prescribed dose objectives will be achieved; these analyses result in the radiological component of a site-specific WAC. One analysis required by DOE Order 5820.2A is an assessment of the impact of inadvertent intrusion into a disposal facility. The Hanford Category 1 limits are based on the results of a "homesteader" intruder scenario, and the Category 3 limits are based on the results of a "post-

DOE Order 5820.2A is currently being revised as part of DOE's Implementation Plan for the Defense Nuclear Facilities Safety Board Recommendation 94-2. One of the expected revisions is related to the evaluation of the consequences of inadvertent intrusion. Because the radiological limits in the Hanford WAC are largely based on intrusion scenarios, changes to the DOE Order 5820.2A are likely to affect these limits as well as limits in WAC for other DOE disposal facilities.

4.1.3 Waste Volumes for Disposal

In this section, the assumptions and uncertainties used in the RA for estimating waste stream volumes for disposal are discussed. These assumptions and uncertainties are important in (1) the use of the data for estimating the treated volume of each waste stream and (2) the selection and evaluation of treatment options.

Data for Estimating Waste Stream Volumes

The primary sources of input data for waste stream volumes used in the analyses were the 1995 MWIR database and updates based on site-specific reviews. The MWIR database has evolved over the last four years in response to additional waste characterizations and increased knowledge of waste characteristics at the DOE sites, and the site-specific updates reflect more recent changes due to waste stream treatment and better estimates of existing waste stream volumes and projections of future wastes.

The waste stream volumes associated with current inventories are known; there is very little uncertainty about these numbers because they have been measured. However, there are larger uncertainties about the volume estimates for the 5-year projections of waste streams to be generated; there are often uncertainties in the operations that will generate these wastes. The values used for these projected volumes reflect the best estimates of the DOE site personnel responsible for generating these waste streams. The actual generation rates may be higher or lower than estimated for some waste streams, and the duration of the waste generation may be longer or shorter than the five-year period for which estimates are provided.

Selection and Evaluation of Treatment Options

The treatment processes selected for each waste stream in the RA were based on "preferred alternatives" in site treatment plans. While many of the preferred alternatives were associated with specific, existing treatment facilities, preferred alternatives for some waste streams were either non-specific, were based on proposed facilities that have no operating data, or were not specified.

For waste streams associated with existing, operating treatment facilities, no major assumptions were required to estimate the treatment results; the site contacts provided the operating parameters for the treatment process during review. For waste streams associated with either treatment facilities that were non-specific or not existing, professional judgment was used to develop estimates of the treatment effects on the waste streams. Research conducted at the SRS (WSRC, 1995) was the basis for the estimates of the treatment effects used in this analysis. This work at SRS contained an analysis for that site's waste streams that is similar to the one described in this report.

The uncertainties about the selection of the actual treatment process for these waste streams are larger than the uncertainties about the effects of specific treatment processes on the waste streams. For example, a waste stream tentatively planned for incineration and grout stabilization (AMR = 1/100) may eventually be treated solely by grout stabilization (AMR =

2), with a resulting change in estimated final volume of 200. This potential difference is much greater than that due to the uncertainty related to the effects of a specific treatment process (e.g., if the AMR for grout stabilization ranges from 1.5 to 3).

4.1.4 Concentrations of Radionuclides

This section discusses (1) the effect of assumptions and uncertainties related to radionuclide concentrations in residual MLLW for the input data used in the RA analysis, and (2) the treatment effects on radionuclide concentrations in residual MLLW.

Data for Estimating Radionuclide Concentrations in Waste Streams

In the RA, the primary data sources for waste stream characterization were the 1995 MWIR database and updates based on site-specific reviews. Much of the data are based on detailed MLLW characterizations, but a large portion of the data are based on "process knowledge" of the engineers and operators of the production processes that created these waste streams.

Although the MWIR database is the product of a complex-wide data call, the data quality from site to site is not expected to be uniform. Differences in waste types and amounts, the available resources to characterize the waste streams, and the waste characterization experience of site personnel cause data quality differences among the sites.

Characterization data for many waste streams in the MWIR database are based on relatively small sample sizes of the individual waste streams. In addition, many waste streams in the MWIR are actually aggregates of smaller waste streams that are expected to have similar treatability characteristics, and many of these wastes are highly heterogeneous. The combination of these conditions tends to cause larger uncertainties in the characterization data, and results of detailed analyses based on these data must be interpreted with circumspection. However, the data used in this analysis represent the best available compilation of characterization data for DOE MLLW, and the data quality is consistent with use in a scoping-level analysis.

The Treatment Effects on Radionuclide Concentrations

For waste streams associated with existing, operating treatment facilities, no major assumptions were required to estimate the treatment results; site contacts supplied the operating parameters for the treatment process during review. For waste streams associated with either treatment facilities that were non-specific or non-existing, professional judgment was used to develop estimates of the treatment effects on the radionuclide concentrations in the waste streams. Research conducted at the SRS (WSRC, 1995) was the primary basis for the estimates of the treatment effects on radionuclide concentrations, with site reviews either confirming or modifying these assumptions.

The assessment of the fate of radionuclides in a treatment process is inherently more uncertain than the estimate of the volume change of a waste stream due to treatment. For example, the specific temperature, pressure, and redox conditions in a treatment process

combined with the specific chemical and physical characteristics of the radionuclide will determine its mass distribution in the residual solids, liquids, and gases. An analysis based on this level of detail was beyond the scope of the RA project and is generally beyond the level of available data and specific treatment plans. This area represents a significant uncertainty; it can be reduced by more definitive plans for use of specific treatment processes and by more detailed analyses of those treatment processes.

4.2 Analysis Results in Perspective

Four areas of uncertainties and limitations on the RA and on the current analysis are discussed in this section. The value of investigating the potential for reclassifying waste streams from Hanford's WAC Category 3 to Category 1 is discussed in Section 4.2.1. The status of the waste streams for which no treatment had been defined is discussed in Section 4.2.2. The issue of waste streams that cannot be evaluated for disposal acceptability because of insufficient radionuclide characterization is discussed in Section 4.2.3. Uncertainties stemming from the compatibility of waste streams and waste forms is discussed in Section 4.2.4.

4.2.1 Reclassification of Potentially Problematic MLLW Residuals

The results summarized in Chapter 3 illustrate that the Hanford Reservation would be a viable disposal option for virtually all of the potentially problematic MLLW. Most of this waste is associated with the limits for Hanford's Category 3 WAC. Some of this waste may meet the limits for Hanford's Category 1 WAC if different treatment processes were used, resulting in a unit disposal cost of approximately 1/3 that for wastes in Category 3. A cost/benefit analysis of treatment costs versus disposal costs would establish the viability of treating wastes to qualify for Hanford's Category 1 WAC.

Several assessment areas provide insight about the quantity of potentially problematic waste that could ultimately qualify for disposal based on Hanford's Category 1 WAC. First, the RA's conservative nature could affect the classification of treated waste streams. Some radionuclide concentrations in treated MLLW streams may have been over-estimated because of assumptions about treatment impacts on waste streams. A more detailed assessment of the effect of proposed treatment processes on MLLW may result in the reclassification of many waste streams from disposal based on Hanford Category 3 to disposal based on Category 1. Those waste streams remaining for disposal as Category 3 waste after a reassessment of treatment effects could be further analyzed based on other treatment options that would result in Category 1 disposal. Treatment options could include combining similar waste streams with different radiological characterizations. Different treatment processes or waste forms may also improve the waste stream's performance with respect to Hanford Category 1 WAC.

4.2.2 Status of "No Process" MLLW

Several waste streams in the MWIR database, accounting for approximately 8700 m^3 of waste, were classified in the RA as "No Process" waste. These are waste streams for

which no potential treatment process had yet been identified. The fact that no treatment process had been identified for these waste streams represents an aspect of uncertainty in the knowledge base of the DOE MLLW inventory. These waste streams can be cataloged into three categories:

1. Waste streams not expected to pose significant problems for processing but which have not yet been characterized, including well-defined future-generated waste;
2. Future-generated waste streams of an undefined nature (e.g., environmental remediation wastes of uncharacterized waste sites); and
3. Waste streams that present real challenges with respect to waste treatment technologies.

Much of the "No Process" waste will likely fall into the first category. For example, a significant contributor to the "No Process" inventory in the RA project is approximately 2500 m^3 of SRS waste identified in the SRS STP as "waste to be generated from future ER work." The physical nature of the waste is expected to be purge water, dirt, tools, and clothing. As indicated in the STP, SRS does not plan to select a treatment process until the waste has been characterized. Because process methods are available for the waste types expected from the SRS ER activities, most of the SRS ER waste streams will probably not represent a potential treatment issue. However, many ER activities involve the remediation of materials of unknown radionuclide assays and concentrations. Uncertainty about the chemical or radionuclide nature of the materials being remediated could cause some of the SRS future-generated waste streams to fall in the second or third category.

A detailed, site-specific review of the "No Process" waste streams would delineate the estimated 8700 m^3 of "No Process" waste into the three categories defined above. Those "No Process" waste streams that fall into the first category could be evaluated for disposal acceptability against Hanford's WAC. Insights gained from detailed assessment of the waste streams that fall into the second and third categories would help to identify areas for research in treatment technology and new waste forms.

4.2.3 Status of MLLW with Insufficient Radionuclide Characterization

Another source of uncertainty in the disposability of MLLW is the approximately 27,000 m^3 of MLLW that has insufficient radionuclide characterization to allow assessment of its acceptability for disposal. As shown in Chapter 3, most of the waste identified as potentially problematic would be acceptable for disposal at Hanford. It is not unreasonable to assume that much of the waste lacking radiological characterization would meet the limits of the Hanford WAC. However, the uncharacterized waste cannot, at this point, be assessed for disposal acceptability.

4.2.4 Uncertainty of Waste Compatibility with Site-Selected Waste Forms

The performance analysis of waste forms in this evaluation was based on the assumption that the waste streams were compatible with their associated waste forms.

However, there can be compatibility problems associated with certain waste characteristics, classes of waste, and waste forms. For example, grout does not harden when used to stabilize waste with high sulfate concentrations. A significant uncertainty about MLLW disposal exists until the compatibility of the waste streams and selected waste forms is reviewed. This review would consist of a literature survey of compatibility problems associated with selected waste forms and reexamination of waste streams for the identified characteristics. If compatibility problems are found, then alternative waste forms could be identified.

5. CONCLUSIONS AND RECOMMENDATIONS

The evaluation summarized in this report compares radionuclide concentration estimates of treated MLLW with waste acceptance criteria for the LLW disposal facility at the DOE Hanford Reservation and for the commercial MLLW disposal facility at Envirocare of Utah. The specific waste streams that were analyzed were those identified as potentially problematic in the RA report (DOE, 1997); potentially problematic waste streams are those for which the sum-of-fractions calculations for the combined effects of radionuclide concentrations is greater than ten times the PE-derived limits (DOE, 1996) for disposal at Hanford.

The major benefits of this evaluation are that it (1) provides a substantiated estimate of the capability of the Hanford and Envirocare sites for disposal of treated MLLW, (2) identifies waste streams that require further evaluation to ensure their disposability, allowing DOE to focus its attention on a smaller portion of the MLLW inventory and narrow the scope of further analyses, and (3) indicates the need for further waste characterization and collection of waste form performance data.

5.1 Conclusions

- Of the approximately 6250 m^3 of treated MLLW that was identified in the RA as potentially problematic for disposal at Hanford, all but 96 m^3 has a SOF of 1 or less based on the WAC concentration limits for either Category 1 or Category 3 wastes at Hanford. Additional documented justification for disposal of the 96 m^3 may allow its disposal at Hanford, with possible additional disposal requirements. Disposal of this waste in concrete boxes (as is the current practice for waste that has a SOF of 1 or less based on Category 3 concentration limits) may be sufficient, thus removing the need for additional measures.

  The majority of the MLLW acceptable for disposal at Hanford has a SOF of 1 or less based on the Category 3 concentration limits, indicating that additional intruder barriers will be required to dispose of this waste compared to Category 1 disposal. However, potential changes in the DOE Order 5820.2A that are currently being evaluated related to assessment of disposal facility performance may affect these results.

  In addition, the entire 38,700 m^3 of treated MLLW associated with the ■ SOF symbol in the RA report meets the radiological limits for disposal at Hanford, confirming the assertion in the RA report that this waste is not problematic for disposal.

- Of the approximately 6250 m^3 of treated MLLW that was identified as potentially problematic for disposal at Hanford, approximately 4500 m^3 has a SOF greater than 1 based on the WAC for disposal at the Envirocare of Utah facility. This result illustrates that the Envirocare WAC facility is relatively restrictive compared to the radionuclide concentrations in DOE MLLW.

- Adequate data appear to be available to estimate waste form performance for both grouted wastes and vitrified wastes. However, the data suitable for estimating performance of both polyethylene microencapsulated and macroencapsulated waste is sparse. Based on the data used in this analysis, polymer encapsulation comprises less than 1% of the volume of potentially problematic MLLW for disposal at Hanford.

- The evaluation described in this report analyzed only a portion of the MLLW for disposal. As shown in Figures 1-1, approximately 8700 m^3 of MLLW was insufficiently characterized to allow the sites to determine a treatment process for these waste streams. Some of this volume is associated with MLLW streams that have not been generated. Other insufficiently characterized waste streams may require advanced treatment processes or special waste forms to be acceptable for disposal.

  In addition, as shown in Figure 1-2, approximately 27,000 m^3 of MLLW currently has insufficient radionuclide characterization and was not analyzed for disposability. The MLLW in both of these categories must be analyzed before a complete evaluation of MLLW disposability can be made.

- Compatibility of wastes and waste forms was not evaluated because this issue is a site responsibility.

5.2 Recommendations

- The evaluation described in this report indicated that Hanford could dispose of much of the problematic MLLW based on Category 3 limits. However, the cost for disposal of Category 3 wastes is approximately three times higher than for Category 1 wastes at Hanford. A cost/benefit analysis should be conducted to determine if the use of different or additional treatment processes or different waste forms will result in MLLW that can be disposed of as Category 1 wastes.

- If the polyethylene waste form is expected to be used more extensively for MLLW disposal, more performance data should be collected for both microencapsulation and macroencapsulation. The data currently available is sparse and not radionuclide specific, and it cannot be used to support decisions on waste form performance. Most of the work on polyethylene waste form performance has been conducted at Brookhaven National Laboratory.

- Further analysis should be conducted for MLLW streams that do not currently have an assigned treatment process. Some of these waste streams are being evaluated by the DOE Contractor Integration Effort headed by Lockheed Martin at INEEL, so further analyses should be coordinated with this group.

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Appendix A: Concentration Limits from the Waste Acceptance Criteria at the Hanford Reservation and Envirocare of Utah

The results of the analysis in Chapter 3 are based on the concentration limits listed in the waste acceptance criteria for the Hanford Reservation (WHC, 1993) and Envirocare of Utah (UDRC, 1995). The combined list of radionuclides that have an activity limit at one or both of the sites is contained in Table A-1. At the Hanford Reservation, if mobile radionuclides within a waste stream exceed the reporting limits shown in Table A-2, additional assessment of the waste stream is necessary because the waste may require stabilization.

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Table A-1. Concentration Limits from the WAC at the Hanford Reservation and Envirocare of Utah (Part 1 of 3)

Radionuclide	Hanford		Envirocare
	Category 1 (Ci/m$^{3)}$	Category 3 (Ci/m^3)	(pCi/g)
Ac-227	4.2E-03	3.0E+05	NV
Ag-108m	NV	NV	5.0E+02
Ag-110m	NV	NV	5.6E+02
Am-241	2.1E-03	0.85[b]	2.3E+03
Am-242m	1.9E-03	1.6[b]	NV
Am-243	1.0E-03	0.23[b]	1.7E+03
Au-195	NV	NV	2.0E+03
Ba-133	7.1E-01	c	4.0E+03
Be-7	NV	NV	3.8E+04
Be-10	1.1E+00	2.4E+02	NV
Bi-207	NV	NV	4.0E+02
C-14	9.1E-02	2.1E+01	2.0E+05
C-14[a]	9.1E-01	2.1E+02	NV
Ca-45	NV	NV	4.0E+04
Cd-109	NV	NV	4.6E+04
Cd-113m	7.6E-01	c	NV
Ce-139	NV	NV	2.0E+03
Ce-141	NV	NV	4.0E+03
Ce-144	NV	NV	4.0E+03
Cl-36	6.4E-05	1.4E-01	NV
Cm-242	c,d	c	NV
Cm-243	1.8E-02	340[b]	1.5E+03
Cm-244	1.4E-01	1.6E+02	1.0E+03
Cm-245	1.3E-03	0.22[b]	NV
Cm-246	1.8E-03	0.42[b]	NV
Cm-247	5.6E-04	0.12[b]	NV
Cm-248	5.1E-04	0.11[b]	NV
Cs-134	NV	NV	1.2E+03
Cs-135	1.6E-01	3.5E+01	5.0E+02
Cs-137	5.5E-03	1.2E+04	5.6E+02
Co-56	NV	NV	3.6E+02
Co-57	NV	NV	1.9E+04
Co-58	NV	NV	1.6E+03
Co-60	7.5E+01	c	3.6E+02
Co-60[a]	750[d]	c	NV
Cr-51	NV	NV	6.8E+04
Cu-67	NV	NV	2.0E+03
Eu-150	1.4E-03	6.7E+02	NV
Eu-152	4.8E-02	c	1.7E+03
Eu-154	7.5E-01	c	1.4E+03
Eu-155	NV	NV	1.7E+03
Fe-55	NV	NV	2.0E+04
Fe-59	NV	NV	4.0E+02

Table A-1. Concentration Limits from the WAC at the Hanford Reservation and Envirocare of Utah (Part 2 of 3)

Radionuclide	Hanford		Envirocare
	Category 1 (Ci/m^3)	Category 3 (Ci/m^3)	(pCi/g)
Gd-152	6.4E-03	1.4E+00	NV
Gd-153	NV	NV	3.0E+03
Ge-68	NV	NV	4.0E+03
H-3	9.9E+04	c	2.0E+05
Hf-181	NV	NV	1.0E+03
Hg-203	NV	NV	1.0E+04
I-125	NV	NV	1.5E+03
I-129	8.5E-03	1.8E+00	3.1E+02
Ir-192	NV	NV	2.5E+03
K-40	1.8E-03	3.8E-01	1.0E+03
Mn-54	NV	NV	5.6E+03
Mo-93	8.7E-01	2.0E+02	NV
Na-22	NV	NV	7.8E+02
Nb-94	2.2E-04	4.8E-02	1.6E+02
Nb-94[a]	2.2E-03	4.8E-01	NV
Ni-59	3.9E+00	8.5E+02	7.0E+02
Ni-59[a]	3,9E+01	8.5E+03	NV
Ni-63	5.9E+00	2.0E+04	1.0E+04
Ni-63[a]	5.9E+01	2.0E+05	NV
Np-237	6.8E-04	0.15[b]	2.0E+03
Pa-231	1.4E-04	3.0E-02	NV
Pb-210	3.7E-02	2.1E+06	2.0E+04
Pd-107	1.5E+01	3.3E+03	NV
Pm-147	NV	NV	4.0E+03
Po-209	9.8E-03	3.2E+01	NV
Po-210	NV	NV	2.0E+04
Pu-238	4.7E-03	24[b]	1.0E+03
Pu-239	1.9E-03	0.42[b]	1.0E+03
Pu-240	1.9E-03	0.43[b]	1.0E+03
Pu-241	6.1E-02	2.5E+01	3.5E+03
Pu-242	2.0E-03	0.43[b]	1.0E+03
Pu-244	6.1E-04	0.13[b]	NV
Ra-226	1.7E-04	4.3E-02	2.0E+03
Ra-228	1.7E+01	c	1.8E+03
Rb-83	NV	NV	1.0E+03
Re-187	3.6E+01	7.8E+03	NV
Ru-106	NV	NV	1.9E+04
S-35	NV	NV	4.0E+03
Sb-124	NV	NV	7.9E+02
Sb-125	NV	NV	5.3E+03
Sc-46	NV	NV	4.0E+02
Se-75	NV	NV	1.0E+03
Se-79	5.1E-01	1.1E+02	NV

Table A-1. Concentration Limits from the WAC at the Hanford Reservation and Envirocare of Utah (Part 3 of 3)

Radionuclide	Hanford		Envirocare
	Category 1 (Ci/m^3)	Category 3 (Ci/m^3)	(pCi/g)
Sm-147	1.7E-02	3.7E+00	NV
Sm-151	4.6E+01	2.1E+05	1.0E+03
Sn-113	NV	NV	1.0E+04
Sn-121m	6.7E-01	2.2E+04	NV
Sr-85	NV	NV	5.0E+02
Sr-89	NV	NV	2.0E+03
Sr-90	1.6E-02	5.4E+04	2.0E+04
Ta-182	NV	NV	5.0E+02
Tc-99	2.3E-02	5.0E+00	1.0E+04
Th-229	4.4E-04	9.8E-02	NV
Th-230	2.1E-03	1.5E-01	1.5E+04
Th-232	1.1E-04	2.3E-02	6.8E+02
Tl-204	NV	NV	1.0E+03
U-232	4.6E-04	4.6E+00	NV
U-233	7.6E-03	0.97[b]	NV
U-234	8.9E-03	1.9E+00	3.7E+04
U-235	2.8E-03	5.0E-01	7.7E+02
U-236	9.5E-03	2.0E+00	3.6E+04
U-238	5.7E-03	1.2E+00	2.8E+04
Y-88	NV	NV	3.0E+02
Y-91	NV	NV	2.0E+03
Zn-65	NV	NV	1.1E+04
Zr-93	2.5E+00	5.4E+02	NV
Zr-95	NV	NV	5.0E+02

a Isotope in activated metal
b The lower of this value and 100 nCi/g
c No upper limit exists
d Interim Safety Basis limits are lower. The waste must be checked against the combustible and noncombustible limits.
NV No value at this site

Table A-2. Mobile Radionuclide Reporting at Hanford

Radionuclide	Reporting Limit (Ci/m^3)
H-3	4.4E+00
C-14	1.3E-04
Cl-36	9.2E-05
Se-79	3.4E-05
Tc-99	2.1E-04
I-129	1.0E-06
Re-187	3.3E-02
U (all)	1.4E-05
Np-237	1.1E-05

Appendix B: Classification of Hanford RA ■ Waste Based on Hanford and Envirocare WAC Concentration Limits

Data in this appendix are for the waste streams that had the ■ classification in Figure 1-3. The data were derived in the same manner as that shown and described in Chapter 3 of this report. Figure B-1 shows the classification of Hanford RA ■ wastes based on the Hanford WAC concentration limits. The total treated volume of these streams is 38,700 m^3. About 83% has a SOF of 1 or less based on the Category 1 limits, and 17% has a SOF of 1 or less based on the Category 3 limits. None has a SOF greater than 1 based on the Category 3 limits. Figure B-2 shows the volumes of the Hanford RA ■ wastes that are acceptable and not acceptable according to the Envirocare WAC. The figure indicates that 33,680 m^3 (87%) of the ■ waste volume would be acceptable at Envirocare. Table B-1 shows the list of ■ waste streams from which these summary figures were generated.

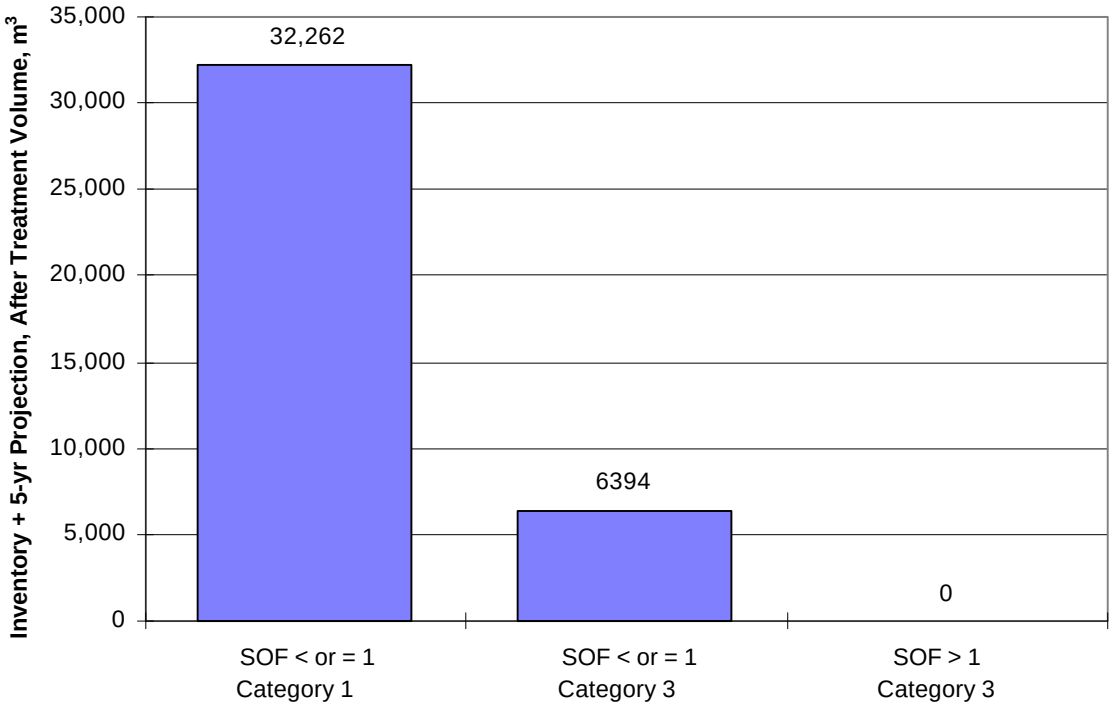

Figure B-1. Classification of Hanford RA ■ based on Hanford WAC concentration limits.

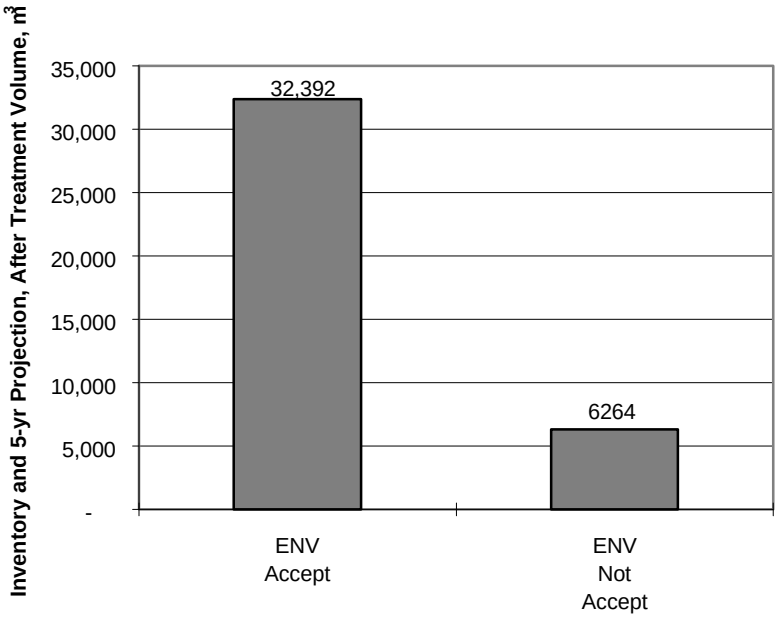

Figure B-2. Classification of Hanford RA ■ based on Envirocare WAC concentration limits.

Table B-1. SOF of ■ Category MLLW Streams at Hanford Based on the Hanford and Envirocare WAC Concentration Limits (Part 1 of 3)

MWIR Survey ID	Treated Volume (m^3)	Hanford PE SOF		Hanford WAC SOF				Envirocare WAC SOF	
				Category 1		Category 3			
AE-W033	34.8	1E+01	■	2E+01	●	7E-02	○	2E+01	●
BT-W010	0.002	9E+00	■	5E-01	□	4E-03	○	2E-02	○
BT-W029	0.01	6E+00	■	8E-01	□	3E-03	○	2E+00	■
DP-W019	21467.3	5E+00	■	2E-01	□	1E-03	○	1E-01	□
DP-W141	145	2E+00	■	3E-01	□	1E-03	○	4E-02	○
FM-W005	0.001	2E+00	■	2E+00	■	8E-03	○	2E-01	□
FM-W075	0.01	2E+00	■	9E-01	□	4E-03	○	3E-01	□
FM-W076	0.001	2E+00	■	2E+00	■	8E-03	○	3E-01	□
FM-W094	0.01	2E+00	■	1E+00	■	7E-03	○	2E-01	□
FM-W126	0.01	4E+00	■	3E+00	■	2E-02	○	6E-01	□
FM-W129	0.001	3E+00	■	2E+00	■	1E-02	○	4E-01	□
FM-W158	0.01	1E+00	■	8E-01	□	4E-03	○	1E-01	□
FM-W161	0.01	2E+00	■	2E+00	■	8E-03	○	1E-01	□
FM-W166	0.8	8E+00	■	6E+00	■	3E-02	○	1E+00	■
FM-W167	0.002	1E+00	■	7E-01	□	3E-03	○	1E-01	□
FM-W171	0.2	1E+01	■	7E+00	■	3E-02	○	1E+00	■
FM-W188	4.2	3E+00	■	2E+00	■	8E-03	○	4E-01	□
FM-W192	0.1	1E+00	■	1E+00	■	5E-03	○	2E-01	□
FM-W194	0.8	5E+00	■	3E+00	■	1E-02	○	8E-01	□
FM-W216	0.001	5E+00	■	4E+00	■	2E-02	○	6E-01	□
FM-W218	0.001	8E+00	■	5E+00	■	2E-02	○	1E+00	■
FM-W229	0.2	4E+00	■	3E+00	■	2E-02	○	5E-01	□
FM-W244	40.8	4E+00	■	2E+00	■	1E-02	○	6E-01	□
FM-W250	1.2	3E+00	■	2E+00	■	1E-02	○	5E-01	□
FM-W264	0.001	2E+00	■	1E+00	■	7E-03	○	3E-01	□
FM-W267	0.02	1E+00	■	9E-01	□	4E-03	○	2E-01	□
FM-W279	0.02	4E+00	■	3E+00	■	1E-02	○	5E-01	□
FM-W288	0.002	3E+00	■	1E+00	■	5E-03	○	7E-01	□
FM-W301	0.001	1E+00	■	9E-01	□	4E-03	○	2E-01	□
FM-W327	0.003	2E+00	■	2E+00	■	8E-03	○	3E-01	□
FM-W330	0.005	8E+00	■	5E+00	■	3E-02	○	1E+00	■
FM-W351	0.02	2E+00	■	1E+00	■	7E-03	○	2E-01	□
FM-W357	0.04	2E+00	■	2E+00	■	8E-03	○	4E-01	□
FM-W380	0.001	3E+00	■	2E+00	■	8E-03	○	4E-01	□
FM-W388	0.004	2E+00	■	1E+00	■	7E-03	○	3E-01	□
FM-W402	0.002	9E+00	■	6E+00	■	3E-02	○	1E+00	■
FM-W408	0.001	3E+00	■	2E+00	■	9E-03	○	4E-01	□
IN-W005	0.01	4E+00	■	1E+01	●	3E-02	○	9E+00	■
IN-W035	2	4E+00	■	5E+01	●	4E-05	○	2E+02	●
IN-W089	0.001	2E+00	■	8E+01	●	9E-05	○	3E+02	●
LA-W073	52.4	5E+00	■	2E+01	●	6E-02	○	1E+01	●
LA-W076	0.1	7E+00	■	8E-03	○	3E-05	○	5E+02	●
LA-W088	9	3E+00	■	2E-02	○	8E-05	○	4E+01	●
LL-W005	11.5	7E+00	■	3E+00	■	1E-02	○	2E+00	■
LL-W009	0.05	2E+00	■	2E+00	■	8E-03	○	6E-01	□
LL-W023	58	4E+00	■	3E+00	■	2E-02	○	5E-01	□
MU-W001	0.8	2E+00	■	7E+00	■	2E-02	○	3E+00	■
PO-W039A	2360.3	6E+00	■	2E-01	□	8E-04	○	3E-02	○
PO-W040	0.002	4E+00	■	8E-01	□	4E-03	○	1E-01	□
PO-W044	0.0001	3E+00	■	6E-01	□	3E-03	○	1E-01	□
PO-W057	0.2	3E+00	■	2E-01	□	1E-03	○	8E-02	○

Table B-1. SOF of ■ Category MLLW Streams at Hanford Based on the Hanford and Envirocare WAC Concentration Limits (Part 2 of 3)

MWIR Survey ID	Treated Volume (m^3)	Hanford PE SOF		Hanford WAC SOF				Envirocare WAC SOF	
				Category 1		Category 3			
PS-W004	0.001	3E+00	■	2E-01	□	1E-03	○	7E+01	●
RF-W003	143.1	1E+00	■	1.1E+00	■	5.0E-03	○	8.9E-02	○
RF-W006	1155	3E+00	■	7E+00	■	3E-02	○	5E+00	■
RL-W019	2.1	4E+00	■	2E+00	■	9E-04	○	5E+00	■
RL-W020	120.6	4E+00	■	1E+00	■	8E-04	○	5E+00	■
RL-W023	16.8	8E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W024	5.7	4E+00	■	2E+00	■	9E-04	○	5E+00	■
RL-W025	4.5	4E+00	■	2E+00	■	9E-04	○	5E+00	■
RL-W026	81.2	4E+00	■	2E+00	■	9E-04	○	5E+00	■
RL-W028	5.2	4E+00	■	2E+00	■	9E-04	○	5E+00	■
RL-W030	10.9	8E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W032	14.2	7E+00	■	3E+00	■	2E-03	○	9E+00	■
RL-W033	0.9	8E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W036	14.4	8E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W041	13.1	7E+00	■	3E+00	■	2E-03	○	9E+00	■
RL-W042	7.8	3E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W046	12.1	3E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W049	114.9	3E+00	■	1E+00	■	7E-04	○	4E+00	■
RL-W050	3.6	3E+00	■	1E+00	■	7E-04	○	4E+00	■
RL-W051	0.6	3E+00	■	1E+00	■	7E-04	○	4E+00	■
RL-W052	3.3	3E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W053	1.6	3E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W054	27	4E+00	■	1E+00	■	8E-04	○	5E+00	■
RL-W055	47.3	8E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W056	83	8E+00	■	3E+01	●	3E-04	○	9E+00	■
RL-W057	438.6	7E+00	■	3E+00	■	2E-03	○	9E+00	■
RL-W058	13	7E+00	■	3E+00	■	2E-03	○	9E+00	■
RL-W059	5.5	8E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W060	33.9	7E+00	■	3E+00	■	2E-03	○	9E+00	■
RL-W061	1	3E+00	■	4E+00	■	2E-03	○	1E+01	●
RL-W063	3.7	3E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W064	39.1	3E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W065	31.9	3E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W066	10.3	3E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W067	0.2	3E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W087	16.8	4E+00	■	2E+00	■	9E-04	○	5E+00	■
RL-W092	0.03	3E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W093	16.1	8E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W094	107.9	3E+00	■	1E+00	■	7E-04	○	4E+00	■
RL-W097	10.6	7E+00	■	3E+00	■	2E-03	○	9E+00	■
RL-W098	26.4	3E+00	■	1E+00	■	7E-04	○	4E+00	■
RL-W099	0.7	3E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W100	36	3E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W113	7.5	8E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W114	2	4E+00	■	2E+00	■	9E-04	○	5E+00	■
RL-W115	1.2	7E+00	■	3E+00	■	2E-03	○	9E+00	■
RL-W116	1.8	7E+00	■	3E+00	■	2E-03	○	9E+00	■
RL-W117	0.2	7E+00	■	3E+00	■	2E-03	○	9E+00	■
RL-W118	1	7E+00	■	3E+00	■	2E-03	○	9E+00	■
RL-W119	0.6	3E+00	■	1E+00	■	7E-04	○	4E+00	■
RL-W122	31	3E+00	■	1E+00	■	7E-04	○	4E+00	■

Table B-1. SOF of ■ Category MLLW Streams at Hanford Based on the Hanford and Envirocare WAC Concentration Limits (Part 3 of 3)

MWIR Survey ID	Treated Volume (m^3)	Hanford PE SOF		Hanford WAC SOF				Envirocare WAC SOF	
				Category 1		Category 3			
RL-W124	3	4E+00	■	2E+00	■	9E-04	○	5E+00	■
RL-W126	0.2	7E+00	■	3E+00	■	2E-03	○	9E+00	■
RL-W127	1	7E+00	■	3E+00	■	2E-03	○	9E+00	■
RL-W128	0.2	7E+00	■	3E+00	■	2E-03	○	9E+00	■
RL-W129	0.7	8E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W130	3	3E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W131	0.2	7E+00	■	3E+00	■	2E-03	○	9E+00	■
RL-W132	1.7	3E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W140	196.5	3E+00	■	1E+00	■	7E-04	○	4E+00	■
RL-W141	15	5E+00	■	2E+00	■	1E-03	○	7E+00	■
RL-W142	3135.5	5E+00	■	3E+01	●	1E-02	○	1E+02	●
RL-W143	0.3	3E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W144	0.2	3E+00	■	3E+00	■	2E-03	○	1E+01	●
RL-W146	0.4	7E+00	■	3E+00	■	2E-03	○	9E+00	■
RL-W149	0.5	4E+00	■	2E+00	■	9E-04	○	5E+00	■
RL-W150	0.4	4E+00	■	2E+00	■	9E-04	○	5E+00	■
RL-W151	0.3	4E+00	■	2E+00	■	9E-04	○	5E+00	■
RL-W153	0.6	3E+00	■	1E+00	■	7E-04	○	4E+00	■
RL-W196	3.1	2E+00	■	1E+00	■	6E-04	○	5E+00	■
RL-W197	5.6	2E+00	■	1E+00	■	6E-04	○	5E+00	■
RL-W199	0.2	3E+00	■	2E+00	■	9E-04	○	8E+00	■
RL-W201	0.9	2E+00	■	1E+00	■	6E-04	○	5E+00	■
RL-W202	2	2E+00	■	1E+00	■	6E-04	○	5E+00	■
RL-W203	1.1	2E+00	■	1E+00	■	6E-04	○	5E+00	■
RL-W205	1.2	2E+00	■	1E+00	■	6E-04	○	5E+00	■
RL-W209	0.2	2E+00	■	1E+00	■	5E-04	○	5E+00	■
RL-W210	27.5	2E+00	■	2E+00	■	8E-04	○	7E+00	■
RL-W211	24.9	3E+00	■	2E+00	■	9E-04	○	8E+00	■
RL-W226	123.3	1E+00	■	8E-01	□	4E-04	○	3E+00	■
RL-W227	0.1	2E+00	■	2E+00	■	8E-04	○	7E+00	■
RL-W228	18.8	3E+00	■	2E+00	■	9E-04	○	8E+00	■
SR-W001	0.1	9E+00	■	7E+00	■	3E-02	○	9E+00	■
SR-W018	14.1	6E+00	■	4E+00	■	2E-02	○	4E-01	□
SR-W031	0.1	9E+00	■	1.9E+00	■	1.0E-02	○	2.6E+00	■
YP-W005	8157	2E+00	■	8E-02	○	1E-03	○	6E-03	○
Total	**38,656**								

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Appendix C - Waste Form Release Mechanisms, Release Data, and Data Needs

Polyethylene is an inert thermoplastic material used for encapsulating wastes for safe long-term storage (Kalb et al., 1995). It has a melting point of 120°C and processing temperature range of 120 - 150°C (Kalb and Fuhrmann, 1992). As such, it is not susceptible to chemical interactions between the waste and binder and generally results in a monolithic solid waste form if compatible with the waste. Wastes can be microencapsulated or macroencapsulated in polyethylene. Estimates of the time scale for which polyethylene is considered effective for encapsulation without external forces are on the order of 1000 years (Brown, 1996). With time, cross-linking of the long polymers takes place and embrittlement in the polyethylene ensues, leading to the possibility of cracks in the polyethylene. Crack formation is enhanced by physical and radiation stresses. Physical stresses are assumed to be minimal. Degradation of physical properties of polyethylene by gamma irradiation and ultraviolet light (UV), in combination with oxidation, has been observed (Brown and Lu, 1993). UV light should not be a factor for disposed polyethylene waste forms. However, radiation could be significant for disposal of highly radioactive waste, since the Nuclear Regulatory Commission (NRC) Class C limits on activity for low-level wastes (10 CFR Part 61) are presently about two orders of magnitude greater than the dose rates predicted to create radiation damage in polyethylene wire coatings (Gillen and Clough, 1989).

There is little information available about radionuclide release mechanisms for macroencapsulated polyethylene. Macroencapsulated waste is used as a waste form for disposal in the sole commercially-licensed mixed waste disposal facility (Envirocare, Inc., in Utah). At this facility, regulations related to waste form performance are those of the Resource Conservation and Recovery Act (Toxicity Characteristic Leach Procedure or TCLP); hence, investigation of release mechanisms is not a consideration since the waste form passes the TCLP test (Lucerna, 1996). Contaminant permeation through a continuous polyethylene barrier would probably be the release mechanism. There is a low probability that this contaminant permeation would result in a large rate since polyethylene absorbs almost no water under experimental conditions (Kalb et al., 1991). Based on this conceptual model, a recommendation to Envirocare, Inc. was to use 1 inch of polyethylene around the perimeter of macroencapsulated waste (Kalb, 1996). Envirocare's decision was to use 2 inches instead as a waste form requirement (Lucerna, 1996). The dominant release mechanism for microencapsulated polyethylene is leaching by diffusion. Performance data for polyethylene to date has been based primarily on the Accelerated Leach Test (ALT) (Fuhrmann and Zhou, 1994). Results of the ALT are typically plotted as the cumulative fraction of contaminant leached versus time. Treybal (1980) gives a textbook method for determining cumulative fraction leached as a function of a composite parameter consisting of the diffusion coefficient, the leaching time, and a waste form dimension. This mechanism is a strong function of size, releasing at a higher rate as the waste form dimensions decrease.

The dominant radionuclide release mechanism for vitrified waste is dissolution of the glass (EPA, 1992). Extensive dissolution data are available as a function of composition, temperature and solution conditions (pH, etc.). As the glass matrix dissolves, the bound radionuclides are released along with silicic acid (H_4SiO_4) into the solution. The rate for this

phenomenon is directly proportional to the water accessible surface area of the waste (Grambow, 1996). Upon cooling, cracks can develop in the glass (NRC, 1996). Cracking of glass is a well recognized phenomenon, and increases in the geometric surface area due to cracking by a factor of five (Mayberry et al., 1993) and 20 (Cunnane and Allison, 1994) have been suggested. In the model used here, a factor of 20 was assumed for the 60-cm canister glass form and no increase for the 1-cm pellets. These are equivalent to cooling for 40 hours and 1 hour, respectively (Peters and Slate, 1981). The effect of glass composition on release mechanisms has also been modeled (Jantzen et al., 1992; Piepel et al., 1996). In general, the more silicon in the glass, the more durable the waste form.

Radionuclide Release Data

Data using the ALT have been gathered (Fuhrmann and Zhou, 1994) for sodium wastes microencapsulated with polyethylene. The 28-day cumulative fractions of sodium leached are 0.15, 0.32 and 0.52, respectively, using 50, 60, and 70% loading. Table C-1 gives diffusivities found (Kalb and Fuhrmann, 1992) for waste containing nitrate. The data indicate diffusion increases with waste loading and temperature.

Table C-1. Diffusivities (cm^2/s) for Nitrate Containing Polyethylene (Kalb and Fuhrmann, 1992)

Waste Loading	50%	60%	70%
20°C	3.05×10^{-9}	8.6×10^{-9}	5.58×10^{-8}
35°C	2.65×10^{-9}	1.90×10^{-8}	7.63×10^{-8}
50°C	5.32×10^{-9}	3.10×10^{-8}	1.34×10^{-7}
70°C	9.69×10^{-9}	2.40×10^{-8}	2.33×10^{-7}

All radionuclides are given the same diffusivity for two reasons. First, there are few experimental data which compare the leaching of different contaminants from polyethylene. Second, the contaminants must be solubilized before diffusing out of the waste form. In this situation, the contaminants are molecular sized while the dimensions of the pores in the waste form are much larger (on the order of a micrometer). So, polyethylene will likely impart no discriminating factor on different radionuclides.

The forward rate of leaching for a vitreous waste form is determined similarly to the ALT (Lutze and Ewing, 1988). That is, the water used in solution is exchanged frequently, thus producing the greatest possible leaching conditions. However, the solubility of a particular radionuclide can limit this release, termed by some as the retention factor (Cunnane and Allison, 1994). A cumulative fraction of calcium leached from glass of 6.2×10^{-7} using the ALT, which equates to a forward rate of 4×10^{-4} g/m^2-day, has been recorded (Fuhrmann and Zhou, 1994). Mazer and Walther (1994) computed the linear dissolution rate for pure silica glass to be 7.6×10^{-6} g/m^2-day at pH 4 and 40°C (6×10^{-7} g/m^2-day corrected to

20°C). The data showed that this value was approximately constant up to pH 7 and should represent a lower bound on this parameter since pure silica is the most durable of the borosilicate glasses. Release rates for glass used in storing Hanford's low activity waste have also been defined (McGrail et al., 1996). For the glass LD6-5412, the forward leach rate is 1.0×10^{-4} g/m^2-day at 20°C and pH 7, with pH and temperature dependence described by exponential and Arrhenius functions, respectively. A value of 2.5×10^{-3} g/m^2-day was assumed for evaluations, which consider the forward rate and a saturation condition at 90°C (3×10^{-6} g/m^2-day at 20°C assuming 20 kcal/mol activation energy) (Cunnane and Allison, 1994). Based on this discussion, a conservative estimate for the long-term corrosion rate of glass is assumed to be 1.0×10^{-4} g/m^2-day.

Data Needs

Based on the above discussion, the primary data needs in terms of waste form performance with respect to glass and polyethylene are in the area of polyethylene encapsulated waste using the accelerated leach test or a similar test under various conditions. These should include radionuclide-specific diffusivities under various conditions. In addition, compatibility evaluations for the wastes that are prescribed to be encapsulated must be ensured through product consistency testing. The performance data for glass and grout appear to be sufficient for disposal of MLLW.

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