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OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

Treatment Requirements for Decontamination of ORNL Low-Level Liquid Waste

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MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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Chemical Technology Division

TREATMENT REQUIREMENTS FOR DECONTAMINATION OF ORNL LOW-LEVEL LIQUID WASTE

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CONTENTS

LIST OF TABLES

ACRONYMS AND INITIALISMS

ALARA	As Low As Reasonably Achievable
ARF	Activity Reduction Factor
CFR	Code of Federal Regulations
DF	Decontamination Factor (C_0/C)
DCG	Derived Concentration Guide
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
EPTC	Extraction Procedure Toxicity Characteristic
FCN	Potassium or sodium—cobalt or nickel ferrocyanide ion exchanger
IX	Ion Exchange (processes)
LDR	Land Disposal Restrictions
LLLW	Low-Level (radioactive) Liquid Waste
LLW	Low-Level (radioactive) Waste
LLWDDD	Low-Level Waste Disposal Development and Demonstration (Program)
MVST	Melton Valley Storage Tank
NPDES	National Pollutant Discharge Elimination System
NRC	Nuclear Regulatory Commission
NRWTP	Nonradiological Waste Treatment Plant
ORNL	Oak Ridge National Laboratory
PWTP	Process Waste Treatment Plant
RCRA	Resource Conservation and Recovery Act
RH	Remote Handled
TCLP	Toxicity Characteristic Leaching Procedure
TDHE	Tennessee Department of Health and Environment
TOC	Total Organic Carbon
TRU	Transuranic
TSD	Treatment/Storage/Disposal
WAC	Waste Acceptance Criteria
WIPP	Waste Isolation Pilot Plant
WOC	White Oak Creek

TREATMENT REQUIREMENTS FOR DECONTAMINATION OF ORNL LOW-LEVEL LIQUID WASTE

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ABSTRACT

Experimental studies have been made to provide data for the development of improved processes for decontaminating low-level liquid wastes (LLLWs) that exist and continue to be generated at Oak Ridge National Laboratory. The concept underlying this work is that there is a net benefit if the major radionuclides (^{137}Cs, ^{134}Cs, ^{90}Sr, and actinides) can be separated into small volumes, thereby reducing the activity of the bulk of the waste so that it can be disposed of or managed at a lower total cost.

Data-base calculations on the LLLW supernate and sludges contained in the active Melton Valley Storage Tanks and evaporator storage and service tanks are essential in order to define and determine the extent of the problem. These calculations indicate to what extent alpha- and beta-gamma-emitting radionuclides must be removed and/or treated before final disposition of the waste can be made. They also show that many of the inorganic constituents (e.g., regulated metals and nitrate) and minor radionuclides such as ^{14}C and actinides (in terms of quantity present) must be removed before the LLLW can be disposed of as either liquid to the environment or solidified and disposed of as solid NUS Class L-I or L-II LLW.

1. INTRODUCTION

Low-level liquid waste (LLLW) at Oak Ridge National Laboratory (ORNL) consists of various concentrates from evaporators and from the elution of ion-exchange columns, as well as solutions from laboratories and chemical processing operations for radioisotope and actinide element production. The volume is small, 10 to 20 m^3/year, but has a very high concentration of dissolved solids. Typically, it contains about 5 M sodium nitrate, excess NaOH, significant concentrations of potassium, calcium, and magnesium, and small amounts of several other elements, including some Resource Conservation and

Recovery Act (RCRA) metals. The hazardous components in the wastes are dominated by actinides, $^{137}Cs/^{134}Cs$, ^{60}Co, ^{14}C, and ^{90}Sr. In stored, highly basic LLLW, the actinides are generally insoluble, and most have precipitated out so that the supernate is generally a nontransuranic waste. However, traces of some actinides remain at measurable levels.

The concept underlying the present work is to treat the LLLW so that it can be disposed of in an appropriate manner. In many cases, the disposal option would require decontamination of the LLLW so that the main bulk of the waste can be managed as a less hazardous material which has an approved disposal mechanism. The small volume of high-activity concentrate separated from the bulk can be handled with great care, possibly also being disposed of or stored until an acceptable disposal method has been established. To implement this strategy, the removal of cesium, cobalt, and strontium from very large amounts of sodium and potassium, and smaller amounts of other elements, including alkaline earths and transition metals, may be necessary. In addition, the trace quantities of actinides remaining in some of the supernates may need to be removed to meet some of the storage or disposal requirements. The ^{14}C present in the supernate, either as inorganic carbonate or organic compounds, may also require removal to meet some requirements.

2. SEPARATION REQUIREMENTS

In chemical separations processes for the isolation of cesium, the primary interferences are usually other alkali metals, especially the heavier ones. In the case of the LLLW supernate, sodium is present in very high concentrations, 3 to 4 M, and the potassium concentration is also significant, 0.25 to 2.0 M, with an average of 0.5 M. Therefore, depending on the particular process, sodium and/or potassium tend to interfere with cesium removal. In a similar way, alkaline-earth elements interfere with strontium removal. Calcium and magnesium are present in high concentrations in the LLLW supernate. In some cases, high alkali-metal concentrations also interfere with strontium decontamination steps.

In order to determine which separation methods may be required for decontamination, it was important to know the contents of each tank, both chemically and radiologically, and the quantity of each constituent present. Until this information is known and has been compared with the current and proposed Treatment/Storage/Disposal (TSD) requirements, processes for efficient decontamination cannot be designed with any certainty.

3. DATA-BASE CALCULATIONS

3.1 LLLW AND RCRA TREATMENT/STORAGE/DISPOSAL CRITERIA

Data have been collected, collated, and analyzed for the supernate and sludge contained in the MVSTs and in tanks W-21 and W-23, the evaporator storage tanks. The analytical data, obtained from samples acquired during a 1989 sampling campaign, have been reviewed over the past several months.[1,2] Earlier analyses of tanks W-29 and W-30 sludge were used because sludge sampling of these two tanks could not be done in the configuration for the solidification campaign.[3] The results were then compared with the criteria for the release and disposal of LLLW and solid radioactive waste via various disposal options that are given in Tables 1 and 2.[4-7] The waste acceptance criteria (WAC) for the Process Waste Treatment Plant (PWTP) and the Nonradiological Waste Treatment Plant (NRWTP) are included.[8] The NRWTP discharge limits are currently based on the National Pollutant Discharge Elimination System (NPDES) permit and are subject to change as new permits are negotiated with the TDHE. They are not included at this time. Also included in these criteria tables is a listing of the RCRA limits, primary and secondary drinking-water limits, and groundwater/water quality limits for components found in either the supernate or the sludge.[9-15] The largest nonradioactive contaminant in the supernate is nitrate, when compared with the various water quality standards. A maximum of 10 ppm nitrate, as nitrogen, is allowed for drinking water and in the WAC for the PWTP and NRWTP. Since the supernate is 3 to 6 $\underline{M}$ in nitrate, nitrate removal is required before any of this material can be released.

An additional complication for supernate and sludge solidification and disposal is that the solids may be considered mixed waste according to the definition:[16]

> . . . waste that satisfies the definition of low-level radioactive waste in the Low-Level Radioactive Waste Policy Amendments Act of 1985 and contains hazardous waste that either (1) is listed as a hazardous waste in Subpart D of 40 CFR 261 or (2) causes the LLW to exhibit any of the hazardous waste characteristics identified in Subpart C of 40 CFR 261.

The supernates contain radioactive species, and those with pH >12.5 exhibit the hazardous waste characteristic of corrosivity (40 CFR 261, Subpart C). Several of the RCRA metals are also contained in the supernate in amounts that may be in excess of those allowed, although analyses are at the limits of detection in the high-sodium, high-potassium matrix. The sludges contain significantly more of the RCRA metals and may

Table 1. Release and acceptance criteria for LLLW

A. Radioactive Materials

			10 CFR 20 App.B,					
			Tab.II, Col. 2	Tab. I, Col. 2		4% DOE 5400.5		
Component	PWTP WAC[a]	DOE 5400.5 (NRWTP WAC[a])	Plant boundary	To a mixed sewer stream	10 CFR 20, App. C	for drinking water systems	Specific activity	A_2[b]
	(nCi/L)	(nCi/L)	(nCi/L)	(nCi/L)	(μCi/d)	(nCi/L)	(Ci/g)	(Ci)
H-3	2000	2000	3000	100,000	1000	80.00	9.7E+03	1000
C-14	70	70	800	20,000		2.80	4.6E+00	60
Co-60	5.0	5.0	50	1,000	1	0.20	1.1E+03	7
Ni-63	300	300	30	800	10	12.00	4.6E+01	100
Sr-90	270	1.0	0.3	10	0.1	0.04	1.5E+02	0.4
Zr-93	90	90	800	20,000	10	3.60	3.5E-03	200
Nb-95	40	40	100	3,000	10	1.60	3.9E+04	20
Zr-95	40	40	60	2,000	10	1.60	2.1E+04	20
Tc-99	100	100	300	10,000	10	4.00	1.7E-02	25
Ru-106	6.0	6.0	10	300	1	0.24	3.4E+03	7
I-129	0.5	0.5	0.06	10	0.1	0.02	1.6E-04	2
I-131	3.0	3.0	0.30	60	1	0.12	1.2E+05	10
Cs-134	2.0	2.0	9	300	1	0.08	1.2E+03	10
Cs-137	10.8	3.0	20	400	10	0.12	9.8E+01	10
Ce-144	7.0	7.0	70	200	10	0.28	3.2E+03	7
Sm-151	400.	400	400	40,000	10	16.00	2.6E+01	90
Eu-152	20.	20.0	80	2,000	1	0.80	1.9E+02	10
Eu-154	20.	20.0	20	600	1	0.80	1.5E+02	5
Eu-155	100.	100.0	200	6,000	10	4.00	1.4E+03	60
Th-natural	0.05	0.05				0.0004	2.2E-07	No limit
Th-230	0.30	0.3	2	50	100	0.012	1.9E-02	0.003
Th-232	0.05	0.05	2	50	100	0.002	1.1E-07	No limit
Pa-231	0.01	0.01	0.9	30		0.0004	4.5E-02	0.002
U-232	0.10	0.10	30	800		0.004	2.1E+01	0.03
U-233	0.50	0.50	30	900	0.01	0.02	9.5E-03	0.1
U-234	0.60	0.60	30	900	0.01	0.024	6.2E-03	0.1
U-235	0.60	0.60	30	800	0.01	0.024	2.1E-06	0.2
U-238	0.50	0.50	40	1,000	100	0.02	3.3E-07	No limit
U-natural	0.60	0.60				0.024	7.1E-07	No limit
Np-237	0.03	0.03	3	90		0.0012	6.9E-04	0.005
Pu-238	3.00	3.00	5	100		0.12	1.7E+01	0.003
Pu-239	2.00	2.00	5	100	0.01	0.08	6.2E-02	0.002
Pu-240	2.00	2.00	5	100		0.08	2.3E-01	0.002
Pu-241	2.00	2.00	200	7000		0.08	1.1E+02	0.1
Pu-242	0.03	0.03	5	100		0.0012	3.9E-03	0.003
Am-241	0.03	0.03	4	100	0.01	0.0012	3.2E+00	0.008
Am-243	0.03	0.03	4	100		0.0012	1.9E-01	0.008
Cm-243	0.05	0.05	5	100		0.002	4.2E+01	0.009
Cm-244	0.06	0.06	7	200		0.0024	8.2E+01	0.01
Gross alpha	0.27	0.015	0.03	0.40	0.01	0.0006		0.002
Gross beta	270							

[a]WAC = Waste Acceptance Criteria.

[b]A_2 is the maximum activity of radioactive material permitted in a type A package according to 10 CFR 71 for the packaging, shipment, and transportation of radioactive material (see ref. 17).

Table 1 (continued)

B. Nonradioactive Materials

Component	PWTP WAC[a] (mg/L)	NRWTP WAC[a] (mg/L)	40 CFR 261 (mg/L)	40 CFR 265, App. III Drinking Water (mg/L)	40 CFR 141.11 Primary D.W. (mg/L)	40 CFR 143.3 Secondary D.W. (mg/L)
Chloride						250
Cyanide		0.09				
SO_4	0.0	940.00				250
PO_4	5.0	----				
NO_3 as N	10.0	8.60		10.	10.0	
Antimony		42.00				
Arsenic		5.25	5.0	0.05	0.05	
Barium		6.00	100.0	1.0	1.0	
Beryllium		0.009				
Cadmium	0.7	1.90	1.0	0.01	0.01	
Chromium	3.0	10.00	5.0	0.05	0.05	
Copper	3.5	19.50				1.0
Iron		105.00				0.3
Lead	0.7	5.25	5.0	0.05	0.05	
Manganese						0.05
Mercury		0.009	0.2	0.002	0.002	
Nickel	4.0	38.00	50.0			
Selenium		3.75	1.0	0.01	0.01	
Silver	0.5	0.26	5.0	0.05	0.05	
Thallium			0.9			
Zinc	2.7	38.00				5.0
TOC		37.50				

[a]These are maximum limits that can be accepted into the facilities. They apply to waste volumes under 300 gal/d. Larger waste volumes must receive special ORNL Waste Management approval before being discharged to the NRWTP.

Table 2. NRC, LLWDDD, and NUS waste classification limits for solid LLW

Component	Conversion factor (mol/L equivalent to μCi/m³)	LLWDDD[a] L-I (μCi/m³)	LLWDDD[a] L-II (μCi/m³)	LLWDDD[a] L-III (μCi/m³)	NUS[b] L-I (μCi/m³)	NUS[b] L-II[c] (μCi/m³)	NRC A (μCi/m³)	NRC B (μCi/m³)	NRC C (μCi/m³)
H-3		1.88E05	7.29E11		**4.30E02**[d]	[e]	4.0E7		
Be-10		3.63E03	5.82E03	3.45E05	5.18E03	[e]			
C-14	6.70E-7	4.32E04	1.08E05	5.40E05	**1.07E00**	**2.01E02**	8.0E5	8.0E5	8.0E6
Co-60	2.25E-10	1.49E04	3.82E18		3.24E07	[e]	7.0E8		
Ni-63		4.71E04	4.27E05		5.60E04	2.83E04	3.5E6	7.0E7	7.0E8
Sr-90	6.84E-11	9.24E02	6.24E05		**8.80E02**	2.28E06	4.0E4	1.5E8	7.0E9
Zr-93		1.95E05	1.94E05	5.99E05	**2.50E02**	[e]			
Tc-99		8.02E02	1.38E03	5.00E05	**8.38E00**	**5.53E00**	3.0E5		3.0E6
Cd-113m		2.65E03	1.49E09		1.68E04	[e]			
Sn-121m		1.81E06	3.01E07		**1.36E03**	[e]			
I-129						**1.06E00**	8.0E3		8.0E4
Cs-137	2.19E-11	3.07E02	1.54E05		7.22E02	1.26E09	1.0E6	4.4E7	4.6E9
Sm-151		3.83E06	2.53E06		**1.34E05**	1.55E08			
Eu-152	1.91E-13	6.39E02	3.54E08		1.04E04	[e]			
Eu-154	9.87E-11	2.28E03	1.13E12		1.82E05	[e]			
Eu-155	1.37E-8	2.98E06	7.14E21		9.74E08	[e]			
Th-232	6.98E-4	1.78E01	2.72E01	5.09E02	**4.18E-01**	[e]	5.0E3[f]		5.0E4
U-233	3.58E-8	7.92E01	4.36E03	8.70E03	**5.20E01**	**2.36E01**	5.0E3		5.0E4
U-235	1.57E-4	7.77E01	8.34E02	9.46E03	**8.56E00**	**2.53E01**	5.0E3		5.0E4
U-238	4.71E-10	8.57E01	2.54E03	9.61E03	**3.05E01**	**2.75E01**	5.0E3		5.0E4
Np-237	8.86E-8	1.45E01	2.86E01	5.21E02	**1.63E-02**	2.86E01	5.0E3		5.0E4
Pu-238	4.71E-10	1.91E03	4.91E03		**2.08E02**	**1.49E01**	5.0E3		5.0E4
Pu-239	7.70E-8	1.14E03	3.99E02	6.05E02	**4.99E-01**	**2.95E-01**	5.0E3		5.0E4
Pu-241	1.62E-9				**8.09E02**	**1.45E05**	1.8E5		1.8E6
Pu-242	4.55E-5				**5.20E00**	**2.22E07**	5.0E3		5.0E4
Am-241	1.26E-9	9.74E02	6.37E02	9.58E02	**1.09E01**	2.15E03	5.0E3		5.0E4
Am-243	7.00E-9	3.23E02	2.73E02	6.03E02	**1.03E00**	**1.81E01**	5.0E3		5.0E4
Cm-242							1.0E6		1.0E7
Cm-243	1.18E-10				1.66E03	1.03E06	5.0E3		5.0E4
Cm-244	6.80E-11	1.36E04	7.35E07		1.01E03	**2.14E02**	5.0E3		5.0E4
Gross alpha							5.0E3		5.0E4

[a]LLWDDD Class L-I, L-II, and L-III concentrations.
[b]Proposed NUS Class L-I and L-II concentrations, based on limiting intruder scenarios (May 1990 data).
[c]Wastes exceeding the L-II limits are classed as L-IV wastes.
[d]NUS limits that are more strict than the previous LLWDDD limits are given in **bold**.
[e]Allowable inventory is greater than 1 x 10^{12} (>1E12) Ci.
[f]Assumes a density of 2 g/cm³ to convert from nCi/g to μCi/m³ for all alpha emitters for solidified grout.

also contain some of the Toxicity Characteristic Leaching Procedure (TCLP) organics, in addition to the bulk of the actinides in the tanks. Summaries of the maximum, minimum, and average concentrations of radionuclides and chemical compositions for both supernate and sludge are shown in Table 3 and 4, respectively.[1-3]

Table 2 lists the proposed LLWDDD LLW limits for Class I, II, and III.[18] LLWDDD values were originally developed as conservative estimates of the projected WAC for on-site disposal. Currently, only on-site disposal or disposal at WIPP is approved for ORNL solid LLW. Updated limits have been proposed by NUS (May 1990) for classes L-I and L-II, based on studies using pathway analysis for homesteader (10 mrem), drinking water (4 mrem), and general public (10-mrem air pathway) to define limits for the Oak Ridge Reservation site Environmental Impact Statement (EIS). The NRC limits, although not currently applicable to the Laboratory LLW, are given for comparison with requirements of the nuclear power industry. The NRC categorizes LLW as Class A, B, C, or greater than C, depending on the nuclides present and their concentrations. If ^{14}C, ^{99}Tc, ^{129}I,^{241}Pu, ^{242}Cm, or gross alpha composed of isotopes with half-lives greater than 5 years are present at greater-than-Class-A limits in Table 2 but less-than-Class-C limits, the waste is Class C. If they are present at less-than-Class-A limits, the waste is classified by the short-lived nuclides ^{137}Cs, ^{90}Sr, ^{3}H, ^{60}Co, or ^{63}Ni that may be present. The Class A and C limits for alpha materials are taken from 10 CFR 61, which gives the units as nCi/g. These limits were converted to μCi/m^3 for use in determining the classification of a solid waste form by assuming a density of 2 g/cm^3. Therefore, a limit of 10 nCi/g becomes 5000 μCi/m^3. If more than one of these isotopes is present, the sum of the fractions of nuclides must be less than 1 to fall into that classification.

3.2 LLLW DISPOSAL UNCERTAINTIES

Several problems still must be resolved with regard to the handling of the supernate for TSD. These have to do with EPA, DOE, and DOT regulations regarding the handling, treatment, storage, transportation, and final disposal of LLW, LLLW, and mixed waste. To date, the state of Tennessee and the Southeastern Compact currently have no provisions for the treatment or disposal of mixed waste (there are no currently licensed mixed waste treatment or disposal sites in the United States).[19] In addition, the DOE is not allowed to dispose of waste in commercial facilities because it is not a prudent use of commercial burial facilities. The DOE and other regulatory agencies have not finalized approval to use the LLWDDD classification system for disposal of LLW or mixed waste on the Oak Ridge Reservation. Another factor that will force action in the near

Table 3. Maximum, minimum, and average radiochemical concentrations in the LLLW tanks

Isotope	Supernate (nCi/L) Max.	Supernate (nCi/L) Min.	Supernate (nCi/L) Avg.	Sludge (nCi/L) Max.	Sludge (nCi/L) Min.	Sludge (nCi/L) Avg.
Analyses of MVSTs						
H-3	1.67E+04	3.21E+04	7.16E+03	N.D.[a]		
C-14	2.12E+04	2.70E+01	6.18E+03	2.87E+04	3.06E+03	7.85E+03
Co-60	3.29E+05	8.34E+03	1.03E+05	9.12E+06	2.76E+05	1.38E+06
Sr-90	4.73E+06	1.11E+04	1.48E+06	8.44E+07	1.55E+07	3.67E+07
Nb-95	7.56E+03	8.10E+02	2.90E+03	2.53E+05	1.91E+04	3.44E+04
Zr-95	1.92E+05	1.40E+03	1.66E+04	5.41E+06	5.78E+04	8.69E+05
Ru-106	1.02E+05	2.97E+04	5.18E+04	2.24E+06	1.94E+05	3.67E+05
Cs-134	3.54E+05	3.62E+04	1.49E+05	2.64E+05	2.11E+04	4.97E+04
Cs-137	5.59E+07	5.08E+06	1.38E+07	2.84E+07	6.52E+05	9.51E+06
Ce-144	6.21E+04	2.00E+04	3.51E+04	1.06E+06	1.33E+05	2.07E+05
Eu-152	8.94E+05	2.51E+03	6.67E+04	4.91E+07	5.78E+05	5.75E+06
Eu-154	4.48E+05	1.62E+03	3.34E+04	1.86E+07	1.99E+05	3.33E+06
Eu-155	1.41E+05	1.08E+04	2.59E+04	5.03E+06	2.72E+04	8.97E+05
Gross alpha	5.78E+04	2.70E+01	7.12E+03	8.15E+06	5.16E+05	1.56E+06
Gross beta	5.94E+07	5.24E+06	1.75E+07	2.41E+08	4.90E+07	9.83E+07
U-232	1.84E+03	1.08E+02	2.28E+02	5.87E+04	4.97E+04	6.36E+03
U-233	2.48E+04	1.62E+02	3.55E+03	4.27E+05	1.63E+04	6.29E+04
U-235	N.D.			1.06E+06	1.26E+05	2.08E+05
U-238	2.70E+02	2.70E+02	2.70E+02	N.D		
Pu-239/Pu-240	1.67E+03	1.62E+02	1.38E+02	9.41E+05	2.99E+04	8.61E+04
Pu-238/Am-241	7.05E+03	4.05E+02	5.01E+02	1.94E+06	8.27E+04	2.41E+05
Cm-243	N.D.			9.45E+05	1.22E+05	2.05E+05
Cm-244	3.11E+04	1.08E+02	1.92E+03	6.04E+06	1.36E+05	1.05E+06

[a]N.D. = not determined in all tanks.

Table 4. Maximum, minimum, and average chemical concentrations in the LLLW tanks

	Supernate			Sludge		
	Max.	Min.	Avg.	Max.	Min.	Avg.
pH	13.1	0.56	10.75			
Density	1.29	1.20	1.23	1.54	1.26	1.35
Dissolved solids, mg/mL	485	348	386			
Total solids, mg/mL	478	334	386	544	369	470
Total carbon, μg/mL	9,500	364	1,340	22,200	1,820	10,900
Inorganic carbon, μg/mL	8,340	1	779	18,100	1,410	7,620
Organic carbon, μg/mL	1,285	167	565	6,480	410	3,330

Elemental analysis	Max. (mol/L)	Min. (mol/L)	Avg. (mol/L)	Max. (mol/L)	Min. (mol/L)	Avg. (mol/L)
Hydroxide	0.29	0.01	0.082	0.29	0.01	0.082
Carbonate				2.02	0.15	0.85
Chloride	0.14	0.06	0.085	0.14	0.06	0.085
Fluoride	0.053	0.026	0.031	0.053	0.026	0.031
Nitrate	5.97	3.23	4.38	5.97	3.23	4.38
Phosphate	0.053	0.053	0.053	0.053	0.053	0.053
Sulfate	0.081	0.052	0.055	0.081	0.052	0.055
Aluminum	1.70E-03	4.45E-05	4.58E-04	4.28E-01	4.58E-02	1.57E-01
Arsenic	5.07E-05	4.00E-05	4.86E-05	1.34E-03	5.37E-04	7.72E-04
Barium	1.82E-04	1.38E-06	3.21E-05	9.76E-04	1.56E-04	5.26E-04
Boron	9.25E-04	1.85E-05	1.72E-04	3.10E-03	1.40E-04	8.73E-04
Cadmium	4.00E-05	1.07E-06	8.48E-06	5.75E-04	1.91E-05	2.15E-04
Calcium	5.74E-01	1.10E-04	8.44E-02	2.00E+00	4.40E-01	2.50E+00
Chromium	5.19E-04	7.31E-06	9.37E-05	5.04E-03	6.54E-04	2.42E-03
Cobalt	9.67E-06	N.D.[a]	5.80E-06	N.D.		
Iron	4.30E-03	1.25E-05	4.68E-04	6.34E-02	9.48E-03	3.30E-02
Lead	3.43E-05	1.01E-05	1.59E-05	3.49E-03	7.30E-04	1.58E-03
Magnesium	2.30E-01	5.35E-05	2.97E-02	9.19E-01	4.51E-02	4.62E-01
Mercury	4.60E-06	2.30E-07	8.48E-07	4.92E-04	6.92E-05	2.02E-04
Nickel	2.55E-04	6.47E-06	5.10E-05	2.51E-03	3.65E-04	1.15E-03
Potassium	1.99	0.22	0.615	0.62	0.20	0.36
Selenium	5.95E-05	2.91E-05	5.34E-05	1.07E-03	4.43E-04	7.63E-04
Silicon	8.72E-03	3.56E-05	9.70E-04	3.60E-02	3.60E-03	9.36E-03
Silver	1.11E-05	4.08E-06	7.11E-06	6.49E-04	7.13E-05	2.22E-04
Sodium	4.78	2.65	3.84	4.78	2.92	3.83
Strontium	1.83E-03	4.57E-06	3.24E-04	4.44E-03	4.31E-04	2.16E-03
Thallium	6.85E-06	4.60E-06	6.40E-06	1.28E-04	6.56E-05	9.86E-05
Thorium	4.10E-04	4.31E-06	5.77E-05	8.27E-02	8.04E-03	3.20E-02
Uranium	4.75E-03	4.20E-07	8.05E-04	1.82E-01	7.17E-03	4.39E-02

[a]N.D. = none detected or not analyzed for.

future is the hazardous waste land disposal ban that establishes treatment standards; prohibits land disposal of wastes, including those in 40 CFR 261.31, dioxin-containing wastes, and California list wastes (liquids with pH ≤2, those containing PCBs, and liquids or solids containing halogenated organic compounds); and determines a schedule for disposal prohibition and treatment standards.[20]

Because of the low levels of transuranic isotope (TRU) contamination in the supernate (the supernates are not TRU waste per se) and much higher levels in the sludge, disposal at the Waste Isolation Pilot Plant (WIPP) is a possibility. To ensure acceptance at the WIPP, sludge and supernate would be mixed together to meet the minimum TRU-content WAC. Because RCRA materials are present in the MVST sludges, the TRU waste going to WIPP would be mixed or potentially mixed. An acceptable waste form and the availability of the designed-for capability for remote-handled TRU (RH-TRU) waste are still in question. Also questionable is whether WIPP will be allowed to open fully after the initial 5-year trial period, during which 1% of the space will be used. If it does receive approval, will it be in a time frame that will benefit the storage problems in the MVSTs? Also, WIPP must receive a "No Migration" variance from the RCRA Land Disposal Restrictions (LDR) from the EPA for storage of RCRA materials if the MVST material is to be disposed of without treatment. If the LDR variance is not granted, the wastes will have to be treated to LDR criteria. Because of these uncertainties, the exact nature of the optimum treatment scheme cannot be determined at present. However, based on the compositions of the various tanks and the expectations for the directions that the regulations will take, some basic steps can be examined.

3.3 RESULTS OF DATA-BASE CALCULATIONS

3.3.1 Radiological Results

Table 3 gives a summary of the maximum, minimum, and average radiochemical concentrations in both supernate and sludge in the LLLW storage tanks. At the time of sampling, the supernate contained 100.5 Ci of ^{60}Co (86.4 Ci in MVSTs); 13,523 Ci of ^{137}Cs (12,810 Ci in MVSTs); 1,444 Ci of ^{90}Sr (1,322 Ci in MVSTs); 6.1 Ci of ^{14}C (6.0 Ci in MVSTs); 6.92 Ci of gross alpha (3.41 Ci of alpha in MVSTS); and 4.57 Ci of alpha without ^{244}Cm (3.29 Ci of alpha in MVSTs without ^{244}Cm). Ninety-two percent of the ^{60}Co, 94% of the ^{90}Sr, 60% of the ^{14}C, 99.6% of the gross alpha (excluding W-21, which was at pH 0.71 and had not been neutralized when sampled and, therefore, contained much soluble alpha), and 98.5% of the europium are contained in the sludge, while the supernate contains 73.2% of the ^{137}Cs.

Several important observations can be made by comparing the limits in Tables 1 and 2 with concentrations in Table 3 for the alpha-, beta-, and gamma-emitting isotopes present in the LLLW. Most isotopes in the supernate are not in compliance with DOE 5400.5 Derived Concentration Guide (DCG) standards for direct discharge to the environment. Primary concerns for the discharge of liquid waste according to DOE 5400.5 are the gross alpha (TRU components) and the ^{137}Cs, ^{60}Co, and ^{90}Sr, which must be reduced by factors of up to 10^5 to 10^7 for direct liquid discharge. Europium isotopes must also be removed from a few tanks, but this should not be a problem since they are expected to be removed in steps that remove the alpha components. Some of the other isotopes listed (^{95}Zr, ^{95}Nb, ^{144}Ce, ^{106}Ru) may need removal for liquid discharge; however, their concentrations, and hence needed removals, are not known accurately because analyses could only give "less than" values that were used in the calculations. Treatment to the DOE 5400.5 standards for drinking water requires an additional decontamination factor of 25. In addition, the tables show that ^{99}Tc and ^{237}Np have limits, but they were not analyzed for and may require measurement and removal. Neptunium-237, in particular, has a very low permissible level.

3.3.2 Chemical Composition Results

Table 4 summarizes the maximum, minimum, and average chemical concentrations of the supernate and sludge in the LLLW tanks. At the time of sampling, about 258,000 gal of supernate (237,800 gal in MVSTs) and 109,000 gal (86,600 gal sludge in MVSTs) of sludge required processing. These volumes included about 105,000 kg of water-insoluble solids and 555,000 kg of water-soluble solids, primarily sodium and potassium nitrate. The supernate contains 368,630 kg of soluble salts, including 741 kg of inorganic carbon and 541 kg of organic carbon. Maximum levels of the RCRA metals in the supernate were above the levels listed in 40 CFR 261 for arsenic, lead, cadmium, chromium, nickel, and selenium. All of the metals were present in concentrations greater than those allowable in the primary and secondary drinking-water standards, based on the limits of the analytical techniques (also the PWTP and NRWTP WAC). The drinking-water standard for nitrate is 0.00071 M, while the concentration present in the LLLW is 3 to 6 M, a difference of four orders of magnitude. Nitrate is not a RCRA metal or a listed element or compound for solid waste disposal; however, the liquid WAC requirements for the PWTP and NRWTP prohibit levels above 1 and 10 ppm nitrate as nitrogen, respectively; therefore, removal of essentially all of the nitrate is required if the supernate is to be discharged to the PWTP or the NRWTP.

Although the treatment of the sludge in the LLLW storage tanks is not the primary subject of this report, the concentration data for the sludge are reported and some comparisons are made and conclusions drawn. The levels of RCRA metals in the sludge are generally one to three orders of magnitude higher than in the supernate. An additional complication in the sludge analyses for metals is that the recommended EPA toxic material testing process has recently been changed from the Extraction Procedure Toxicity Characteristic (EPTC) to the TCLP; thus, resampling and analysis by TCLP will be required for sludge previously determined to be hazardous by EPTC.[21] The new definition also adds 25 organic constituents and the regulatory levels for each constituent. If waste was previously determined to be nonhazardous by EPTC but had metals at concentrations near the regulatory limit, it should also be resampled and analyzed by TCLP. In addition, waste suspected to contain organics must be sampled and analyzed by TCLP. If a sludge is converted to a waste form, such as cement grout, that waste form must pass the TCLP leach test unless a RCRA LDR variance is obtained for the disposal site.

3.4 LLLW STORAGE TANK DATA

The specific data obtained on the material in each tank are shown in Tables A.1—A.10, Appendix A, which give a summary of concentrations and inventories for both radioactive and nonradioactive components. Summations of constituents in the MVSTs and in the ten LLLW tanks are given in Table 5 and Table A.11, respectively. The definitions used in the table and the calculational methods are included in Appendix B.

Estimates for the quantities of the various isotopes were calculated, based on the volumes of supernate or sludge, the supernate or sludge density, and the radiological and nonradiological analyses given in the tank sample analyses.[3-5] Chemical data for the supernate are shown as reported or converted to a molar basis. Radiological data were converted from becquerels per milliliter (Bq/mL) to nanocuries per liter (nCi/L). Sludge analyses were presented in units of milligrams per kilogram (mg/kg) and converted to the moles-per-liter (mol/L) concentrations shown, using the measured density of the sludge. For both supernate and sludge, many of the analyses were reported as "less than xxx mg/L." The xxx concentration was then assumed so that calculations could be made. The estimated concentrations, therefore, result in maximum values for those constituents.

To determine the quantities of soluble and insoluble solids present in the sludge, several assumptions were made, including:

- Soluble nitrate, chloride, and hydroxides were present in the sludge as interstitial liquid at the same concentrations as in the supernate.
- The analyzed cations other than sodium and potassium are present as insoluble compounds with the compounds shown, based on common precipitates at the conditions in the tanks.
- The carbonate was present as calcium carbonate, and the reported value was derived from the inorganic carbon analyses.

The total sludge and supernate quantity of an element or compound were based on the supernate elemental total plus that element's part of the total mass of that sludge compound. The sludge values for mass present are estimates, assuming that the cations are present as the compounds shown. This method was used to compare the analytical physical characterization and to estimate the quantity of insoluble materials present in the sludge. The total solids calculated in this manner were compared with the measured solids; and the difference, called "solids unaccounted for," was used to measure the accuracy of the estimation of the solids composition. Other assumptions are listed in Appendix B.

The total amounts of individual radioactive constituents in the supernate differ markedly from tank to tank. The quantities of ^{60}Co, for instance, vary from less than 1 Ci in tank W-27 to almost 40 Ci in tank W-28. The quantity of ^{137}Cs ranges from 195 Ci in W-23 to 6338 Ci in W-26, ^{14}C ranges from 2 mCi in W-21 to 2.7 Ci in W-24, ^{90}Sr from 0.2 Ci in W-23 to 788 Ci in W-28, and gross alpha from 3 mCi in W-27 to 4.37 Ci in W-21. Some tanks have low concentrations of gross alpha; thus, a differentiated alpha analysis was not performed. Variability of this type from tank to tank necessitates planning the decontamination of the LLLW carefully to ensure compliance with all of the various waste TSD rules, orders, and laws.

Table 5. Summation of constituents in the MVSTs

A. Radiochemical Analyses

Constituent	MVSTs supernate (total Ci)	MVSTs sludge (total Ci)	MVSTs supernate + sludge (Ci)
H-3	6.38		6.38
C-14	6.02	3.25	9.26
Co-60	86.52	572.26	658.77
Sr-90	1,323.94	15,182.96	16,506.90
Nb-95	2.55	14.26	16.81
Zr-95	4.62	359.72	364.34
Ru-106	45.84	151.86	197.71
Cs-134	135.28	20.60	155.88
Cs-137	12,814.88	3,938.11	16,752.99
Ce-144	31.17	85.62	116.79
Eu-152	11.09	2,379.23	2,390.32
Eu-154	5.50	1,378.85	1,384.35
Eu-155	16.46	371.40	387.86
Gross alpha	3.43	645.12	648.56
Gross beta	16,099.12	40,696.25	56,795.37
U-232	0.11	2.63	2.74
U-233	2.83	26.04	28.87
U-238	0.03		0.03
U-235		85.99	85.99
Pu-239/Pu-240	0.03	35.64	35.67
Pu-238/Am-241	0.05	99.79	99.84
Cm-243		84.84	84.84
Cm-244		435.25	435.

			MVSTs supernate	MVSTs sludge	MVSTs supernate + sludge
Tank volume	1,230,463 L	Sum Co,Cs,Eu =	13,069.73	8,660.45	21,730.18
Supernate volume	901,411 L	Sum Sr,C,^3H =	1,336.34	15,186.21	16,522.54
Supernate H_2O	761,938 L	Sum alpha =	3.05	770.18	773.23
Sludge volume	328,952 L	Sum alpha-^{244}Cm =	3.05	334.93	337.98
Sludge H_2O	237,643 L				

B. Physical/Chemical Analyses

Constituent		MVSTs supernate (total kg)	MVSTs sludge (total kg)	MVSTs supernate + sludge (kg)
Dissolved solids		347,696.67		463,919.0
Total solids		346,330.89	204,205.3	550,536.1
Total carbon		1,121.47	4,130.2	5,251.6
Inorganic carbon		622.50	2,744.5	3,367.0
Organic carbon		498.73	1,387.5	1,886.2
	Sludge solids calculated as:			
Hydroxide		1,060.83	411.4	1,472.2
Carbonate		3,262.04	(13,540.4)	16,802.4
Chloride		2,853.65	934.5	3,788.1
Fluoride		445.26	162.5	607.7
Nitrate		253,550.93	86,143.4	339,694.3
Phosphate		4,537.35	1655.8	6,193.2
Sulfate		4,502.84	1643.2	6,146.1
Aluminum	$Al(OH)_3$	12.49	4,830.0	1,683.2
Arsenic		3.34	19.6	23.0
Barium	$BaSO_4$	2.42	41.6	26.9
Boron		0.85	2.2	3.1
Cadmium	$Cd(OH)_2$	0.68	9.5	8.0
Calcium	$CaCO_3$	1,616.60	38,231.6	16,925.9
Chromium	$CrCl_3$	2.42	100.5	35.4
Cobalt		0.43		0.4
Iron	$Fe(OH)_3$	2.34	1,048.5	550.2
Lead	$PbCO_3$	2.66	131.0	104.2
Magnesium	$Mg(OH)_2$	265.37	7,162.3	3,250.8
Mercury	Hg_2CO_3	0.08	18.4	14.3
Nickel	$NiCO_3$	1.41	37.2	19.8
Potassium	KNO_3	16,802.15	10,863.2	21,003.1
Selenium		4.24	22.0	26.3
Silicon	SiO_2	34.85	372.6	305.4
Silver	AgCl	0.68	7.3	6.1
Sodium	$NaNO_3$	82,764.21	105,359.1	111,262.3
Strontium	$SrCO_3$	17.05	89.8	70.4
Thallium		1.26	7.3	8.5
Thorium	ThO_2	2.70	2,021.8	1,779.5
Uranium	$Na_2U_2O_7$	130.71	5,136.3	3,987.3
Solids, kg		373,381	176,899	537,684
Water, kg		761,938	237,643	999,582
TOTAL, kg		1,108,269	441,849	1,550,118

Sludge insolubles, kg calculated minimum		58,928
Sludge insolubles, kg calculated maximum		87,983
Sludge insolubles, kg estimated (70% of high)		79,266
Solids unaccounted for (measured - calculated total)		(12,852)
C in KCoFCN added at 300 ppm	161.53	
Total organic carbon	1867.	
Ratio TOC:NO_3 at 1.2 NO_3 to insolubles	0.0205	

3.5 TREATMENT REQUIREMENTS

Based on these data, the required reductions of supernate activity for individual components were calculated, assuming various scenarios for the disposition of the resulting treated product. The activity reduction factors (ARFs) for various components are the total decontamination required and the product of the decontamination factor (DF = C_0/C) achieved by waste processing times any dilution factor between the LLLW as it exists now and the final volume discharged to the environment. Table 6 is a summary of the maximum, minimum, and average activity reduction factors required for the supernate to meet the various liquid and solid waste discharge and disposal regulations.

Table 6. Required activity reduction factors to meet various standards

Waste type and criteria	Range	^{3}H	^{14}C	^{60}Co	^{90}Sr	^{106}Ru	^{137}Cs	^{152}Eu	Gross alpha
Liquid Wastes									
DOE 5400.5	Max.	8.3	304	6.6×10^{4}	4.7×10^{6}	1.7×10^{4}	1.9×10^{7}		3.9×10^{6}
	Min.	1.6	<1	1.7×10^{3}	1.1×10^{4}	4.9×10^{3}	1.7×10^{6}		1.8×10^{3}
	Ave.	3.6	88	2.1×10^{4}	1.5×10^{6}	8.6×10^{3}	4.6×10^{6}		4.7×10^{5}
Solid Wastes									
Class L-I	Max.	38.8	2.0×10^{4}	<1	5.4×10^{3}		7.7×10^{4}	86	1.2×10^{5}[a]
	Min.	7.5	25	<1	12.6		7.0×10^{3}	<1	324[a]
	Ave.	16.6	5.8×10^{3}	<1	1.7×10^{3}		1.9×10^{4}	6.4	1.4×10^{4}[a]
Class L-II	Max.	<1	106	<1	2.1		<1	<1	2.0×10^{5}[a]
	Min.	<1	<1	<1	<1		<1	<1	92[a]
	Ave.	<1	31	<1	<1		<1	<1	2.4×10^{4}[a]
NRC Class A[b]	Max.	<1	<1	<1	118		55.9	<1	1.2
	Min.	<1	<1	<1	<1		5.1	<1	<1
	Ave.	<1	<1	<1	37		13.8	<1	<1
NRC Class B[b]	Max.	<1	<1	<1	<1		1.3	<1	8.9
	Min.	<1	<1	<1	<1		<1	<1	<1
	Ave.	<1	<1	<1	<1		<1	<1	<1
NRC Class C[b]	No DF is required to meet NRC Class C requirements								

[a]Gross alpha is assumed to be ^{239}Pu, the most restricted alpha emitter for Classes L-I and L-II.

[b]NRC limits are not presently applicable to DOE facilities but are presented for comparison.

These data indicate that decontamination of the supernate for disposal as a liquid waste through the PWTP will require removal of most of the radioactive cesium contained in the tanks. Quantities of ^{90}Sr, ^{60}Co, ^{14}C, and TRU contaminants may also require removal, depending on the tank in question, for release to the PWTP. The amount of TRU material in the supernate (<10 nCi/g average) also does not qualify it for classification as a TRU material for purposes of the WIPP waste acceptance criteria, which require >100 nCi/g TRU content.[22] In order for the supernate to be classified as TRU waste, the tank contents (including the insoluble sludge) would have to be processed as a homogenous mixture. Without removal of the ^{137}Cs and ^{90}Sr, and possibly some of the ^{60}Co, this material would be a RH-TRU waste. If WIPP did not accept RH-TRU waste, there would be no place for disposal of the solidified RH supernate. Currently proposed (May 1990) NUS Class L-II LDR could not be met by solidifying the supernate in grout because of ^{14}C and TRU contamination. In addition, the solidified mixture would have to be tested to determine whether it would be classified as a mixed waste because of the presence of RCRA materials and radioactive contamination in the original waste.

To meet DOE 5400.5 for LLLW treatment for release to the PWTP, the concentrations of radionuclides must be reduced by factors of less than 10 for ^{3}H; 10^2 for ^{14}C; 10^4 for ^{60}Co and ^{106}Ru; 10^5 to 10^6 for ^{90}Sr and gross alpha; and 10^7 for ^{137}Cs. In addition to the limits for the individual radionuclides, DOE 5400.5 also restricts the total content of the summation of the concentration divided by the DCG limits to <1. The NUS Class L-I reductions for solid LLW require reduction of $<10^2$ for ^{3}H; 10^3 to 10^4 for ^{14}C, ^{90}Sr, and ^{137}Cs; and up to 10^5 for alpha. NUS Class L-II limits require reductions only for ^{14}C (~100) and gross alpha (10^4 to 10^5). In comparison, NRC regulations for commercial nuclear waste materials require reductions only for strontium, cesium, and some alpha for Class A, only alpha for Class B, and no reductions for Class C, assuming a waste form such as grout with a density of 2 g/cm^3.

One scenario considered includes feeding the treated liquid (DOE Order 5400.5) to the PWTP (which discharges to the NRWTP) with subsequent release of the treated supernate to White Oak Creek through the NPDES permit. The LLLW can also be treated by solidifying the supernate, along with some sludge in sodium nitrate salt cake, for disposal at WIPP. Alternatively, the LLLW can be solidified by formulating it into a cement grout to meet NUS L-I, L-II, or L-IV limits. The appropriate regulatory limits were used when known (10 CFR 20, DOE 5400.5, 10 CFR Part 61, Class A, B, or C) or assumed when not known or not yet finalized, such as the WAC for Class L-I and L-II solid waste for on-site disposal and the NPDES permit discharge limits for liquid disposal.

3.5.1 Treatment for Liquid Wastes

Table 7 shows the ARFs required to meet the requirements of DOE Order 5400.5 for the possible radionuclides that are known to be present in each of the tanks. Europium must be removed from the liquids in only two tanks (W-28 and W-21), while ^{106}Ru must be removed from four of the tanks (W-24, W-26, W-28, and W-23), although DFs are generally 10^3 to 10^4 for all the tanks. Uranium—232 and —233, ^{239}Pu, and ^{241}Am are present in high concentrations in W-26, W-21, and W-23, while the ^{244}Cm content is high in W-21

Table 7. ARFs to treat supernate to DOE 5400.5 DCG standards and to the WAC for the NRWTP

Constituent	W24	W25	W26	W27	W28	W29	W30	W31	W21	W23
H-3	4.2	4.7	8.3	2.8	1.6	2.1	2.7	2.7	4.7	1.6
C-14	304	127	47	70	64	43	35	34	<1	24
Co-60	1.8E+03	1.0E+04	6.6E+04	1.7E+03	4.7E+04	1.7E+03	3.4E+03	2.6E+03	4.6E+04	3.4E+03
Sr-90	2.5E+04	5.3E+05	1.3E+04	1.5E+06	4.7E+06	2.0E+05	1.9E+05	1.8E+05	2.0E+06	1.1E+04
Nb-95	189	43	94	20	81	22	43	37	101	68
Zr-95	338	81	182	35	148	38	68	66	4.8E+03	68
Ru-106	5.0E+04	8.6E+03	1.3E+04	5.0E+03	1.4E+04	4.9E+03	9.2E+03	8.6E+03	8.8E+03	1.7E+04
Cs-134	1.8E+04	5.1E+04	1.8E+05	2.2E+03	1.4E+05	6.8E+03	3.4E+04	2.7E+04	6.9E+04	6.2E+04
Cs-137	2.0E+06	2.9E+06	1.9E+07	1.9E+06	5.1E+06	2.1E+06	2.0E+06	1.7E+06	2.9E+06	3.9E+06
Ce-144	2.9E+03	5.0E+03	8.9E+03	2.9E+03	6.9E+03	3.0E+03	5.1E+03	4.7E+03	5.8E+03	6.2E+03
Eu-152	432	216	284	148	2.3E+03	126	284	270	4.5E+04	283
Eu-154	81	162	324	89	1.0E+03	90	194	162	2.2E+04	216
Eu-155	108	186	324	108	251	113	194	179	1.4E+03	230
Th-nat	9.7	9.7	441	210	9.7	4.4	4.4	71	410	69
U-nat	11	<1	1.3E+03	<1	<1	5.1	6.8	<1	900	20
U-232[a]			9.7E+03						1.8E+04	1.1E+03
U-233[a]			5.0E+04						2.1E+04	324
U-238[a]			540							
Pu-239/240[a]			135						837	81
Am-241/Pu-238[a]			1.4E+04						2.3E+05	3.5E+04
Cm-244[a]									5.2E+05	1.8E+03
Gross alpha	9.0E+03	3.6E+03	1.9E+06	1.8E+03	7.9E+04	1.8E+04	1.8E+04	1.8E+04	3.9E+06	1.5E+05
(40 CFR 261 RCRA Metals Removal Requirements)										
Ag	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
As	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ba	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ni	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cd	<1	<1	4.5	<1	<1	<1	<1	<1	2.0	1.7
Cr	<1	<1	<1	<1	<1	<1	<1	1.3	5.4	<1
Hg	<1	<1	<1	<1	<1	<1	<1	<1	4.6	<1
Pb	1.3	<1	<1	<1	<1	<1	<1	<1	1.4	<1
Se	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	2.3	2.3
Tl	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.0	1.0

[a]Blanks indicate no analytical data are available.

and W-23. Required gross alpha decontamination factors are all in the 10^3 to 10^6 range. Further analytical work will be required to determine whether any of the individual alpha-emitters will require decontamination. Since the ^{134}Cs concentrations are generally 1% or less of the ^{137}Cs concentrations, have similar allowable limits, and are reduced by the same processes, they can generally be "lumped together" for design purposes. Table 8 lists the ARFs for treatment of radioactivity to drinking-water standards. These standards are only 4% of the DOE Order 5400.5 requirements and, thus, result in a 25-fold increase of the ARFs for 5400.5. Although these standards apply to the waste after it enters the Clinch River and is thereby diluted, they are shown for comparison.

The RCRA metal concentrations (see Table 7) indicate that small removals would be required for Cd, Cr, Pb, Se, Tl, and Hg, depending on the tank. Primary and secondary drinking-water standards requirements are given in Table 8 and show that, by far, the largest problem is nitrate removal; Cd, Cr, Se, and Fe also present problems in selected tanks. For many of the RCRA metals, the values shown in the tables are the maxima because the analyses gave "less than" values that were used for the calculations.

The ARFs in Tables 9-12 are calculated for releasing the treated supernate to White Oak Creek (WOC) through an NPDES permit or through the PWTP or the NRWTP. Table 9 shows reductions required for general release to WOC, based on 10 CFR 20, Appendix B, Table II, Column 2, but do not necessarily reflect the current NPDES permit values. The greatest reductions are required for ^{90}Sr, ^{137}Cs, and gross alpha, with lesser reductions for ^{60}Co, ^{106}Ru, ^{144}Ce, and Eu. These same general trends were also observed with DOE Order 5400.5.

If any of the LLLW from the MVSTs were qualified for release, it would have to pass through the PWTP. Table 10 shows the ARFs required to meet the WAC for liquids to be treated there. In this case, ^{137}Cs, ^{60}Co, ^{106}Ru, and gross alpha are the isotopes requiring the greatest removal. Strontium-90 has lower ARFs than in earlier tables because it is removed in the PWTP. In addition to the radioactive components, nitrate, phosphate, and sulfate require major treatment to meet the PWTP WAC. Following the PWTP, the waste flows to the NRWTP; the ARFs required to meet the WAC for the NRWTP are shown in Table 11. The WAC are essentially the DOE Order 5400.5 limits for radioisotopes, so ^{60}Co, ^{90}Sr, ^{137}Cs, ^{106}Ru, and alpha removal are required. Nitrate and sulfate are also limited, and the total organic carbon requires some treatment.

Table 8. ARFs to treat supernate to DOE 5400.5 DCG drinking-water standards

Constituent	W24	W25	W26	W27	W28	W29	W30	W31	W21	W23
H-3	104	116	209	71	40	53	68	68	118	40
C-14	7.6E+03	3.2E+03	1.2E+03	1.8E+03	1.6E+03	1.1E+03	874	8.5E+03	9.6	612
Co-60	4.4E+04	2.5E+05	1.6E+06	4.2E+04	1.2E+06	4.4E+04	8.4E+04	6.6E+04	1.2E+06	8.4E+04
Sr-90	6.2E+05	1.3E+07	3.3E+05	3.8E+07	1.2E+08	5.0E+07	4.8E+06	4.5E+06	5.0E+07	2.8E+05
Nb-95	4.7E+03	1.1E+03	2.4E+03	5.1E+02	2.0E+03	5.6E+02	1.1E+03	9.3E+02	2.5E+03	1.7E+03
Zr-95	8.4E+03	2.0E+03	4.6E+03	8.8E+02	3.7E+03	9.6E+02	1.7E+03	1.7E+03	1.2E+05	1.7E+03
Ru-106	1.2E+06	2.1E+05	3.2E+05	1.2E+05	3.4E+05	1.2E+05	2.3E+05	2.1E+05	2.2E+05	4.2E+05
Cs-134	4.5E+05	1.3E+06	4.4E+06	5.4E+05	3.6E+06	1.7E+06	8.6E+05	6.8E+05	1.7E+06	1.6E+06
Cs-137	5.0E+07	7.4E+07	4.7E+08	4.9E+07	1.3E+08	5.2E+07	4.9E+07	4.2E+07	7.2E+07	9.8E+07
Ce-144	7.1E+04	1.3E+05	2.2E+05	7.2E+04	1.7E+05	7.5E+04	1.3E+05	1.2E+05	1.4E+05	1.5E+05
Eu-152	1.1E+04	5.4E+03	7.1E+03	3.7E+03	5.6E+04	3.1E+03	7.1E+03	6.8E+03	1.1E+06	7.1E+03
Eu-154	2.0E+03	4.1E+03	8.1E+03	2.2E+03	2.5E+04	2.2E+03	4.9E+03	4.0E+03	5.6E+05	5.4E+03
Eu-155	2.7E+03	4.7E+03	8.1E+03	2.7E+03	6.3E+03	2.8E+03	4.9E+03	4.5E+03	3.5E+04	5.7E+03
Th-nat	240	240	1.1E+03	5.4E+03	2.4E+02	1.1E+03	1.1E+03	1.8E+03	1.0E+04	1.7E+03
U-nat	270	3	3.3E+04	3.0	3.0	130	170	7.7	2.2E+04	500
U-232[a]			2.4E+05						4.6E+05	2.7E+04
U-233[a]			1.2E+06						5.4E+05	8.1E+03
U-238[a]			1.4E+04							
Pu-239/240[a]			3.4E+03						2.1E+04	2.0E+03
Am-241/Pu-238[a]			3.4E+05						5.9E+06	8.8E+05
Cm-244[a]									1.3E+07	4.5E+04
Gross alpha	2.2E+05	9.0E+04	4.6E+07	4.5E+04	2.0E+06	4.5E+05	4.5E+05	4.5E+04	9.6E+07	3.7E+06

(40 CFR 141.11 Primary Drinking Water and 40 CFR 143.3 Secondary Drinking Water)

Constituent	W24	W25	W26	W27	W28	W29	W30	W31	W21	W23
NO_3	5869	5869	4608	6331	8362	6331	6331	6093	7003	4524
Cd	22	12	450	12	51	12	12	12	200	170
Cr	62	38	36	56	8	120	48	58	540	8
Pb	134	42	64	42	42	42	44	54	142	54
Ag	14	14	24	14	14	14	14	14	24	9
As	74	74	74	74	74	74	74	74	76	60
Ba	<1	3	<1	4	6	4	1	<1	25	<1
Se	470	470	470	470	470	470	470	470	230	230
Hg	23	27	40	24	70	75	45	50	460	35
Cl	10	10	14	10	20	10	12	11	8	14
SO_4	20	20	20	20	20	20	20	20	20	31
Fe	9	9	9	9	9	9	9	9	800	2

[a]Blanks indicate no analytical data are available.

Table 9. Supernate ARFs for 10 CFR 20 standards for release to White Oak Creek[a]

Constituent	W24	W25	W26	W27	W28	W29	W30	W31	W21	W23
H-3	2.8	3.1	5.6	1.9	1.1	1.4	1.8	1.8	3.1	1.1
C-14	26.6	11.1	4.2	6.1	5.6	3.8	3.1	3.0	<1	2.1
Co-60	178	1.0E+03	6.6E+03	167	4.7E+03	174	336	264	4.6E+03	340
Sr-90	8.2E+04	1.8E+06	4.4E+04	5.0E+06	1.6E+07	6.6E+05	6.4E+05	6.1E+06	6.7E+06	3.7E+04
Nb-95	76	17	38	8.1	32	9	17	14.9	40	27
Zr-95	225	54	121	23	99	26	45	45	3.2E+03	45
Ru-106	3.0E+04	5.1E+03	7.6E+03	3.0E+03	8.2E+03	3.0E+03	5.5E+03	5.1E+03	5.3E+03	1.0E+04
Cs-134	4.0E+03	1.1E+04	3.9E+04	4.8E+03	3.2E+04	1.5E+04	7.6E+03	6.0E+03	1.5E+04	1.4E+04
Cs-137	3.0E+05	4.4E+05	2.8E+06	2.9E+05	7.6E+05	3.1E+05	3.0E+05	2.5E+05	4.3E+05	5.9E+05
Ce-144	2.9E+02	5.0E+02	8.9E+02	2.9E+02	6.9E+02	3.0E+02	5.1E+02	4.7E+02	5.8E+02	6.2E+02
Eu-152	108	54	71	37	564	31	71	68	1.1E+04	71
Eu-154	81	162	324	89	1.0E+03	90	194	162	2.2E+04	216
Eu-155	54	93	162	54	126	57	97	90	705	115
Th-nat	<1	<1	1.1	5.4	<1	<1	<1	1.8	10	1.7
U-nat	<1	<1	20	<1	<1	<1	<1	<1	14	<1
U-232[b]			32						61	3.6
U-233[b]			828						356	5.4
U-238[b]			6.8							
Pu-239/240[b]			54						335	32
Pu-238/Am-241[b]			101						1.7E+03	263
Cm-244[b]									4.4E+03	15
Gross alpha	4.5E+03	1.8E+03	9.3E+05	9.0E+02	4.0E+04	9.0E+03	9.0E+03	9.0E+02	1.9E+06	7.4E+04

[a]Appendix B, Table II, Column 2.
[b]Blanks indicate that no analytical data are available.

Table 10. ARFs to treat supernate to WAC for the PWTP

Constituent	W24	W25	W26	W27	W28	W29	W30	W31	W21	W23
Co-60	1.8E+03	1.0E+04	6.6E+04	1.7E+03	4.7E+04	1.7E+03	3.4E+03	2.6E+03	4.6E+04	3.4E+03
Sr-90	91	1.9E+03	49	5.6E+03	1.8E+04	7.4E+03	7.1E+03	672	7.5E+03	41
Nb-95	189	43	94	20	81	22	42	37	101	68
Zr-95	338	81	182	35	148	38	68	69	4.8E+03	68
Ru-106	5.0E+03	8.6E+03	1.3E+04	5.0E+03	1.4E+04	5.0E+03	9.2E+03	8.6E+03	8.8E+03	1.7E+04
Cs-137	5.5E+05	8.2E+05	5.2E+06	5.4E+05	1.4E+06	5.7E+05	5.5E+05	4.7E+05	8.0E+05	1.1E+06
Eu-152	432	216	284	148	2.2E+03	126	284	270	4.5E+04	284
Eu-154	81	162	324	89	1.0E+03	90	194	162	2.2E+04	216
Eu-155	108	186	324	108	251	113	194	179	1.4E+03	230
Gross alpha	500	200	1.0E+05	100	4.4E+03	1.0E+02	1.0E+03	1.0E+03	2.1E+05	8.2E+03
Gross beta	2.3E+04	3.9E+04	2.2E+05	3.3E+04	9.8E+04	3.6E+04	2.1E+04	1.9E+04	5.0E+04	4.6E+04
NO_3[a]	5.9E+04	5.9E+04	4.6E+04	6.3E+04	8.4E+04	6.3E+04	6.3E+04	6.1E+04	7.0E+04	4.5E+04
PO_4[a]	1.0E+04	1.0E+04	1.0E+04	1.0E+04	1.0E+04	1.0E+04	1.0E+04	1.0E+04	1.0E+04	1.0E+04
SO_4[a]	5.0E+04	5.0E+04	5.0E+04	5.0E+04	5.0E+04	5.0E+04	5.0E+04	5.0E+04	5.0E+04	7.8E+04
Cadmium	<1	<1	6.4	<1	<1	<1	<1	<1	2.9	2.4
Chromium	1.03	<1	<1	<1	<1	2.0	<1	<1	9.0	<1
Lead	9.6	3.0	4.6	3.0	3.0	3.0	3.1	3.9	10	3.8
Nickel	<1	<1	2.0	<1	<1	<1	<1	<1	3.8	<1
Silver	1.4	1.4	2.4	1.4	1.4	1.4	1.4	1.4	2.4	<1

[a]PWTP WAC are NO_3 = 1 ppm N (assumed for calculation), PO_4 = 5 ppm, SO_4 = 0.1 ppm.

Table 11. ARFs to treat supernate to the NRWTP WAC for the nonradioactive components[a]

Constituent	W24	W25	W26	W27	W28	W29	W30	W31	W21	W23
TOC	13	12	34	9.6	15	12	12.9	4.4	15	31
NO_3[b]	6820	6820	5360	7360	9720	7360	7360	7080	8140	5260
SO_4	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	8.3
Ag	2.7	2.7	4.6	2.7	2.7	2.7	2.7	2.7	4.6	1.7
As	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ba	<1	<1	<1	<1	<1	<1	<1	<1	4.2	<1
Cd	<1	<1	2.4	<1	<1	<1	<1	<1	1.1	<1
Cr	<1	<1	<1	<1	<1	<1	<1	<1	2.7	<1
Fe	<1	<1	<1	<1	<1	<1	<1	<1	2.3	<1
Hg	5.1	6.0	8.9	5.3	15.6	16.7	10	11.1	102	7.8
Ni	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Pb	1.3	<1	<1	<1	<1	<1	<1	<1	1.3	<1
Se	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	<1	<1

[a]Radioisotope limits are the same as the DOE 5400.5 DCG limits.
[b]Limit was assumed to be 1 ppm N for calculation purposes.

Table 12. Supernate DFs to reach the NRWTP WAC with dilution[a] for the radioactive components by feeding to the PWTP

Constituent	W24	W25	W26	W27	W28	W29	W30	W31	W21	W23
H-3	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
C-14	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Co-60	1.3	7.0	46.0	1.2	32.7	1.2	2.3	1.8	32	2.3
Sr-90	17	370	9.2	1.0E+03	3.3E+03	1.4E+03	133	126	1.4E+03	7.7
Nb-95	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Zr-95	<1	<1	<1	<1	<1	<1	<1	<1	3.3	<1
Ru-106	3.4	6.0	8.8	3.4	9.4	3.4	6.4	5.9	6.1	11.8
Cs-134	12.6	35.3	123	15.1	99.4	47.0	23.8	18.8	48	43.4
Cs-137	1.4E+03	2.0E+03	1.3E+04	1.4E+03	3.6E+03	1.4E+03	1.4E+03	1.2E+03	2.0E+03	2.7E+03
Ce-144	2.0	3.5	6.2	2.0	4.8	2.1	3.6	3.3	4.0	4.3
Eu-152	<1	<1	<1	<1	1.6	<1	<1	<1	31	<1
Eu-154	<1	<1	<1	<1	<1	<1	<1	<1	15.6	<1
Eu-155	<1	<1	<1	<1	<1	<1	<1	<1	1.0	<1
Th-nat	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
U-nat	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
U-232[b]			6.8						12.8	<1
U-233[b]			34.5						14.8	<1
U-238[b]			<1							
Pu-239/240[b]			<1						<1	<1
Am-241/Pu-238[b]			9.4						163	24.4
Cm-244[b]									359	1.3
Gross alpha	6.3	2.5	1.3E+03	1.3	55	1.2	12.5	12.5	2.7E+03	103
NO_3 (1 ppm N)	4.7	4.7	3.7	5.1	6.8	5.1	5.1	4.9	5.7	3.6
SO_4, TOC	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ag, Cd, Cr	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Pb, Ni, Ba	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
As, Se, Fe	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

[a]Dilution, 1440:1.
[b]Blanks indicate that no analytical data were available.

In order to remove the radioactive constituents, a very small amount of radioactive material must be separated from the large amounts of nonradioactive materials contained in the tanks. For example, ^{137}Cs, at 5.9 x 10^6 nCi/L, in tank W-27 supernate consists of about 6.0 x 10^{-5} g ^{137}Cs/L (60 ppb) or 4.4 x 10^{-7} M, while the sodium is at 4.52 M and the potassium is 0.22 M. In other words, W-27 contains ~6.6 g of ^{137}Cs, which must be separated from 30,766 kg of sodium and 933 kg of potassium. Stable cesium may also be present but was not analyzed. The ^{90}Sr situation is similar for W-27, with a concentration of 1.0 x 10^{-5} g/L (1.1 x 10^{-7} M), or 1.1 g, ^{90}Sr in the supernate. A process that removes ^{90}Sr will also remove the nonradioactive strontium, which amounts to almost 2 kg in W-27; however, additional removal capacity (~2000 times that for the ^{90}Sr alone) would be required.

These ARFs do not take into account the dilutions obtained when the treated supernate is fed to the creek or to the treatment facilities, because the TDHE has ruled that ORNL cannot use dilution as a treatment method. If the rules change and the treated supernate is allowed to go through the PWTP and meet the NRWTP WAC, then the DFs shown in Table 12 would be required prior to feed to the PWTP. These DFs are calculated assuming dilution into a stream with a flow rate of 200 gal/min from the PWTP to the NRWTP and an LLLW feed rate of 200 gal/d to the PWTP. This results in an activity reduction of 1440. Nitrate concentrations will have to be reduced to the PWTP WAC before the streams can be mixed. The nuclides that require the most extensive treatment (DFs of 10^3) in this scenario include ^{137}Cs and ^{90}Sr for all tanks. Removals of ^{60}Co and ^{106}Ru are also required at DFs of ~10, and the gross alpha is still high in W-26, W-21, and W-23. Nitrate requires a DF of 4 to 9 to meet the NRWTP WAC. Essentially all of the nitrate would have to be removed before the treated supernate could be released to the PWTP if the WAC for the PWTP that prohibits the discharge of nitrate to the plant at levels above 1 ppm nitrogen is enforced.

From the point of view of achieving processing requirements, process DFs corresponding to the larger ARFs of Table 7 (on the order of 10^6 to 10^7 for ^{137}Cs and ^{90}Sr and 10^4 to 10^5 for ^{60}Co, gross alpha, and some actinides) might be obtained only with considerable difficulty and at high cost. In such a case, processing the supernate with the objective of environmental discharge is probably not a viable option; instead, a solidification process would probably be favored, resulting in an increased volume of solid waste. However, if dilution can be included, the DF requirements are reduced about three orders of magnitude; in that case, processing the supernate for environmental discharge may be viable. Therefore, the choice as to whether waste processing is advantageous, or even technically achievable, depends on the regulatory rules as much as it does on process technology.

3.5.2 Treatment Required for Solid LLW

The requirements for treating the supernate to reach the standards for solid LLW disposal are shown in Tables 13 and 14. These tables are calculated based on the assumption that the supernate is solidified in a grout mixture with a volume increase of 30%. Results show that NRC Class A standards can be met by removing only ^{137}Cs (with DFs ranging from 3.9 to 43). Also, ^{90}Sr must be removed from all tanks, except for W-24, -26, and -23, with DFs ranging from 3.4 to 90.9. Further, gross alpha contamination must be removed from tanks W-26 (DF = 4.3) and W-21 (DF = 8.9). For NRC Class B LLW, tanks W-26 and W-21 require removal of gross alpha as for class A. The individual isotopes ^{238}Pu, ^{239}Pu, ^{241}Am, and ^{244}Cm in W-21 are also above the Class A and B limits. No DF is required for any supernate to meet the requirements of NRC Class C if the waste form is grout with a density of 2 g/cm^3.

The DFs required to meet the original LLWDDD proposed limits for solidified supernate for classes L-I, L-II, and L-III are shown in Table 14; the DFs for the proposed NUS Class L-I and Class L-II limits are given in Table 15. The waste forms are assumed to be concrete in which the supernate is solidified at a volume increase of 30%. The NUS limits were proposed by the NUS Corporation in May 1990 for use in the Reservation Waste Management Environmental Impact Statement, using the most restrictive intruder scenario. The scenarios examined included the homesteader (10-mrem limit), drinking water (4-mrem limit), and air pathway to the general public (10-mrem limit). The NUS values are not finalized and may change significantly.

NUS Class L-I requires decontamination for ^{3}H, ^{14}C, ^{137}Cs, and ^{90}Sr for all tanks. The cesium DFs range from 5.5 x 10^3 to 6.0 x 10^4, and ^{14}C DFs are generally in the 10^3 to 10^4 range, while strontium DFs vary from ≈10 to 1.7 x 10^3. Cesium-134, ^{106}Ru, and ^{242}Cm have inventory limits exceeding 10^{12} Ci and need no DF. The alpha isotopic breakdown for the three tanks W-26, W-21, and W-23 show that removal of alpha contamination is required for ^{233}U, ^{238}U, ^{238}Pu, ^{239}Pu, ^{241}Am, and ^{244}Cm. If the uranium and thorium shown in the lower part of the tables are assumed to be ^{238}U and ^{232}Th, the radioactivity represented by them can be calculated and reveals that ^{232}Th is above the limits in all but W-29 and W-30; however, the DFs required are small except in W-21, which was at a low pH level when sampled. Uranium, as ^{238}U, is above the limits only in tanks W-26 and W-21.

Table 13. Supernate DFs to reach NRC Class A, B, and C standards for solid waste forms with a 1.3:1 volume increase

Constituent	W24	W25	W26	W27	W28	W29	W30	W31	W21	W23
A. Class A										
H-3	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
C-14	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Co-60	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Sr-90	<1	13.2	<1	27.6	118.1	49.8	4.8	4.5	50.3	<1
Cs-137	6.0	8.8	55.9	5.8	15.3	6.2	5.9	5.1	8.6	11.8
Gross alpha	<1	<1	5.6	<1	<1	<1	<1	<1	11.6	<1
B. Class B										
H-3	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
C-14	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Co-60	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Sr-90	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cs-137	<1	<1	1.3	<1	<1	<1	<1	<1	<1	<1
Gross alpha	<1	<1	5.6	<1	<1	<1	<1	<1	11.6	<1
U-233	<1	<1	5.0	<1	<1	<1	<1	<1	2.1	<1
Pu-239	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Pu-240	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Pu-238	<1	<1	<1	<1	<1	<1	<1	<1	1.4	<1
Am-241	<1	<1	<1	<1	<1	<1	<1	<1	1.4	<1
Cm-244	<1	<1	<1	<1	<1	<1	<1	<1	6.2	<1

C. Class C

No DF required for any tanks for any component for Class C.

Table 14. Supernate DFs for LLWDDD Class L-I, L-II, and L-III for concrete waste forms with a 1.3:1 volume increase

A. Class L-I[a]

Constituent	W24	W25	W26	W27	W28	W29	W30	W31	W21	W23
Co-60	<1	2.6	17.0	<1	12.1	<1	<1	<1	11.8	<1
Sr-90	20.5	438	11	1.3E+03	3.9E+03	1.7E+03	159	151	1.7E+03	9.3
Cs-137	1.5E+04	2.2E+04	1.4E+05	1.5E+04	3.8E+04	1.5E+04	1.5E+04	1.3E+04	2.2E+04	2.9E+04
Eu-152	10.4	5.2	6.8	3.6	54.3	3.0	6.8	6.5	1.1E+03	6.8
Eu-154	<1	1.1	2.2	<1	6.7	<1	1.3	1.1	151	1.5
Th-nat	<1	<1	<1	<1	<1	<1	<1	<1	1.5	<1
U-nat	<1	<1	6.0	<1	<1	<1	<1	<1	4.1	<1
U-233[b]			241						104	1.6
U-238[b]			2.8							
Pu-238[b]			<1						5.6	<1
Pu-239[b]			<1						1.1	<1
Am-241[b]			<1						5.6	<1
Cm-244[b]									17.5	<1
Alpha as Pu-239	<1	<1	18.8	<1	<1	<1	<1	<1	39.0	1.5

[a]Cesium-134 and ^{106}Ru have no LLWDDD I limits and are not shown; ^{3}H, ^{14}C, and ^{155}Eu are <1 for all tanks.
[b]Blanks indicate that no analytical data are available.

B. Class L-II[a]

Constituent	W24	W25	W26	W27	W28	W29	W30	W31	W21	W23
Sr-90	<1	<1	<1	1.9	5.8	2.5	<1	<1	2.5	<1
Cs-137	29.8	44.1	279.2	29.1	76.3	30.9	29.5	25.4	43.0	58.8
Th-nat	<1	<1	<1	<1	<1	<1	<1	<1	1.0	<1
U-233[b]			4.4						1.9	<1
Pu-238[b]			<1						8.5	1.3
Pu-239[b]			<1						3.2	<1
Am-241[b]			<1						8.5	1.3
Cm-244[b]									<1	<1
Alpha as Pu-239	<1	<1	53.6	<1	2.3	<1	<1	<1	111.4	4.3

[a]Cesium-134 and ^{106}Ru have no LLWDDD II limits and are not shown; ^{3}H, ^{14}C, ^{60}Co, and ^{152}Eu, ^{154}Eu, and ^{155}Eu are <1 for each tank.
[b]Blanks indicate that no analytical data are available.

C. Class L-III[a]

Constituent	W24	W25	W26	W27	W28	W29	W30	W31	W21	W23
U-233[b]			2.2						<1	<1
Pu-238[b]			<1						5.7	<1
Pu-239[b]			<1						2.1	<1
Am-241[b]			<1						5.7	<1
Cm-244[b]									<1	<1
Alpha as Pu-239	<1	<1	35.4	<1	1.5	<1	<1	<1	73.5	2.8

[a]Tritium, ^{60}Co, ^{90}Sr, ^{134}Cs, ^{137}Cs, ^{106}Ru, ^{152}Eu, ^{154}Eu, and ^{155}Eu have no LLWDDD III limits and are not shown; carbon-14 is <1 for each tank.
[b]Blanks indicate that no analytical data are available.

Table 15. Supernate DFs for NUS Class L-1 and L-2 limits for concrete waste forms

A. Class L-1[a]

Constituent	W24	W25	W26	W27	W28	W29	W30	W31	W21	W23
H-3	15	17	30	10	5.8	7.5	9.7	9.8	17	5.8
C-14	1.5E+04	6.4E+03	2.4E+03	3.5E+03	3.2E+03	2.2E+03	1.8E+03	1.7E+03	19	1.2E+03
Co-60	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Sr-90	21.5	460	12	1.3E+03	4.1E+03	1.7E+03	167	159	1.8E+03	9.6
Cs-137	6.4E+03	9.4E+03	6.0E+04	6.2E+03	1.6E+04	6.6E+03	6.3E+03	5.4E+0 3	9.2E+03	1.3E+04
Eu-152	<1	<1	<1	<1	3.3	<1	<1	<1	66	<1
Eu-154	<1	<1	<1	<1	<1	<1	<1	<1	1.9	<1
Eu-155	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
U-nat	<1	<1	9.3	<1	<1	<1	<1	<1	6.3	<1
Th-nat	1.5	1.5	6.8	1.5	1.5	<1	<1	1.5	65	11
U-233[b]			367						158	2.4
U-238[b]			6.8							
Pu-238[b]			1.5						26.1	3.8
Pu-239[b]			416						2.6E+03	250
Am-241[b]			29						498	74.1
Cm-244[b]									23.7	<1
Alpha as Pu-239	2.1E+02	8.3E+01	4.3E+04	4.2E+01	1.8E+03	4.7E+02	3.3E+02	4.2E+01	8.9E+04	3.4E+03

[a]Cesium-134 and ^{106}Ru have inventory limits of >1E+12 Ci and are not shown.
[b]Blanks indicate that no analytical data are available.

B. Class L-2[a]

Constituent	W24	W25	W26	W27	W28	W29	W30	W31	W21	W23
C-14	110	44	17	24	22	<1	<1	15	<1	8.5
Sr-90	<1	<1	<1	<1	1.6	<1	<1	<1	<1	<1
Cs-137	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
U-nat	<1	<1	10	<1	<1	<1	<1	<1	7.0	<1
U-233[b]			820						349	5.3
U-238[b]			7.5							
Pu-238[b]			21						360	5.7
Pu-239[b]			700						4.4E+03	420
Am-241[b]			<1						2.5	<1
Cm-244[b]									112	<1
Alpha as Pu-239	360	140	7.3E+04	71	3.0E+03	710	560	71	1.5+E05	5.8E+03

[a]Tritium, ^{60}Co, ^{134}Cs, ^{106}Ru, ^{152}Eu, ^{154}Eu, ^{155}Eu, ^{232}Th, and ^{242}Cm have inventory limits of >1E+12 Ci and are not shown.
[b]Blanks indicate that no analytical data are available.

For those tanks for which no analysis is given for the alpha isotopes, the worst case would be for all the alpha to be present as ^{239}Pu (for which the limits are very low). If the alpha is assumed to be ^{239}Pu, then DFs of 42 to 420 are required. This may not be a poor assumption because the ^{239}Pu present in tanks W-26, W-21, and W-23 requires the highest DFs, within an order of magnitude of the assumption of all alpha being ^{239}Pu. A more-detailed isotopic analysis of the gross alpha will be required for the remaining tanks to give a breakdown of the isotopes present and determine what treatment is required.

NUS Class L-II requires decontamination for ^{14}C and for alpha. If the uranium present is again assumed to be ^{238}U, then tanks W-26 and W-21 need DFs for that radionuclide. Tanks W-26, W-21, and W-23 require alpha removal for ^{233}U, ^{238}Pu, ^{239}Pu, and ^{244}Cm. If the gross alpha is assumed to be ^{239}Pu, as above, DFs of 71 to 10^5 would be required to meet the L-II limits. The inventory limits for Class L-II are $\geq 1 \times 10^{12}$ for ^{3}H, ^{60}Co, ^{106}Ru, ^{134}Cs, ^{152}Eu, ^{154}Eu, ^{155}Eu, ^{232}Th, and ^{242}Cm. Also, ^{137}Cs and ^{90}Sr levels are low enough that only W-28 requires any DF for ^{90}Sr.

Additional calculations were made to determine the radioactivity that would be contained in the solid product from the treatment processes if the supernate were incorporated into cement grout at a supernate:resulting concrete ratio of 1:1.3. The results of these calculations are shown in Table 16. The contributions of the various isotopic constituents are shown for each tank in nCi/L. Values for the solid, in nCi/g for each constituent, are calculated based on a concrete density of 2 g/cm^3. Based on the results in the table, this concrete would be above NUS Class L-I for ^{137}Cs and ^{90}Sr for all tanks. It would also be above the gross alpha limits for NUS Classes L-I and L-II if all of the alpha is assumed to be ^{239}Pu.

Total alpha-, beta-, and gamma-emitting radioactive contents for a drum of the solidified supernate are shown in Table 17. The nitrate content of a drum of solidified supernate was also calculated, based on the supernate nitrate concentration and ranged from 41.7 to 77.06 kg/drum, or about 10 to 19% of the mass in the drum. Only W-21 and W-26 have a gross alpha content above 10 nCi/g, making the waste from these tanks fall under NRC Class C criteria. None of the supernates has a TRU content sufficient to be classified as TRU waste, according to the WAC of the WIPP (>100 nCi/g).

Table 16. Radiation content when untreated supernate is solidified in concrete[a]

Constituent (units)	W24	W25	W26	W27	W28	W29	W30	W31	W21	W23
H-3 (nCi/L) (nCi/g)[b]	**6400**[c] 3.2	**7170** 3.6	**1.3E+04** 6.4	**4340** 2.2	**2470** 1.2	**3240** 1.6	**4170** 2.1	**4200** 2.1	**7270** 3.6	**2470** 1.2
C-14	**1.6E+04**[d] 8.2	**6831** 3.4	**2550** 1.3	**3760** 1.9	**3470** 1.7	**2330** 1.2	**1880** 0.9	**1830** 0.9	**21** 0.01	**1320** 0.6
Co-60	6830 3.4	3.9E+04 19.5	2.5E+05 127	6420 3.2	1.8E+05 90.6	6.7E+03 3.4	1.3E+04 6.5	1.0E+04 5.1	1.8E+05 88.3	1.3E+04 6.4
Sr-90[e]	**1.9E+04** 9.5	**4.1E+05** 203	**1.0E+04** 5.1	**1.2E+06** 578	**3.6E+06** 1820	**1.5E+06** 766	**1.5E+05** 73.5	**1.4E+05** 69.8	**1.6E+06** 775	**8560** 4.3
Cs-137[e]	**4.6E+06** 2300	**6.8E+06** 3400	**4.3E+07** 2.2E+04	**4.5E+06** 2240	**1.2E+07** 5880	**4.8E+06** 2380	**4.6E+06** 2270	**3.9E+06** 1950	**6.6E+06** 3310	**9.1E+06** 4530
Eu-152[e]	6650 3.3	3320 1.7	4360 2.2	2280 1.1	**3.5E+04** 17.3	1930 1.0	4360 2.2	4150 2.1	**6.9E+05** 344.	4360 2.2
Eu-154	1246 0.6	2492 1.2	4980 2.5	1369 0.7	1.5E+04 7.7	1390 0.7	3000 2.2	2490 2.1	**3.4E+05** 172	3320 1.7
Eu-155	8310 4.2	1.4E+04 7.2	2.5E+04 12.5	8310 4.2	1.9E+04 9.7	8720 4.4	1.5E+04 7.5	1.4E+04 6.7	1.1E+05 54.0	1.8E+04 8.8
Gross alpha	**104** 0.05	**42** 0.02	**2.1E+04** 10.7	**21** 0.01	**914** 0.5	**21** 0.01	**208** 0.1	**208** 0.1	**4.4E+04** 22.2	**1700** 0.8
Gross beta	4.8E+06 2.4E+03	8.1E+06 4.1E+03	4.6E+07 2.3E+04	6.8E+06 3.4E+03	2.0E+07 1.0E+04	7.4E+06 3.7E+03	4.3E+06 2.1E+03	4.0E+06 2.0E+03	1.0E+07 5.2E+03	9.6E+06 4.8E+03

[a]Assumes a volume increase of 1.3:1 upon making concrete from the supernate.
[b]Assumes a density of 2.0 for concrete.
[c]Bold numbers exceed limits for NUS Class L-I.
[d]Bold and underlined exceed the limits for NUS Class L-II.
[e]Strontium-90, Cs-137, and Eu-152 also exceed limits for LLWDDD Class L-I; Cs-137 exceeds limits for LLWDDD Class L-II.

Table 17. Radiation content of drums when untreated supernate is solidified in concrete[a]

Constituent	W24	W25	W26	W27	W28 (Ci/drum[a])	W29	W30	W31	W21	W23
Alpha	2.2E-05	8.6E-06	4.4E-03	4.3E-06	1.9E-04	4.3E-06	4.3E-05	4.3E-05	9.3E-03	3.6E-04
Beta[b]	0.99	1.69	9.5	1.4	4.2	1.55	0.89	0.84	2.16	2.00
Gamma[c]	0.97	1.44	9.07	0.94	2.55	1.02	0.96	0.83	1.68	1.91
NO_3 (kg/drum)	54.1	54.1	99.3	58.3	77.1	58.3	58.3	56.1	49.6	41.7

[a]Assumes a volume increase of 1.3:1 upon making concrete from the supernate.
[b]Beta is calculated from gross beta.
[c]Gamma is the total ^{137}Cs, ^{60}Co, and Eu isotopes.

3.5.3 Solidification of Supernate to a Fused Nitrate Salt Cake or Grout

The radionuclide contents for solidified wastes from incorporation of the supernate from the MVSTs into solid LLW nitrate waste forms are shown in Table 18. The volumes were calculated by assuming a density of 2 g/cm^3 for the fused salt cake. The total volume of salt was then divided by 55 gal to determine the number of 55-gallon drums required to hold the material for disposal. Drums of this size were chosen because they were indicated as the type to be used in the Waste Handling Pilot Plant for (WHPP) packaging the RH-TRU waste for shipment to WIPP. The drums would be placed into shielded shipping casks in WHPP for transfer. In the first case, no decontamination of the supernate was assumed, and the results showed TRU components (expressed as gross alpha) slightly less than the 10-nCi/g limit for classification as NRC Class A. No gross alpha limits are given for NUS solid LLW, but if the alpha isotopes are assumed to be present as ^{239}Pu, then the amount in each drum exceeds the Class L-I and L-II limits by several orders of magnitude. Carbon-14 also exceeds the proposed NUS Class L-I by four orders of magnitude and NUS Class L-II limits by two orders of magnitude.

The second case assumes that the supernate is decontaminated by using a method that removes 99.9% of the ^{137}Cs and 99% of the ^{90}Sr. In this case, the proposed NUS Class L-II limits are exceeded only by alpha as ^{239}Pu and ^{14}C. Class L-I limits for both ^{137}Cs and ^{90}Sr require another two orders-of-magnitude decontamination. In both cases, however, the problem remaining is the alpha as ^{239}Pu and ^{14}C contamination because no easy method of decontamination exists for the very low levels of activity present. The third case shows the solidification of the solids as a cement grout with a volume increase assumed to be 150%. Decontamination of both ^{14}C and alpha is still required to meet the proposed NUS Class L-II limits.

In addition to the problem with ^{14}C removal to meet proposed NUS LLW limits, organic carbon and its reaction with nitrate at elevated temperatures have raised concerns at Hanford over the use of organic ion-exchange material for removing ^{137}Cs from LLLW solutions.[23] In order to determine whether this reaction could be a problem in the MVSTs, the ratio of organic carbon to nitrate was computed for various solidification scenarios. Investigations into the problem at Hanford[24] have resulted in findings that

- dilution with inorganic salts other than nitrate increased the explosion temperature;
- increasing the ratio of nitrate to ferrocyanide beyond stoichiometry reduces explosivity;
- nitrite reacts more explosively than nitrate; and
- water, if present, increases the difficulty of initiating a reaction.

Table 18. MVST supernates processed to sodium nitrate salt cake

Total Solids in Supernate (kg)

373,381 kg to solidify (from Table 5)
353,117 kg Na and KNO_3
(ρ = 2.23) 157,970-L (41,736-gal) volume to solidify
759 drums (55 gal) of sodium nitrate

Organic Carbon in Supernate

498.73 kg total organic carbon
0.66 kg/drum organic carbon
0.00197 = $C:NO_3$ ratio

A. Assume no removal of strontium or cesium

Constituent	Supernate (Ci)	Ci/drum (759 drums)		$\mu Ci/m^3$
C-14	6.02	0.0079		3.79E04[b,c]
Co-60	86.5	0.114		5.48E05
Sr-90	1,324	1.74[a]		8.36E06[b,c]
Cs-137,-134	12,950	17.06[a]		8.20E07[c]
Eu	33.1	0.0044		2.11E05[c]
Alpha	3.4	0.0045[a]	(9.69 nCi/g)	2.16E04[d]

B. Assume that 99% of the strontium and 99% of the cesium are removed from supernate prior to solidification as salt

Constituent	Supernate (Ci remaining)	Ci/drum (759 drums)		$\mu Ci/m^3$
C-14	6.02	0.0079		3.79E04[b,c]
Co-60	86.5	0.114		5.48E05
Sr-90	13.24	0.0174		8.36E04[c]
Cs-137,-134	129.50	0.1706		8.20E05[c]
Eu	33.1	0.0044		2.11E05[c]
Alpha	3.4	0.0045[a]	(9.69 nCi/g)	1.82E04[d]

C. Assume that 99% of the strontium and 99.9% of the cesium are removed from supernate prior to solidification as salt

Constituent	Supernate (Ci remaining)	Ci/drum (759 drums)		$\mu Ci/m^3$
C-14	6.02	0.0079		3.79E04[b,c]
Co-60	86.4	0.114		5.48E05
Sr-90	13.24	0.0175		8.36E04[c]
Cs-137,-134	12.95	0.0171		8.20E04[c]
Eu	33.1	0.0044		2.11E05[c]
Alpha	3.4	0.0045[a]	(9.69 nCi/g)	2.16E04[d]

[a]Above Type A limits for packaging according to 10 CFR 71.
[b]Above NUS Class L-II limits.
[c]Above NUS Class L-I limits.
[d]Above NUS Class L-I and L-II limits for some of the alpha-emitting isotopes.

The overall nitrate:organic carbon ratio in the MVST supernate is very much larger than stoichiometric, and the concentration of organic carbon would be increased very little by the ion-exchange removal of cesium or strontium, using potassium cobalt ferrocyanide. Thus, the chance for explosion is very low and would occur only if a concentrated portion of carbon was in contact with nitrate and was allowed to heat up to the reaction temperature. Data for the calculated organic carbon present and the calculated carbon:nitrate ratios are shown in Table 18. Any organic carbon that is present could react, and the presence of organic complexing agents could lower the temperature of explosion.[25] Additional analyses of the types of carbon present will be required to rule out the possibility of an explosion during any processing of MVST supernate that would heat the salt mixture to greater than 200°C in the presence of organic carbon.

3.5.4 Solidification of Sludge to a Fused Nitrate Salt Cake or Grout

The sludge present in the MVSTs could be solidified in a fused nitrate salt cake after it has been removed from the tanks. Speculated solidifications are shown in Table 19. The insoluble solids, as estimated from the tank analyses for minimum, maximum, and estimated insoluble masses, were assumed to be incorporated in the following types of matrixes:

- the solids obtained by drying the sludge, including the interstitial nitrates present, without additional cesium and strontium removed from the supernate;
- the solids obtained by drying the sludge, including all the interstitial nitrates present, plus incorporation of ^{134}Cs, ^{137}Cs, and ^{90}Sr removed by ion exchange from the supernate;
- the minimum calculated insoluble components, plus an equal mass of sodium nitrate, plus the ^{134}Cs, ^{137}Cs, and ^{90}Sr removed by ion exchange from the supernate;
- the minimum insoluble components, plus two times the insoluble mass of sodium nitrate, plus the ^{134}Cs, ^{137}Cs, and ^{90}Sr removed by ion exchange from the supernate;
- the maximum calculated insoluble components, plus an equal mass of sodium nitrate, plus the ^{134}Cs, ^{137}Cs, and ^{90}Sr removed by ion exchange from the supernate;
- the maximum insoluble components, plus two times the insoluble mass of sodium nitrate, plus the ^{134}Cs, ^{137}Cs, and ^{90}Sr removed by ion exchange from the supernate;
- the estimated insoluble components, plus an equal mass of sodium nitrate, plus the ^{134}Cs, ^{137}Cs, and ^{90}Sr removed by ion exchange from the supernate;
- the estimated insoluble components, plus two times the insoluble mass of sodium nitrate, plus the ^{134}Cs, ^{137}Cs, and ^{90}Sr removed by ion exchange from the supernate; and
- the estimated and maximum mass of insoluble components, plus the ^{134}Cs, ^{137}Cs, and ^{90}Sr removed by ion exchange from the supernate, in 150% volume of cement grout.

Table 19. MVST sludges processed to sodium nitrate salt cake or cement grout

TOTAL SOLIDS IN SLUDGE, kg (from Table 5)

Total sludge	441,849 kg
Total $NaNO_3$ and KNO_3 in sludge	116,222 kg
Volume of sludge at ρ = 1.4	315.61 m^3 (83,384 gal = 1516 drums)
Mass of insolubles (avg. estimate)	79,266 kg = 191 drums at ρ = 2.0
(Low estimate)	58,928 kg = 142 drums at ρ = 2.0
(High estimate)	87,983 kg = 212 drums at ρ = 2.0

A. Radioactivity content in the sludge if it was placed "as is" in drums

Constituent	Sludge (Ci)	Supernate (Ci)	Total (Ci)	Sludge (Ci/drum)	Total (Ci/drum[a]) (1516 drums)	
C-14	3.3	6.0	3.3	0.0022	0.0022	(Class A limit = 0.167)
Co-60	572	87	659	0.38	0.43	(Class A limit = 145)
Sr-90	15,183	1,324 from IX	16,507	10.0	10.9	(Class A limit = 0.0083) (Class B limit = 31.2)
Cs	3,959	12,950 from IX	16,909	2.61	11.2	(Class A limit = 0.208) (Class B limit = 9.15)
Eu	4,129	33	4,163	2.72	2.75	(no Class A limit)
Gross alpha	645	3.4	649	0.425	0.43 (1469 nCi/g)	(Limit = 0.001)

B. Radioactivity content of dry sludge insolubles solidified with $NaNO_3$

Estimated insolubles		Nitrate added (kg)	Volume solidified (55-gal drums)	Ci/55-gal drum[a] ^{14}C	^{60}Co	^{90}Sr	Cs	Eu	Gross alpha	(nCi/g)
58,928 kg (low)	1:1	58,928	284	0.0116	2.32	58.1	59.5	14.7	2.29	(5500)
Nitrate	X2	117,856	425	0.0078	1.55	38.8	39.8	9.8	1.53	(3675)
79,266 kg (avg.)	1:1	79,266	381	0.0087	1.73	43.3	44.4	10.9	1.70	(4083)
Nitrate	X2	158,532	572	0.0058	1.15	28.9	29.6	7.3	1.13	(2714)
87,983 kg (high)	1:1	87,983	423	0.0078	1.56	39.0	40.0	9.8	1.53	(3675)
Nitrate	X2	175,966	634	0.0052	1.04	26.0	26.7	6.6	1.02	(2450)

C. Radioactivity content of dry sludge insolubles solidified with cement grout

Estimated insolubles	Volume increase of 50% grout added	Solids volume (55-gal drums)	Ci/55-gal drum[a] ^{14}C	^{60}Co	^{90}Sr	Cs	Eu	Gross alpha	(nCi/g)
58,928 kg (low)	14,732 L	213	0.0155	3.09	77.5	79.4	19.5	3.05	(7326)
79,266 kg (avg.)	19,817 L	286	0.0115	2.30	57.7	59.1	14.6	2.27	(5452)
87,983 kg (high)	21,996 L	317	0.0104	2.08	52.1	53.3	13.1	2.05	(4924)

[a]Values for ^{137}Cs and alpha exceed Class A and B requirements from 10 CFR 71 for all formulations. Values for ^{90}Sr exceed Class A requirements for all and Class B requirements for most formulations.

The isotopic contributions to each 55-gal drum of LLW for ^{90}Sr, ^{137}Cs, ^{14}C, ^{60}Co, Eu isotopes, and gross alpha are given for each case. The organic carbon:nitrate ratio was also calculated for each case, using nitrate salt cake, and includes organic ion exchanger added to pick up the cesium from the supernate, if that process were used, and the organic carbon from the supernate. The results are shown in Table 20. It must be pointed out that the samples of sludge reported are "point samples" from one sampling point in each tank. Therefore, they are limited in their ability to predict the composition of the sludge in the rest of the tank and, hence, do not preclude the existence of a slug of organic which could react during processing steps that concentrate the nitrate and increase the temperature of the mixture. For the solidified sludge containing the supernate cesium, about 30 to 50 Ci of ^{137}Cs and 2000 to 4700 nCi/g of gross alpha will be present in each drum. These concentrations will ensure that the drums will be RH-TRU. The guidelines for WIPP WAC require a surface dose rate <200 mrem/h for contact-handled waste.

4. SUMMARY

In this study, data are presented on the chemical species and radiochemical compositions present in the LLLW tank supernates and sludges. These data allow the calculation of the degree of decontamination required to meet various treatment/storage/disposal rules and laws. They also help determine whether liquid and solid LLW and mixed-waste acceptance criteria can be met for the various TSD facilities. Results show that ^{137}Cs, ^{90}Sr, ^{60}Co, actinides, and ^{14}C, plus RCRA metals and nitrate, must be removed from the supernate to meet wastewater release limits or treatment plant WAC. Actinides and ^{14}C must be removed to meet the proposed NUS Class L-1 and L-II solid LLW disposal limits. Solidified supernate, when treated separately from the sludge, does not meet the WIPP WAC. Solidified MVST sludge contains actinides at greater than 100 nCi/g, RCRA metals, and gamma sources that make it a mixed, RH-TRU waste.

Table 20. Organic carbon in solidified solids

Organic carbon in MVSTs

From KCoFeCN IX removal of cesium from supernate	161.8 kg
From supernate solids	498.7 kg
Total organic carbon from MVST sludge	1387.5 kg
Total organic carbon to be solidified	2048.0 kg

Ratio of organic carbon to nitrate in drums solidified in sodium nitrate salt cake from Table 19

Total sludge volume placed in drums	0.024
Low estimate with 1:1 insolubles to nitrate	0.048
Low estimate with 1:2 insolubles to nitrate	0.024
Average estimate with 1:1 insolubles to nitrate	0.035
Average estimate with 1:2 insolubles to nitrate	0.018
High estimate with 1:1 insolubles to nitrate	0.032
High estimate with 1:2 insolubles to nitrate	0.016

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APPENDIX A.

DATA FOR LLLW TANKS W-21 and W-23–W-31

Table A.1. Analytical and radiological data for LLLW tank W-21

A. Radiological Analyses

Constituent	W21-L2 Supernate (nCi/L)	(Ci)	W21 Sludge (nCi/L)	(Ci)	W21 Totals (Ci)
H-3	9.45E+03	0.57			0.57
C-14	2.70E+01	0.002	6.80E+03	0.16	0.16
Co-60	2.30E+05	13.88	3.05E+06	70.77	84.66
Sr-90	2.01E+06	121.86	2.84E+07	659.47	781.33
Nb-95	4.05E+03	0.24	1.78E+05	4.12	4.37
Zr-95	1.92E+05	11.60	1.47E+06	34.20	45.78
Ru-106	5.27E+04	3.18	1.66E+06	38.59	41.77
Cs-134	1.38E+05	8.36	2.64E+05	6.13	14.49
Cs-137	8.61E+06	521.09	9.41E+06	218.36	739.45
Ce-144	4.05E+04	2.45	1.06E+06	24.56	27.01
Eu-152	8.94E+05	54.07	4.91E+07	1,140.05	1,194.12
Eu-154	4.48E+05	27.12	1.80E+07	418.31	445.43
Eu-155	1.41E+05	8.53	5.03E+06	116.64	125.16
Gross alpha	5.78E+04	3.50	4.88E+06	113.13	116.62
Gross beta	1.35E+07	815.12	1.27E+08	2,946.59	3,761.70
U-232	1.84E+03	0.11			0.11
U-233	1.07E+04	0.65	3.07E+05	7.13	7.77
U-235			1.06E+06	24.56	24.56
Pu-239/Pu-240	1.67E+03	0.10	9.41E+05	21.84	21.94
Pu-238/Am-241	7.05E+03	0.43	1.94E+06	44.99	45.41
Cm-243			9.45E+05	21.92	21.92
Cm-244	3.11E+04	1.88	1.69E+06	39.11	40.99
Tank volume = 83,700 L	Sum Co, Cs, Eu =	633.05		1,970	2,603
Supernate volume = 60,500 L	Sum Sr, C, ^{3}H =	122.43		660	782
Supernate H_2O = 49,526 L	Sum alpha =	3.16		160	163
Sludge volume = 23,200 L	Sum alpha - ^{244}Cm =	1.29		120	122
Sludge H_2O' = 15,883 L					

B. Physical/Chemical Analyses

Constituent		W21 Supernate (mol/L)	(kg)	W21 Sludge (mol/L)	(kg)	(Elemental) W21 Totals (kg)
pH(liquid)/compaction of solids		0.56		0.66		
Density/bulk density		1.239		1.4		
Dissolved solids, mg/mL		393	23,777			30,255
Total solids, mg/mL		421	25,470	715	16,597	42,067
Total carbon, µg/mL		571	35	25,900	601	·635
Inorganic carbon, µg/mL		1	0	16,800	390	390
Organic carbon, µg/mL		571	35	9,072	210	245
Sludge solids (calculated as:)						
Carbonate			1.40	(1,949)	1,949	
Chloride		0.06	126.5	0.06	49	175
Fluoride		0.053	60.9	0.053	23	84
Nitrate		5.00	18,756.5	5.00	7,193	25,949
Phosphate		0.053	304.5	0.053	117	421
Sulfate		0.052	302.2	0.052	116	418
Aluminum	$Al(OH)_3$	1.4E-04	0.07	5.0E-02	93.9	32.6
Arsenic		5.1E-05	0.23	7.9E-04	1.3	1.6
Barium	$BaSO_4$	1.8E-04	1.51	7.9E-04	4.3	4.0
Boron		9.2E-05	0.06	8.6E-04	0.2	0.3
Cadmium	$Cd(OH)_2$	1.8E-05	0.12	3.4E-04	1.1	1.0
Calcium	$CaCO_3$	5.7E-01	1,391.50	1.57	1,461.2	2,853
Chromium	$CrCl_3$	5.2E-04	1.63	4.3E-03	15.8	6.8
Cobalt						
H^+		0.09	5.2	0.09	2	7
Iron	$Fe(OH)_3$	4.3E-03	14.52	5.8E-02	142.9	89.2
Magnesium	$Mg(OH)_2$	2.3E-01	338.80	0.55	748.1	651.0
Lead	$PbCO_3$	3.4E-05	0.43	2.0E-03	12.1	9.8
Mercury	Hg_2CO_3	4.6E-06	0.06	3.9E-04	2.4	1.9
Nickel	$NiCO_3$	2.6E-04	0.91	1.8E-03	4.9	3.3
Potassium	KNO_3	0.51	1,210.0	0.30	714	1,486
Selenium		2.9E-05	0.14	4.4E-04	0.8	0.9
Silicon	SiO_2	3.6E-05	0.06			0.1
Silver	AgCl	1.1E-05	0.07	6.5E-04	2.2	1.7
Sodium	$NaNO_3$	2.65	3,690.5	2.92	5,764	5,249
Strontium	$SrCO_3$	1.8E-03	9.68	3.2E-03	10.9	16.2
Thallium		4.6E-06	0.06	6.8E-05	0.3	0.4
Thorium	ThO_2	4.1E-04	5.75	8.3E-02	506.3	450.7
Uranium	$Na_2U_2O_7$	3.2E-03	45.37	1.8E-01	1,341.0	1,052.3
Solids, kg			26,302		13,979	39,603
Water, kg			49,526		15,883	65,409
Total, kg			74,966		32,480	107,446
Sludge insolubles, kg calculated (minimum)					4,350	
Sludge insolubles, kg calculated (maximum)					10,120	
Sludge insolubles, kg estimated (70% of high)					8,389	
Solids unaccounted for (measured - calculated, total)					2,465	
C in KCoFCN added at 300 ppm			10.99			
Total organic carbon			245.09			
Ratio TOC:NO_3 at 1.2 NO_3 to Insolubles			0.0241			

Table A.2. Analytical and radiological data for LLLW tank W-23

A. Radiological Analyses

Constituent	W23 Supernate (nCi/L)	W23 Supernate (Ci)	W23 Sludge (nCi/L)	W23 Sludge (Ci)	W23 Totals (Ci)
H-3	3.21E+03	0.05			0.05
C-14	1.71E+03	0.029	1.32E+04	0.8	0.85
Co-60	1.68E+04	0.28	9.12E+06	564.4	564.65
Sr-90	1.11E+04	0.19	8.25E+07	5,106.4	5,106.34
Nb-95	2.70E+03	0.04	2.53E+05	15.7	15.72
Zr-95	2.70E+03	0.04	1.63E+06	100.7	100.83
Ru-106	1.02E+05	1.72	2.24E+06	138.9	140.57
Cs-134	1.25E+05	2.10	2.35E+05	14.5	16.66
Cs-137	1.18E+07	197.77	1.79E+07	1,108.6	1,306.34
Ce-144	4.32E+04	0.73	9.77E+05	60.5	61.19
Eu-152	5.67E+03	0.09	2.61E+07	1,616.9	1,617.04
Eu-154	4.32E+03	0.07	1.86E+07	1,151.1	1,151.20
Eu-155	2.30E+04	0.39	4.38E+06	271.0	271.37
Gross alpha	2.21E+03	0.04	8.07E+06	499.4	499.45
Gross beta	1.25E+07	209.56	2.41E+08	14,937.7	15,147.31
U-232	1.08E+02	0.002			0.002
U-233	1.62E+02	0.003	4.27E+05	26.4	26.43
U-235			1.01E+06	62.7	62.71
Pu-239/Pu-240	1.62E+02	0.003	4.27E+05	26.4	26.43
Pu-238/Am-241	1.05E+03	0.018	1.16E+06	71.9	71.91
Cm-243			9.41E+05	58.2	58.23
Cm-244	1.08E+02	0.002	6.04E+06	374.0	374.39
Tank volume = 78,800 L	Sum Co, Cs, Eu =	200.70		4,727	4,927
Supernate volume = 16,800 L	Sum Sr, C, ^3H =	0.27		5,107	5,107
Supernate H_2O = 14,437 L	Sum alpha =	0.03		620	620
Sludge volume = 61,900 L	Sum alpha - ^{244}Cm =	0.03		246	246
Sludge H_2O = 37,824 L					

B. Physical/Chemical Analyses

Constituent		W23 Supernate (mol/L)	W23 Supernate (kg)	W23 Sludge (mol/L)	W23 Sludge (kg)	(Elemental) W23 Totals (kg)
pH(liquid)/compaction of solids		12.8		0.70		
Density/bulk density		1.242		1.34		
Dissolved solids, mg/mL		381	6,400			37,407
Total solids, mg/mL		383	6,434	729	45,122	51,557
Total carbon, µg/mL		9,500	160	29,748	1,841	2,001
Inorganic carbon, µg/mL		8,340	140	24,254	1,501	1,641
Organic carbon, µg/mL		1,160	19	5,521	342	361
Sludge solids (calculated as:)						
Hydroxide		0.15	43	0.15	158	201
Carbonate		0.70	706	2.02	(7,498)	8,204
Chloride		0.10	60	0.10	219	279
Fluoride		0.053	17	0.053	62	79
Nitrate		3.23	3,365	3.23	12,397	15,761
Phosphate		0.053	85	0.053	312	396
Sulfate		0.081	131	0.081	482	612
Aluminum	$Al(OH)_3$	6.7E-05	0.03	1.4E-01	671.4	232.3
Arsenic		4.0E-05	0.05	8.9E-04	4.1	4.2
Barium	$BaSO_4$	1.4E-06	0.003	6.1E-04	8.9	5.3
Boron		9.2E-04	0.17	1.2E-03	0.8	1.0
Cadmium	$Cd(OH)_2$	1.5E-05	0.03	3.8E-04	3.5	2.7
Calcium	$CaCO_3$	4.5E-04	0.30	1.84	11,393.7	11,393
Chromium	$CrCl_3$	8.1E-06	0.01	4.9E-03	46.0	15.8
Cobalt						
Iron	$Fe(OH)_3$	1.3E-05	0.01	4.6E-02	301.6	157.6
Lead	$PbCO_3$	1.3E-05	0.04	2.9E-03	48.1	37.4
Magnesium	$Mg(OH)_2$	1.4E-04	0.06	0.88	3,183.9	1,327.2
Mercury	Hg_2CO_3	3.5E-07	0.001	1.3E-04	2.0	1.6
Nickel	$NiCO_3$	5.1E-05	0.05	2.5E-03	18.4	9.2
Potassium	KNO_3	1.99	1,310	0.62	3,861	2,803
Selenium		2.9E-05	0.04	6.6E-04	3.2	3.3
Silicon	SiO_2	3.6E-05	0.02			0.01
Silver	AgCl	4.1E-06	0.01	3.5E-04	3.1	2.3
Sodium	$NaNO_3$	3.57	1,378	4.78	25,146	8,179
Strontium	$SrCO_3$	4.6E-06	0.01	4.4E-03	40.5	24.1
Thallium		4.6E-06	0.02	1.0E-04	1.3	1.3
Thorium	ThO_2	6.8E-05	0.26	6.9E-02	1,132.6	995.6
Uranium	$Na_2U_2O_7$	7.1E-05	0.29	4.8E-02	1,878.0	1,410.4
Solids, kg			7,114		48,091	52,501
Water, kg			14,437		37,824	52,261
Total, kg			20,871		82,946	103,817
Sludge insolubles, kg calculated (minimum)					18,742	
Sludge insolubles, kg calculated (maximum)					16,116	
Sludge insolubles, kg estimated (70% of high)					16,904	
Solids unaccounted for (measured - calculated, total)					(-944)	
C in KCoFCN added at 300 ppm			7.29			
Total organic carbon			392.			
Ratio TOC:NO_3 at 1.2 NO_3 to insolubles			0.0206			

Table A.3. Analytical and radiological data for LLLW tank W-24

A. Radiological Analyses

Constituent	W24 Supernate (nCi/L)	W24 Supernate (Ci)	W24 Sludge (nCi/L)	W24 Sludge (Ci)	W24 Totals (Ci)
H-3	8.32E+03	1.08			1.08
C-14	2.12E+04	2.75	2.87E+04	1.44	4.19
Co-60	8.88E+03	1.15	1.15E+06	57.78	58.93
Sr-90	2.47E+04	3.19	3.57E+07	1,789.62	1,792.81
Nb-95	7.56E+03	0.98	1.91E+04	0.95	1.93
Zr-95	1.35E+04	1.75	9.53E+04	4.77	6.52
Ru-106	2.97E+04	3.84	1.94E+05	9.72	13.56
Cs-134	3.62E+04	4.68	2.11E+04	1.06	5.74
Cs-137	5.97E+06	772.13	6.67E+06	334.06	1,106.19
Ce-144	2.00E+04	2.59	1.33E+05	6.65	9.23
Eu-152	8.64E+03	1.12	2.11E+06	105.67	107.79
Eu-154	1.62E+03	0.21	1.22E+06	61.36	61.57
Eu-155	1.08E+04	1.40	3.50E+05	17.56	18.95
Gross alpha	1.35E+02	0.02	7.96E+05	39.88	39.90
Gross beta	6.21E+06	803.57	8.91E+07	4,465.53	5,269.11
U-233			1.75E+04	0.88	0.88
U-235			1.26E+05	6.31	6.31
Pu-239/Pu-240			5.24E+04	2.63	2.63
Pu-238/Am-241			1.27E+05	6.37	6.37
Cm-243			1.26E+05	6.14	6.14
Cm-244			5.54E+05	27.78	27.78
Tank volume = 179,500 L	Sum Co, Cs, Eu	= 780.69		577.48	1,358.17
Supernate volume = 129,400 L	Sum Sr, C, ^{3}H	= 7.02		1,791.06	1,798.07
Supernate H_2O = 110,223 L	Sum alpha	= 0.02		50.10	50.10
Sludge volume = 50,100 L	Sum alpha − ^{244}Cm	= 0.02		22.32	22.32
Sludge H_2O = 32,384 L					

B. Physical/Chemical Analyses

Constituent		W24 Supernate (mol/L)	W24 Supernate (kg)	W24 Sludge (mol/L)	W24 Sludge (kg)	(Elemental) W24 Totals (kg)
pH(liquid)/compaction of solids		13.1		0.43		
Density/bulk density		1.235		1.26		
Dissolved solids, mg/mL		377	48,784			66,128
Total solids, mg/mL		383	49,560	614	30,742	80,303
Total carbon, µg/mL		2,400	311	12,058	604	915
Inorganic carbon, µg/mL		1,910	247	8,354	419	666
Organic carbon, µg/mL		489	63	3,704	186	249
Sludge solids (calculated as:)						
Hydroxide		0.29	638	0.29	247	885
Carbonate		0.15	1,165	0.69	(2,093)	3,257
Chloride		0.07	335	0.07	130	464
Fluoride		0.026	64	0.026	25	89
Nitrate		4.19	33,618	4.19	13,016	46,634
Phosphate		0.053	651	0.053	252	904
Sulfate		0.052	646	0.052	250	891
Aluminum	$Al(OH)_3$	1.7E-03	5.95	7.5E-02	292.0	106.9
Arsenic		4.9E-05	0.48	7.1E-04	2.6	3.1
Barium	$BaSO_4$	2.1E-06	0.04	4.0E-04	4.7	2.8
Boron		8.8E-05	0.12	3.6E-04	0.2	0.3
Cadmium	$Cd(OH)_2$	2.0E-06	0.03	6.8E-05	0.5	0.4
Calcium	$CaCO_3$	1.8E-04	0.93	2.3E+00	4,571.7	1,831.6
Chromium	$CrCl_3$	6.0E-05	0.40	8.7E-04	6.9	2.7
Cobalt		9.7E-05	0.07			0.1
Iron	$Fe(OH)_3$	4.7E-05	0.34	1.4E-02	72.5	38.2
Lead	$PbCO_3$	3.2E-05	0.87	9.1E-04	12.2	10.3
Magnesium	$Mg(OH)_2$	5.3E-05	0.17	2.9E-01	848.1	343.7
Mercury	Hg_2CO_3	2.3E-07	0.01	1.6E-04	2.1	1.6
Nickel	$NiCO_3$	6.5E-06	0.05	4.7E-04	2.8	1.4
Potassium	KNO_3	0.28	1,423	0.24	1,241	1,903
Selenium		5.9E-05	0.61	8.3E-04	3.3	3.9
Silicon	SiO_2	8.7E-03	31.70	3.6E-03	10.8	42.5
Silver	AgCl	6.4E-06	0.09	9.0E-05	0.6	0.6
Sodium	$NaNO_3$	4.35	12,940	3.78	16,103	17,295
Strontium	$SrCO_3$	8.4E-06	0.10	1.6E-03	11.7	7.0
Thallium		6.8E-06	0.18	9.9E-05	1.0	1.2
Thorium	ThO_2	9.5E-06	0.29	8.0E-03	106.3	93.7
Uranium	$Na_2U_2O_7$	3.9E-05	1.22	9.8E-03	311.1	234.8
Solids, kg			51,588		23,791	75,315
Water, kg			110,223		32,384	142,607
Total, kg			159,783		63,126	222,909
Sludge insolubles, kg calculated (minimum)					6,261	
Sludge insolubles, kg calculated (maximum)					13,398	
Sludge insolubles, kg estimated (70% of high)					11,257	
Solids unaccounted for (measured − calculated, total)					4,987	
C in KCoFCN added at 300 ppm			23.6			
Total organic carbon			267.			
Ratio TOC:NO_3 at 1.2 NO_3 to insolubles			0.0209			

Table A.4. Analytical and radiological data for LLLW tank W-25

A. Radiological Analyses

Constituent	W25 Supernate (nCi/L)	W25 Supernate (Ci)	W25 Sludge (nCi/L)	W25 Sludge (Ci)	W25 Totals (Ci)
H-3	9.32E+03	0.85			0.85
C-14	8.88E+03	0.81	6.09E+03	0.54	1.35
Co-60	5.08E+04	4.61	1.44E+06	127.26	131.87
Sr-90	5.27E+05	47.86	5.88E+07	5,210.21	5,258.07
Nb-95	1.70E+03	0.15	2.10E+04	1.86	2.02
Zr-95	3.24E+03	0.29	1.64E+05	14.52	14.82
Ru-106	5.13E+04	4.66	2.10E+05	18.63	23.29
Cs-134	1.02E+05	9.25	2.52E+04	2.23	11.48
Cs-137	8.83E+06	802.56	7.88E+06	697.85	1,500.41
Ce-144	3.51E+04	3.19	1.50E+05	13.26	16.45
Eu-152	4.32E+03	0.39	2.90E+06	257.04	257.43
Eu-154	3.24E+03	0.29	1.80E+06	159.78	160.07
Eu-155	1.86E+04	1.69	5.81E+05	51.47	53.16
Gross alpha	5.40E+01	0.005	1.66E+06	146.83	146.84
Gross beta	1.06E+07	962.09	1.43E+08	12,630.82	13,592.90
U-233			2.98E+04	2.64	2.64
U-235			1.50E+05	13.26	13.26
Pu-239/Pu-240			1.04E+05	9.25	9.25
Pu-238/Am-241			2.62E+05	23.21	23.21
Cm-243			1.39E+05	12.32	12.31
Cm-244			1.18E+06	104.84	104.84
Tank volume = 179,500 L	Sum Co, Cs, Eu	= 818.80		1,295.63	2,114.43
Supernate volume = 90,900 L	Sum Sr, C, ^{3}H	= 49.51		5,210.75	5,260.26
Supernate H_2O = 78,883 L	Sum alpha	= 0.00		165.52	165.52
Sludge volume = 88,600 L	Sum alpha - ^{244}Cm	= 0.00		60.68	60.68
Sludge H_2O = 54,850 L					

B. Physical/Chemical Analyses

Constituent		W25 Supernate (mol/L)	W25 Supernate (kg)	W25 Sludge (mol/L)	W25 Sludge (kg)	(Elemental) W25 Totals (kg)
pH(liquid)/compaction of solids		12.5		0.90		
Density/bulk density		1.202		1.32		
Dissolved solids, mg/mL		348	31,633			61,678
Total solids, mg/mL		334	30,360	701	62,102	92,462
Total carbon, µg/mL		478	43	8,250	731	774
Inorganic carbon, µg/mL		16	1	5,174	458	460
Organic carbon, µg/mL		462	42	3,076	272	314
Sludge solids (calculated as:)						
Hydroxide		0.06	93	0.06	90	183
Carbonate		0.01	55	0.43	(2,292)	2,347
Chloride		0.07	229	0.07	223	452
Fluoride		0.026	45	0.026	44	89
Nitrate		4.19	23,615	4.19	23,018	46,634
Phosphate		0.053	458	0.053	446	904
Sulfate		0.052	454	0.052	443	897
Aluminum	$Al(OH)_3$	1.6E-04	0.38	1.4E-01	947	328
Arsenic		4.9E-05	0.34	7.2E-04	4.8	5.1
Barium	$BaSO_4$	2.3E-05	0.29	5.7E-04	11.7	7.2
Boron		5.5E-05	0.06	1.8E-04	0.2	0.2
Cadmium	$Cd(OH)_2$	1.1E-06	0.01	1.3E-04	1.7	1.3
Calcium	$CaCO_3$	7.0E-03	25.45	3.13	11,098	4,470
Chromium	$CrCl_3$	3.7E-05	0.17	1.5E-03	21.0	7.1
Cobalt		9.7E-06	0.05			0.1
Iron	$Fe(OH)_3$	4.7E-05	0.24	2.2E-02	210.4	110.2
Lead	$PbCO_3$	1.0E-05	0.19	1.4E-03	33.2	25.9
Magnesium	$Mg(OH)_2$	5.3E-05	0.12	3.2E-01	1,655	690
Mercury	Hg_2CO_3	2.7E-07	0.005	2.4E-04	5.6	4.3
Nickel	$NiCO_3$	7.7E-06	0.04	7.6E-04	8.0	4.0
Potassium	KNO_3	0.43	1,545	0.31	2,782	2,621
Selenium		6.0E-05	0.43	8.5E-04	6.0	6.4
Silicon	SiO_2	3.6E-05	0.09	3.6E-02	192	90
Silver	$AgCl$	6.4E-06	0.06	9.3E-05	1.2	1.0
Sodium	$NaNO_3$	3.39	7,090	3.79	28,537	14,809
Strontium	$SrCO_3$	2.6E-04	2.09	2.3E-03	29.6	19.6
Thallium		6.8E-06	0.13	1.0E-04	1.9	2.0
Thorium	ThO_2	9.5E-06	0.20	2.2E-02	513.7	451.6
Uranium	$Na_2U_2O_7$	4.2E-07	0.01	1.3E-02	747.7	561.4
Solids, kg			33,656		47,080	76,034
Water, kg			78.883		54,850	133,733
Total, kg			109,244		116,952	226,196
Sludge insolubles, kg calculated (minimum)					15,297	
Sludge insolubles, kg calculated (maximum)					30,782	
Sludge insolubles, kg estimated (70% of high)					26,136	
Solids unaccounted for (measured - calculated, total)					16,428	
C in KCoFCN added at 300 ppm			19.98			
Total organic carbon			333.			
Ratio TOC:NO_3 at 1.2 NO_3 to insolubles			0.0180			

Table A.5. Analytical and radiological data for LLLW tank W-26

A. Radiological Analyses

Constituent	W26 Supernate (nCi/L)	W26 Supernate (Ci)	W26 Sludge (nCi/L)	W26 Sludge (Ci)	W26 Totals (Ci)
H-3	1.67E+04	1.90			1.90
C-14	3.32E+03	0.38	8.86E+03	0.51	0.88
Co-60	3.29E+05	37.52	4.28E+06	244.97	282.49
Sr-90	1.32E+04	1.51	8.44E+07	4,828.10	4,829.61
Nb-95	3.78E+03	0.43	1.08E+05	6.18	6.61
Zr-95	7.29E+03	0.83	5.41E+06	309.19	310.02
Ru-106	7.56E+04	8.61	1.04E+06	59.46	68.07
Cs-134	3.54E+05	40.28	1.23E+05	7.06	47.35
Cs-137	5.60E+07	6,365.87	2.84E+07	1,626.81	7,992.68
Ce-144	6.21E+04	7.07	4.99E+05	28.54	35.61
Eu-152	5.67E+03	0.65	2.05E+07	1,170.16	1,170.81
Eu-154	6.48E+03	0.74	1.33E+07	758.70	759.44
Eu-155	3.24E+04	3.69	3.12E+06	178.62	182.31
Gross alpha	2.78E+04	3.17	3.80E+06	217.15	220.31
Gross beta	5.94E+07	6,765.66	2.37E+08	13,556.74	20,322.40
U-232	9.72E+02	0.11			0.11
U-233	2.48E+04	2.83	2.77E+05	15.84	18.67
U-235			4.99E+05	28.54	28.54
U-238	2.70E+02	0.03			0.03
Pu-239/Pu-240	2.70E+02	0.03	2.12E+05	12.15	12.18
Pu-238/Am-241	4.05E+02	0.05	6.15E+05	35.20	35.25
Cm-243			5.40E+05	30.92	30.92
Cm-244			2.55E+06	146.03	146.03
Tank volume = 171,200 L	Sum Co, Cs, Eu =	6,448.75		3,986.32	10,435.08
Supernate volume = 113,900 L	Sum Sr, C, ^3H =	3.79		4,828.61	4,832.40
Supernate H_2O = 97,009 L	Sum alpha =	3.08		268.69	271.76
Sludge volume = 57,200 L	Sum alpha - ^{244}Cm =	3.08		122.65	125.73
Sludge H_2O = 48,536 L					

B. Physical/Chemical Analyses

Constituent		W26 Supernate (mol/L)	W26 Supernate (kg)	W26 Sludge (mol/L)	W26 Sludge (kg)	(Elemental) W26 Totals (kg)
pH(liquid)/compaction of solids		11.2		0.704		
Density/bulk density		1.218		1.54		
Dissolved solids, mg/mL		369	42,029			61,713
Total solids, mg/mL		366	41,687	691	39,552	81,239
Total carbon, µg/mL		3,861	440	28,028	1,603	2,043
Inorganic carbon, µg/mL		2,580	294	18,480	1,057	1,351
Organic carbon, µg/mL		1,280	145	9,579	548	694
Sludge solids (calculated as:)						
Hydroxide		0.01	19	0.01	10	29
Carbonate		0.20	1,367	1.54	(5,285)	6,652
Chloride		0.10	400	0.10	201	601
Fluoride		0.026	56	0.026	28	85
Nitrate		3.29	23,235	3.29	11,669	34,904
Phosphate		0.053	573	0.053	288	861
Sulfate		0.052	569	0.052	286	855
Aluminum	$Al(OH)_3$	1.8E-04	0.55	4.3E-01	1,910.0	661.2
Arsenic		4.9E-05	0.42	1.3E-03	5.7	6.1
Barium	$BaSO_4$	1.5E-06	0.02	9.8E-04	13.0	7.7
Boron		3.6E-04	0.44	1.0E-03	0.6	1.1
Cadmium	$Cd(OH)_2$	4.0E-05	0.51	5.7E-04	4.8	4.2
Calcium	$CaCO_3$	5.0E-04	2.28	3.45	7,919	3,173
Chromium	$CrCl_3$	3.5E-05	0.20	5.0E-03	45.6	15.2
Cobalt		9.7E-06	0.06			0.1
Iron	$Fe(OH)_3$	4.7E-05	0.30	6.3E-02	387.7	202.9
Lead	$PbCO_3$	1.5E-05	0.36	3.5E-03	53.4	41.8
Magnesium	$Mg(OH)_2$	1.4E-04	0.40	7.0E-01	2,325	969.4
Mercury	Hg_2CO_3	4.0E-07	0.01	4.9E-04	7.3	5.6
Nickel	$NiCO_3$	1.4E-04	0.93	2.4E-03	16.4	9.0
Potassium	KNO_3	1.30	5,809	0.59	3,417	7,130
Selenium		6.0E-05	0.54	1.1E-03	4.8	5.4
Silicon	SiO_2	4.2E-04	1.36	3.6E-02	124	125.1
Silver	AgCl	1.1E-05	0.14	4.3E-04	3.5	2.8
Sodium	$NaNO_3$	2.96	7,745	3.42	16,609	12,238
Strontium	$SrCO_3$	8.4E-06	0.08	2.1E-03	17.8	10.7
Thallium		6.8E-06	0.16	1.3E-04	1.5	1.6
Thorium	ThO_2	4.3E-05	1.14	6.2E-02	938.2	826.6
Uranium	$Na_2U_2O_7$	4.7E-03	128.70	7.8E-02	2,827.4	2,251.6
Solids, kg			40,058		37,179	72,368
Water, kg			97,009		48,536	145,545
Total, kg			138,696		88,088	226,784
Sludge insolubles, kg calculated (minimum)					16,482	
Sludge insolubles, kg calculated (maximum)					19,526	
Sludge insolubles, kg estimated (70% of high)					18,613	
Solids unaccounted For (measured - calculated, total)					8,871	
C in KCoFCN added at 300 ppm			21.37			
Total organic carbon			648			
Ratio TOC:NO_3 at 1.2 NO_3 to insolubles			0.0331			

Table A.6. Analytical and radiological data for LLLW tank W-27

A. Radiological Analyses

Constituent	W27 Supernate (nCi/L)	W27 Supernate (Ci)	W27 Sludge (nCi/L)	W27 Sludge (Ci)	W27 Totals (Ci)
H-3	5.64E+03	0.62			0.62
C-14	4.90E+03	0.54	6.43E+03	0.43	0.97
Co-60	8.34E+03	0.92	5.48E+05	36.75	37.67
Sr-90	1.50E+06	166.18	1.55E+07	1,038.65	1,204.83
Nb-95	8.10E+02	0.09	2.48E+04	1.67	1.76
Zr-95	1.40E+03	0.16	5.78E+04	3.88	4.04
Ru-106	2.97E+04	3.28	3.74E+05	25.11	28.39
Cs-134	4.35E+04	4.80	4.08E+04	2.74	7.54
Cs-137	5.83E+06	644.44	1.28E+07	856.03	1,500.46
Ce-144	2.03E+04	2.24	1.91E+05	12.78	15.02
Eu-152	2.97E+03	0.33	6.77E+05	45.43	45.76
Eu-154	1.78E+03	0.20	4.29E+05	28.76	28.96
Eu-155	1.08E+04	1.19	1.16E+05	7.76	8.96
Gross alpha	2.70E+01	0.003	7.65E+05	51.36	51.36
Gross beta	8.91E+06	984.56	4.90E+07	3,287.15	4,271.70
U-233			1.76E+04	1.18	1.18
U-235			1.97E+05	13.24	13.24
Pu-239/Pu-240			3.54E+04	2.37	2.37
Pu-238/Am-241			1.50E+05	10.07	10.07
Cm-243			2.21E+05	14.84	14.84
Cm-244			5.44E+05	36.52	36.52
Tank volume = 177,600 L	Sum Co,Cs,Eu =	651.88		977.47	1,629.35
Supernate volume = 110,500 L	Sum Sr,C,^{3}H =	167.34		1,039.08	1,206.42
Supernate H_2O = 94,676 L	Sum alpha =	0.003		78.22	78.22
Sludge volume = 67,100 L	Sum alpha - ^{244}Cm =	0.003		41.70	41.70
Sludge H_2O = 51,911 L					

B. Physical/Chemical Analyses

Constituent		W27 Supernate (mol/L)	W27 Supernate (kg)	W27 Sludge (mol/L)	W27 Sludge (kg)	(Elemental) W27 Totals (kg)
pH(liquid)/compaction of solids		11.8		0.96		
Density/bulk density		1.212		1.26		
Dissolved solids, mg/mL		358	39,559			63,086
Total solids, mg/mL		355	39,228	486	32,635	71,862
Total carbon, µg/mL		364	40	9,689	650	690
Inorganic carbon, µg/mL		5	1	6,615	443	444
Organic carbon, µg/mL		359	40	3,074	206	246
Sludge solids (calculated as:)						
Hydroxide		0.01	19	0.01	11	30
Carbonate		0.01	66	0.55	(2,219)	2,286
Chloride		0.07	278	0.07	169	447
Fluoride		0.026	55	0.026	33	88
Nitrate		4.52	30,969	4.52	18,806	49,775
Phosphate		0.053	556	0.053	338	894
Sulfate		0.052	552	0.052	335	887
Aluminum	$Al(OH)_3$	1.6E-04	0.46	2.0E-01	1,051.0	364.0
Arsenic	-	4.9E-05	0.41	6.6E-04	3.3	3.7
Barium	$BaSO_4$	3.0E-05	0.45	4.5E-04	7.0	4.6
Boron		6.2E-05	0.07	7.4E-04	0.5	0.6
Cadmium	$Cd(OH)_2$	1.1E-06	0.01	1.5E-04	1.4	1.1
Calcium	$CaCO_3$	6.5E-02	287.30	2.98	8,023	3,500.0
Chromium	$CrCl_3$	5.4E-05	0.31	1.6E-03	16.7	5.8
Cobalt		9.7E-06	0.06			0.1
Iron	$Fe(OH)_3$	4.7E-05	0.29	3.2E-02	226.5	118.7
Lead	$PbCO_3$	1.0E-05	0.23	7.3E-04	13.1	10.4
Magnesium	$Mg(OH)_2$	5.3E-05	0.14	2.5E-01	973.6	406.0
Mercury	Hg_2CO_3	2.4E-07	0.01	6.9E-05	1.2	0.9
Nickel	$NiCO_3$	6.5E-06	0.04	5.8E-04	4.6	2.3
Potassium	KNO_3	0.22	939	0.20	1,334	1,455
Selenium		6.0E-05	0.52	7.8E-04	4.1	4.7
Silicon	SiO_2	3.6E-05	0.11	3.6E-03	14.5	14.6
Silver	AgCl	6.4E-06	0.08	8.4E-05	0.8	0.7
Sodium	$NaNO_3$	3.92	9,945	3.89	22,193	15,947
Strontium	$SrCO_3$	2.1E-04	1.99	1.7E-03	17.1	12.1
Thallium		6.8E-06	0.15	1.2E-04	1.7	1.8
Thorium	ThO_2	9.5E-06	0.24	1.0E-02	181.8	160.0
Uranium	$Na_2U_2O_7$	4.2E-07	0.01	7.2E-03	305.2	229.1
Solids, kg			43,711		34,580	76,896
Water, kg			94,676		51,911	146,587
Total, kg			133,903		84,546	218,450
Sludge insolubles, kg calculated (minimum)					10,833	
Sludge insolubles, kg calculated (maximum)					9,109	
Sludge insolubles, kg estimated (70% of high)					9,625	
Solids unaccounted for (measured - calculated, total)					(-5,034)	
C in KCoFCN added at 300 ppm			21.48			
Total organic carbon			266.			
Ratio TOC:NO_3 at 1.2 NO_3 to insolubles			0.0239			

Table A.7. Analytical and radiological data for LLLW tank W-28

A. Radiological Analyses

Constituent	W28 Supernate (nCi/L)	W28 Supernate (Ci)	W28 Sludge (nCi/L)	W28 Sludge (Ci)	W28 Totals (Ci)
H-3	3.21E+03	0.53			0.53
C-14	4.51E+03	0.74	3.06E+03	0.07	0.82
Co-60	2.35E+05	38.87	3.18E+06	77.33	116.20
Sr-90	4.73E+06	780.10	2.24E+07	544.52	1,324.62
Nb-95	3.24E+03	0.54	1.17E+05	2.84	3.37
Zr-95	5.94E+03	0.98	9.66E+05	23.46	24.44
Ru-106	8.15E+04	13.46	1.13E+06	27.37	40.84
Cs-134	2.86E+05	47.25	1.85E+05	4.50	51.75
Cs-137	1.53E+07	2,523.06	7.80E+06	189.65	2,712.71
Ce-144	4.86E+04	8.02	6.84E+05	16.62	24.64
Eu-152	4.51E+04	7.44	2.89E+07	701.91	709.35
Eu-154	1.99E+04	3.28	1.29E+07	312.83	316.11
Eu-155	2.51E+04	4.15	3.90E+06	94.83	98.97
Gross alpha	1.19E+03	0.20	2.17E+06	52.69	52.88
Gross beta	2.65E+07	4,368.55	9.66E+07	2,346.21	6,714.76
U-232			5.87E+04	1.43	1.43
U-233			1.43E+05	3.48	3.48
U-235			6.84E+05	16.62	16.62
Pu-239/Pu-240			6.08E+04	1.48	1.48
Pu-238/Am-241			2.12E+05	5.16	5.16
Cm-243			5.63E+05	13.69	13.69
Cm-244			1.54E+06	37.44	37.44
Tank volume = 179,500 L	Sum Co, Cs, Eu =	2,624.06		1,381.04	4,005.10
Supernate volume = 165,100 L	Sum Sr, C, ^{3}H =	781.37		544.59	1,325.96
Supernate H_2O = 133,270 L	Sum alpha =	0.20		79.29	79.29
Sludge volume = 14,400 L	Sum alpha - ^{244}Cm =	0.20		41.85	41.85
Sludge H_2O = 10,020 L					

B. Physical/Chemical Analyses

Constituent		W28 Supernate (mol/L)	W28 Supernate (kg)	W28 Sludge (mol/L)	W28 Sludge (kg)	(Elemental) W28 Totals (kg)
pH(liquid)/compaction of solids		9.1		0.64		
Density/bulk density		1.285		1.49		
Dissolved Solids, mg/mL		485	80,074			84,762
Total solids, mg/mL		478	78,918	794	11,436	90,354
Total carbon, µg/mL		581	96	9,119	131	227
Inorganic carbon, µg/mL		7	1	5,394	78	79
Organic carbon, µg/mL		574	95	3,725	53	148
Sludge solids (calculated as:)						
Hydroxide		0.01	28	0.01	2	31
Carbonate		0.01	99	0.45	(388)	487
Chloride		0.14	819	0.14	71	891
Fluoride		0.026	82	0.026	7	89
Nitrate		5.97	61,115	5.97	5,330	66,445
Phosphate		0.053	831	0.053	72	903
Sulfate		0.052	825	0.052	72	897
Aluminum	$Al(OH)_3$	1.9E-04	0.86	4.6E-01	51.5	18.7
Arsenic		4.9E-05	0.61	5.4E-04	0.6	1.2
Barium	$BaSO_4$	4.2E-05	0.96	4.2E-04	1.4	1.8
Boron		3.2E-05	0.06	6.8E-04	0.1	0.2
Cadmium	$Cd(OH)_2$	4.5E-06	0.08	3.4E-04	0.7	0.6
Calcium	$CaCO_3$	1.9E-01	1,287.78	5.29	3,054.4	2,510.8
Chromium	$CrCl_3$	7.3E-06	0.06	1.6E-03	3.6	1.2
Cobalt		9.7E-06	0.09			0.1
Iron	$Fe(OH)_3$	4.7E-05	0.43	1.7E-02	25.9	13.9
Lead	$PbCO_3$	1.0E-05	0.35	1.4E-03	5.2	4.4
Magnesium	$Mg(OH)_2$	6.6E-02	264.16	9.2E-01	772.1	586.0
Mercury	Hg_2CO_3	7.0E-07	0.02	8.9E-05	0.3	0.3
Nickel	$NiCO_3$	2.4E-05	0.23	1.6E-03	2.7	1.6
Potassium	KNO_3	0.66	4,293	0.42	610	4,529
Selenium		6.0E-05	0.78	5.5E-04	0.6	1.4
Silicon	SiO_2	3.6E-05	0.17	3.6E-03	3.1	3.3
Silver	AgCl	6.4E-06	0.11	2.4E-04	0.5	0.5
Sodium	$NaNO_3$	4.18	15,850	4.28	5,235	17,265
Strontium	$SrCO_3$	7.4E-04	10.73	2.2E-03	4.7	13.5
Thallium		6.8E-06	0.23	6.6E-05	0.2	0.4
Thorium	ThO_2	9.5E-06	0.36	8.8E-03	33.4	29.8
Uranium	$Na_2U_2O_7$	4.2E-07	0.02	5.3E-02	485.8	364.8
Solids, kg			85,604		10,346	95,240
Water, kg			133,270		10,020	143,290
Total, kg			212,583		21,456	233,643
Sludge insolubles, kg calculated (minimum)					4,444	
Sludge insolubles, kg calculated (maximum)					5,590	
Sludge insolubles, kg estimated (70% of high)					5,246	
Solids unaccounted for (measured - calculated, total)					(-4,886)	
C in KCoFCN added at 300 ppm			27.76			
Total organic carbon			179.			
Ratio TOC:NO_3 at 1.2 NO_3 to insolubles			0.0292			

Table A.8. Analytical and radiological data for LLLW tank W-29

A. Radiological Analyses

Constituent	W29 Supernate (nCi/L)	W29 Supernate (Ci)	W29 Sludge (see ref. 3) (nCi/L)	W29 Sludge (see ref. 3) (Ci)	W29 Totals (Ci)
H-3	5.43E+03	0.39			0.39
C-14	2.45E+03	0.18			0.18
Co-60	1.68E+04	1.22	1.57E+06	21.48	22.69
Sr-90	1.91E+05	13.86	1.67E+07	227.71	241.56
Nb-95	1.70E+03	0.12			0.12
Zr-95	2.73E+03	0.20			0.20
Ru-106	5.49E+04	3.98			3.98
Cs-134	6.68E+04	4.97			4.97
Cs-137	5.91E+06	428.59	2.24E+06	30.55	459.14
Ce-144	3.59E+04	2.60			2.60
Eu-152	5.67E+03	0.41	6.24E+06	84.97	85.38
Eu-154	3.89E+03	0.28	3.86E+06	52.76	52.86
Eu-155	1.94E+04	1.40	1.17E+06	15.92	17.32
Gross alpha	2.70E+02	0.02	8.15E+06	111.08	111.10
Gross beta	5.56E+06	403.15	5.84E+07	796.05	1,199.20
U-233			1.01E+05	1.37	1.37
Pu-239/Pu-240			2.99E+05	4.07	4.07
Pu-238/Am-241			1.17E+06	15.92	15.92
Cm-244			4.89E+06	66.65	66.65
Tank volume = 86,109 L	Sum Co, Cs, Eu =	436.88		205.49	642.37
Supernate volume = 72,483 L	Sum Sr, C, ^3H =	14.43		227.71	242.13
Supernate H_2O = 58,437 L	Sum alpha =	0.02		88.01	88.01
Sludge volume = 13,626 L	Sum alpha - ^{244}Cm =	0.02		21.36	21.36
Sludge H_2O = 9,780 L					

B. Physical/Chemical Analyses

Constituent		W29 Supernate (mol/L)	W29 Supernate (kg)	W29 Sludge (mol/L)	W29 Sludge (kg)	(Elemental) W29 Totals (kg)
pH(liquid)/compaction of solids		13.0		0.70		
Density/bulk density		1.226		1.36		
Dissolved solids, mg/mL		375	27,181			32,333
Total solids, mg/mL		379	27,471	582	7,931	35,402
Total carbon, µg/mL		953	69	13,015	177	257
Inorganic carbon, µg/mL		470	34	9,017	123	157
Organic carbon, µg/mL		482	35	2,638	54	89
Sludge solids (calculated as:)						
Hydroxide		0.07	85	0.07	16	101
Carbonate		0.05	200	0.64	(523)	723
Chloride		0.08	210	0.08	40	250
Fluoride		0.026	36	0.026	7	42
Nitrate		4.52	20,314	4.52	3,819	24,133
Phosphate		0.053	365	0.053	69	433
Sulfate		0.052	362	0.052	68	430
Aluminum	$Al(OH)_3$	6.7E-04	1.30	2.1E-01	227.5	80.0
Arsenic		4.9E-05	0.27	7.6E-04	0.8	1.0
Barium	$BaSO_4$	7.3E-06	0.07	4.4E-04	1.4	0.9
Boron		4.1E-05	0.03	3.9E-04	0.1	0.09
Cadmium	$Cd(OH)_2$	1.1E-06	0.01	7.4E-05	0.1	0.1
Calcium	$CaCO_3$	1.1E-04	0.32	2.87	1,568	628
Chromium	$CrCl_3$	4.6E-05	0.17	9.4E-04	2.0	0.8
Cobalt						
Iron	$Fe(OH)_3$	4.7E-05	0.19	3.5E-02	50.5	26.6
Lead	$PbCO_3$	1.1E-05	0.16	9.8E-04	3.6	2.9
Magnesium	$Mg(OH)_2$	5.3E-05	0.09	3.3E-01	262.3	109.4
Mercury	Hg_2CO_3	4.5E-07	0.01	1.8E-04	0.6	0.4
Nickel	$NiCO_3$	6.5E-06	0.03	5.1E-04	0.8	0.4
Potassium	KNO_3	0.26	725	0.31	427	890
Selenium		6.0E-05	0.34	9.0E-04	1.0	1.3
Silicon	SiO_2	3.6E-05	0.07	3.6E-03	11.8	11.8
Silver	$AgCl$	6.4E-06	0.05	9.7E-05	0.2	0.2
Sodium	$NaNO_3$	4.78	7,973	3.83	4,435	9,173
Strontium	$SrCO_3$	2.2E-05	0.14	1.8E-03	3.7	2.3
Thallium		6.8E-06	0.10	1.1E-04	0.3	0.4
Thorium	ThO_2	4.3E-06	0.07	2.1E-02	75.5	66.5
Uranium	$Na_2U_2O_7$	1.8E-05	0.32	1.9E-02	168.5	126.8
Solids, kg			30,310		7,296	37,326
Water, kg			58,437		9,780	68,217
Total, kg			88,869		18,531	107,400
Sludge insolubles, kg calculated (minimum)					2,367	
Sludge insolubles, kg calculated (maximum)					3,068	
Sludge insolubles, kg estimated (70% of high)					2,858	
Solids unaccounted for (measured - calculated, total)					(-1,924)	
C in KCoFCN added at 300 ppm			11.03			
Total organic carbon			48.78			
Ratio TOC:NO_3 at 1.2 NO_3 to insolubles			0.0125			

Table A.9. Analytical and radiological data for LLLW tank W-30

A. Radiological Analyses

Constituent	W30 Supernate (nCi/L)	W30 Supernate (Ci)	W30 Sludge (see ref. 3) (nCi/L)	W30 Sludge (see ref. 3) (Ci)	W30 Totals (Ci)
H-3	5.45E+03	0.38			0.38
C-14	2.38E+03	0.16			0.16
Co-60	1.32E+04	0.92			0.92
Sr-90	1.81E+05	12.56	2.72E+07	370.26	382.82
Nb-95	1.49E+03	0.10			0.10
Zr-95	2.67E+03	0.19			0.19
Ru-106	5.13E+04	3.55			3.55
Cs-134	5.43E+04	3.76			3.74
Cs-137	5.08E+06	351.40	6.52E+05	8.89	360.29
Ce-144	3.32E+04	2.30			2.30
Eu-152	5.40E+03	0.37			0.37
Eu-154	3.24E+03	0.22			0.22
Eu-155	1.79E+04	1.24	2.72E+04	0.37	1.61
Gross alpha	2.70E+02	0.02	5.17E+05	7.04	7.06
Gross beta	5.24E+06	362.62	7.23E+07	984.88	1,347.50
U-233			1.63E+04	0.22	.0.22
Pu-239/Pu-240			2.18E+05	2.97	2.97
Pu-238/Am-241			1.36E+05	1.85	1.85
Cm-244			1.36E+05	1.85	1.85
Tank volume = 82,854 L	Sum Co, Cs, Eu =	357.91		9.26	367.17
Supernate volume = 69,228 L	Sum Sr, C, ^{3}H =	13.10		370.26	383.36
Supernate H_2O = 57,791 L	Sum alpha =	0.01		6.89	6.89
Sludge volume = 13,626 L	Sum alpha - ^{244}Cm =	0.01		5.04	5.04
Sludge H_2O = 10,021 L					

B. Physical/Chemical Analyses

Constituent		W30 Supernate (mol/L)	W30 Supernate (kg)	W30 Sludge (mol/L)	W30 Sludge (kg)	(Elemental) W30 Totals (kg)
pH(liquid)/compaction of solids		13.3		0.70		
Density/bulk density		1.222		1.36		
Dissolved solids, mg/mL		373	25,822			30,684
Total solids, mg/mL		387	26,791	459.17	8,509.6	35,301
Total carbon, μg/mL		766	53	13,015.2	177.3	230
Inorganic carbon, μg/mL		599	41	9,016.8	122.9	164
Organic carbon, μg/mL		167	12	3,998.4	54.5	66
Sludge solids (calculated as:)						
Hydroxide		0.13	153	0.13	30.1	183
Carbonate		0.053	220	0.64	(523)	744
Chloride		0.08	194	0.08	38.2	232
Fluoride		0.026	34	0.026	6.7	41
Nitrate		4.35	18,672	4.35	3,675.2	22,347
Phosphate		0.053	348	0.053	68.6	417
Sulfate		0.052	346	0.052	68.1	414
Aluminum	$Al(OH)_3$	1.3E-03	2.35	0.21	227.5	81.0
Arsenic		4.9E-05	0.26	0.001	0.8	1
Barium	$BaSO_4$	5.9E-06	0.06	4.4E-04	1.4	0.9
Boron		4.1E-05	0.03	0.003	0.5	0.5
Cadmium	$Cd(OH)_2$	1.1E-06	0.01	7.4E-05	0.1	0.1
Calcium	$CaCO_3$	2.5E-04	0.69	1.15	1,568.4	628.7
Chromium	$CrCl_3$	5.8E-05	0.21	2.9E-03	2.0	0.9
Cobalt						
Iron	$Fe(OH)_3$	4.7E-05	0.18	0.03	50.5	26.6
Lead	$PbCO_3$	1.3E-05	0.19	9.9E-04	3.6	3.0
Magnesium	$Mg(OH)_2$	5.3E-05	0.09	0.33	262.3	109.4
Mercury	Hg_2CO_3	5.0E-07	0.01	1.8E-04	0.6	0.5
Nickel	$NiCO_3$	6.5E-06	0.03	5.1E-04	0.8	0.4
Potassium	KNO_3	0.24	644	0.31	427	809
Selenium		6.0E-05	0.33	9.0E-04	1.0	1.3
Silicon	SiO_2	3.6E-05	0.07	0.01	11.77	11.8
Silver	AgCl	6.4E-06	0.05	1.3E-04	0.2	0.19
Sodium	$NaNO_3$	4.48	7,130	3.83	4436	8,330
Strontium	$SrCO_3$	2.1E-05	0.12	0.0018	3.7	2.3
Thallium		6.8E-06	0.10	1.1E-04	0.3	0.4
Thorium	ThO_2	4.3E-06	0.07	0.02	75.6	66.5
Uranium	$Na_2U_2O_7$	2.4E-05	0.40	0.02	168.5	126.9
Solids, kg			27,759		7,297	34,646
Water, kg			57,791		10,021	67,813
Total, kg			84,583		18,531	103,114
Sludge insolubles, kg calculated (minimum)					2,368	
Sludge insolubles, kg calculated (maximum)					3,646	
Sludge insolubles, kg estimated (70% of high)					3,263	
Solids unaccounted for (measured - calculated, total)					655	
C in KCoFCN added at 300 ppm			11.51			
Total organic carbon			23.28			
Ratio TOC:NO_3 at 1.2 NO_3 to insolubles			0.0059			

Table A.10. Analytical and radiological data for LLLW tank W-31

A. Radiological Analyses

Constituent	W31 Supernate (nCi/L)	W31 Supernate (Ci)	W31 Sludge (nCi/L)	W31 Sludge (Ci)	W31 Totals (Ci)
H-3	4.21E+03	0.63			0.63
C-14	3.02E+03	0.45	1.07E+04	0.26	0.71
Co-60	8.72E+03	1.31	2.76E+05	6.70	8.00
Sr-90	1.99E+06	298.69	4.83E+07	1,173.89	1,472.58
Nb-95	8.91E+02	0.13	3.13E+04	0.76	0.89
Zr-95	1.54E+03	0.23	1.60E+05	3.89	4.12
Ru-106	2.97E+04	4.45	4.76E+05	11.57	16.03
Cs-134	1.35E+05	20.28	1.24E+05	3.01	23.29
Cs-137	6.18E+06	926.83	7.99E+06	194.27	1,121.10
Ce-144	2.11E+04	3.16	3.20E+05	7.77	10.93
Eu-152	2.51E+03	0.38	5.78E+05	14.05	14.43
Eu-154	1.81E+03	0.27	1.99E+05	4.84	5.12
Eu-155	1.13E+04	1.70	2.01E+05	4.88	6.58
Gross alpha	2.70E+01	0.004	7.86E+05	19.10	19.10
Gross beta	9.67E+06	1,448.93	1.08E+08	2,628.86	4,077.80
U-232			4.97E+04	1.21	1.21
U-233			1.73E+04	0.42	0.42
U-235			3.30E+05	8.02	8.02
Pu-239/Pu-240			2.99E+04	0.73	0.73
Pu-238/Am-241			8.27E+04	2.01	2.01
Cm-243			2.86E+05	6.94	6.94
Cm-244			5.82E+05	14.14	14.14
Tank volume = 174,200 L	Sum Co, Cs, Eu	= 950.76		227.75	1,178.52
Supernate volume = 149,900 L	Sum Sr, C, ^3H	= 299.78		1,174.15	1,473.93
Supernate H_2O = 128,689 L	Sum alpha	= 0.004		33.46	33.46
Sludge volume = 24,300 L	Sum alpha - ^{244}Cm	= 0.004		19.32	19.32
Sludge H_2O = 19,319 L					

B. Physical/Chemical Analyses

Constituent		W31 Supernate (mol/L)	W31 Supernate (kg)	W31 Sludge (mol/L)	W31 Sludge (kg)	(Elemental) W31 Totals (kg)
pH(liquid)/compaction of solids		11.7		0.20		
Density/bulk density		1.208		1.26		
Dissolved solids, mg/mL		351	52,615			61,051
Total solids, mg/mL		349	52,315	465	11,298	63,613
Total carbon, μg/mL		464	70	2,293	56	125
Inorganic carbon, μg/mL		19	3	1,777	43	46
Organic carbon, μg/mL		445	67	517	13	79
Sludge solids (calculated as:)						
Hydroxide		0.01	25	0.01	4	30
Carbonate		0.01	89.96	0.15	(216)	306
Chloride		0.07	388	0.07	63	450
Fluoride		0.026	74	0.026	12	86
Nitrate		4.52	42,011	4.52	6,810	48,822
Phosphate		0.053	755	0.053	122	877
Sulfate		0.052	749	0.052	121	870
Aluminum	$Al(OH)_3$	1.6E-04	0.63	6.5E-02	123.9	43.5
Arsenic		4.9E-05	0.56	5.5E-04	1.0	1.6
Barium	$BaSO_4$	2.5E-05	0.52	1.6E-04	0.9	1.0
Boron		1.8E-05	0.03	1.4E-04	0.04	0.1
Cadmium	$Cd(OH)_2$	1.1E-06	0.02	1.9E-05	0.1	0.1
Calcium	$CaCO_3$	2.0E-03	11.84	0.44	428.2	183.3
Chromium	$CrCl_3$	1.2E-04	0.90	6.5E-04	2.5	1.7
Cobalt		1.0E-06	0.09			0.08
Iron	$Fe(OH)_3$	4.7E-05	0.39	9.5E-03	24.6	13.2
Lead	$PbCO_3$	1.0E-05	0.31	1.0E-03	6.7	5.5
Magnesium	$Mg(OH)_2$	5.3E-05	0.19	4.5E-02	63.9	26.8
Mercury	Hg_2CO_3	7.5E-07	0.02	8.8E-05	0.6	0.4
Nickel	$NiCO_3$	6.5E-06	0.06	3.6E-04	1.0	0.6
Potassium	KNO_3	0.24	1,424	0.25	625	1,665
Selenium		6.0E-05	0.70	6.5E-04	1.3	2.0
Silicon	SiO_2	3.1E-04	1.28	3.6E-03	5.3	6.5
Silver	AgCl	6.4E-06	0.10	7.1E-05	0.2	0.3
Sodium	$NaNO_3$	4.09	14,091	3.78	7,811	16,203
Strontium	$SrCO_3$	1.4E-04	1.80	4.3E-04	1.5	2.7
Thallium		6.8E-06	0.21	8.0E-05	0.4	0.6
Thorium	ThO_2	9.5E-06	0.33	1.5E-02	97.2	85.8
Uranium	$Na_2U_2O_7$	1.1E-06	0.04	7.9E-03	122.3	91.9
Solids, kg			59,693		9,588	69,857
Water, kg			128,689		18,909	148,009
Total, kg			181,004		28,497	211,622
Sludge insolubles, kg calculated (minimum)					876	
Sludge insolubles, kg calculated (maximum)					2,862	
Sludge insolubles, kg estimated (70% of high)					2,266	
Solids unaccounted for (measured - calculated, total)					(-6,244)	
C in KCoFCN added at 300 ppm			24.09			
Total organic carbon			102.59			
Ratio TOC:NO_3 at 1.2 NO_3 to insolubles			0.0385			

Table A.11. Summation of constituents in all LLLW tanks

A. Radiological Analyses

Constituent	All LLLW supernate (Ci)	All LLLW sludge (Ci)	Supernate + sludge (Ci)
H-3	7.00		7.00
C-14	6.05	4.22	10.27
Co-60	100.68	1,207.39	1,308.07
Sr-90	1,445.99	20,948.59	22,394.58
Nb-95	2.84	34.06	36.90
Zr-95	16.26	494.70	510.96
Ru-106	50.74	329.30	380.04
Cs-134	145.74	41.28	187.03
Cs-137	13,533.73	5,265.04	18,798.78
Ce-144	34.35	170.65	204.99
Eu-152	65.25	5,136.23	5,201.49
Eu-154	32.69	2,948.29	2,980.98
Eu-155	25.37	759.02	784.39
Gross alpha	6.96	1,257.67	1,264.63
Gross beta	17,123.80	58,580.58	75,704.38
U-232	0.22	2.63	2.86
U-233	3.48	59.59	63.07
U-238	0.03		0.03
U-235		173.25	173.25
Pu-239/Pu-240	0.14	83.90	84.04
Pu-238/Am-241	0.49	216.67	217.16
Cm-243		164.99	164.99
Cm-244	1.88	848.36	850.24

Tank volume = 1,392,963 L	Sum Co, Cs, Eu =	13,903.48	15,357.26	29,260.74
Supernate volume = 978,711 L	Sum Sr, C, ^3H =	1,459.04	20,952.81	22,411.85
Supernate H_2O = 825,870 L	Sum alpha =	6.24	1,549.40	1,555.64
Sludge volume = 414,052 L	Sum alpha - ^{244}Cm =	4.36	701.04	705.40
Sludge H_2O = 291,350 L				

B. Physical/Chemical Analyses

Constituent		All LLLW supernate (kg)	All LLLW sludge (kg)	Supernate + sludge (kg)
Dissolved solids		377,873.97		529,943
Total solids		378,235.79	265,925	644,161
Total carbon		1,315.62	6,572	7,888
Inorg.carbon		762.67	4,636	5,398
Organic carbon		553	1,940	2,492
Sludge solids (calculated as:)				
Hydroxide		1,108.88	571.25	1,680
Carbonate		3,967.78	(22,987.52)	26,955.3
Chloride		3,039.76	1,202.47	4,242
Fluoride		523.09	248	771
Nitrate		275,672.05	105,733.03	381,405
Phosphate		4,926.45	2,084	7,010
Sulfate		4,935.78	2,241	7,177
Aluminum	$Al(OH)_3$	12.59	5,595.38	1,948.0
Arsenic		3.62	25.13	28.7
Barium	$BaSO_4$	3.93	54.78	36.2
Boron		1.07	3.26	4.3
Cadmium	$Cd(OH)_2$	0.83	14.12	11.7
Calcium	$CaCO_3$	3,008.40	51,085.94	31,172.0
Chromium	$CrCl_3$	4.07	164.28	58.0
Cobalt		0.43		0.4
Iron	$Fe(OH)_3$	16.88	1,492.99	797.1
Lead	$PbCO_3$	3.14	191.29	151.5
Magnesium	$Mg(OH)_2$	604.23	11,094.28	5,228.6
Mercury	Hg_2CO_3	0.14	22.85	17.7
Nickel	$NiCO_3$	2.37	60.62	32.3
Potassium	KNO_3	19,322.55	15,437.93	25,292.6
Selenium		4.41	26.09	30.5
Silicon	SiO_2	34.93	372.64	305.5
Silver	$AgCl$	0.76	12.50	10.2
Sodium	$NaNO_3$	87,832.31	136,268.81	124,691.0
Strontium	$SrCO_3$	26.74	141.32	110.6
Thallium		1.34	8.91	10.2
Thorium	ThO_2	8.72	3,660.75	3,225.8
Uranium	$Na_2U_2O_7$	176.37	8,355.34	6,449.9
Solids, kg		405,796	238,969	629,788
Water, kg		825,870	291,350	1,117,219
Total, kg		1,204,105	557,275	1,761,380
Sludge insolubles, kg calculated (minimum)			85,645	
Sludge insolubles, kg calculated (maximum)			111,525	
Sludge insolubles, kg estimated (70% of high)			104,532	
Solids unaccounted for (measured - calculated, total), kg			(-8,381)	
C in KCoFCN added at 300 ppm		180.07		
Total organic carbon		2,504.06		
Ratio TOC:NO_3 at 1.2 NO_3 to insolubles		0.0208		

APPENDIX B.

DEFINITIONS AND COMPUTATIONAL METHODS FOR LLLW TANK COMPOSITIONS

SUPERNATE

1. The radioactive concentration of each supernate component was converted from Bq/mL (Sears et al.[1]) to nCi/L by multiplying by the factor (27 nCi/L/Bq/mL).
2. Ci/tank = component concentration × supernate volume.
3. Volume of material in each tank was given by Sears et al.[1]
4. Volume of sludge in each tank was given by Sears et al.[1]
5. Volume of liquid or supernate in each tank was the Total - Sludge.
6. Dissolved solids content = dissolved solids, mg/mL × supernate volume.
7. Total solids content = total solids, mg/mL × supernate volume.
8. Total carbon content = total carbon, μg/mL × supernate volume.
9. Organic carbon content = organic carbon, μg/mL × supernate volume. (Direct measurement for sludge, and total - inorganic for supernate.)
10. Inorganic carbon content = total carbon - organic carbon for sludge, and direct measurement for supernate.
11. Elemental and inorganic compound concentrations were given by Sears et al.[1]
12. Total elemental and inorganic compound contents were computed from the molar concentrations × molecular weight × supernate volume.
13. Supernate solids total = elemental + inorganic compounds content.
14. Supernate total mass is the volume of supernate × specific gravity.
15. Supernate water is the total mass - solids mass.
16. Gross alpha is measured gross alpha, nCi/L.
17. Gross beta is measured gross beta, nCi/L.
18. Total uranium and total thorium are in μg/mL based on chemical analyses.
19. The breakdown for TRU components (^{232}U, ^{233}U, $^{239/240}$Pu, ^{238}Pu/^{241}Am, and ^{244}Cu) was provided for a few tanks.
20. If an analysis gave a "less than" concentration (e.g., <0.01 mg/L for Co, As, B, Ag, Fe, Cr, Se, Si, Tl, and sometimes Mg, Ni, U, Al, CO_3 and OH), that number (e.g., 0.01 for <0.01) was used to compute the content of that component, giving a maximum amount for the tank.

SLUDGE

1. Bulk density is the density of the fully mixed sludge.

2. Analytical total solids, mg/mL, are the measured solids from evaporation of the sample × sample density.

3. Compact solids were obtained by centrifugation of a given volume and comparison of the settled volume to the total.[2]

4. Total carbon, organic carbon, and inorganic carbon were as described above.

5. Gross alpha and gross beta were as described above for supernate.

6. Hydroxide, mol/L, is the supernate value; and the quantity is based on hydroxide from Mg, Fe, and Al hydroxides plus the hydroxide in interstitial supernate.

7. Chloride, mol/L, is the supernate value; and the quantity is based on chloride from chromium and silver chlorides plus the chloride in the interstitial supernate.

8. Nitrate, mol/L, is the supernate value; and the quantity is based on nitrate from sodium and potassium nitrates.

9. Sodium, mol/L, is analytical data; and the quantity is based on sodium nitrate.

10. Potassium, mol/L, is analytical data; and the quantity is based on potassium nitrate.

11. Carbonate, mol/L, is calculated from the inorganic carbon value; and the quantity in parentheses is calculated from the mol value.

12. Calcium, lead, mercury, nickel, and strontium, mol/L, are the analytical data; and the quantities are based on the insoluble carbonates.

13. Magnesium, aluminum, cadmium, and iron, mol/L, are analytical data; and the quantities are based on insoluble hydroxides.

14. Uranium, mol/L, is analytical uranium data; and the quantity is based on $Na_2U_2O_7$.

15. Thorium, mol/L, is analytical thorium data; and the quantity is based on thorium oxide.

16. Barium, mol/L, is analytical barium data; and the quantity is based on barium sulfate.

17. Chromium, mol/L, is analytical chromium data; and the quantity is based on chromium trichloride.

18. Silver, mol/L, is analytical silver data; and the quantity is based on silver chloride.

SLUDGE (continued)

19. The sludge analyses for W-29 and W-30 were taken from the report by Peretz et al.[3]

20. The total mass of the sludge is the sludge volume multiplied by the sludge density.

21. The total mass of solids in the sludge is found by multiplying the analytical total solids by the volume of sludge.

22. The total solids in sludge are the sum of the masses of solid compounds calculated above, excluding nitrate, chloride, hydroxide, and carbonate masses; total carbon is included.

23. The total water in the sludge is the total sludge mass minus analytical total solids.

24. Soluble solids in the sludge are the sum of the sodium and the potassium nitrates.

25. Insolubles are the solid compounds added together, minus the sodium and potassium nitrates. This quantity also represents the minimum insoluble solids in the sludge.

26. The maximum insoluble solids are found by subtracting the soluble solids from the analytical solids.

27. The estimated insoluble solids in the sludge are found by taking 70% of the difference between the maximum and minimum insolubles (above) and adding the minimum insolubles.

SUPERNATE PLUS SLUDGE TOTALS

1. Carbon, hydroxide, and chloride are supernate-plus-sludge totals.

2. Sodium is the supernate sodium plus the sodium in the sodium nitrate in the sludge.

3. Potassium is the supernate potassium plus the potassium fraction of the potassium nitrate in the sludge.

4. Carbonate is the supernate carbonate plus the carbonate, based on the analytical estimate for the sludge (the value in parentheses).

5. Calcium, lead, mercury, nickel, and strontium are the supernate quantities plus the cation fractions of the carbonate compounds in the sludge.

6. Silicon is the supernate silicon plus the sludge silicon.

7. Magnesium, cadmium, aluminum, and iron are supernate quantities plus the cation fraction of the compound hydroxides in the sludge.

8. Uranium is the uranium in the supernate plus the uranium fraction of the sodium diuranate in the sludge.

9. Barium is the supernate barium plus the barium fraction of the barium sulfate in the sludge.

10. Thorium is the supernate thorium plus the thorium oxide in the sludge.

11. Chromium is the supernate chromium plus the chromium fraction of the chromium trichloride in the sludge.

12. Silver is the supernate silver plus the silver fraction of the silver chloride.

13. Solids unaccounted for are the measured total solids minus the calculated solids.

14. The ratio of TOC:NO_3 at 1.2 NO_3 to insolubles is the total organic carbon from the supernate and sludge plus the carbon in the FCN required to remove the ^{137}Cs from both the supernate and interstitial supernate in the sludge at 300 ppm FCN, divided by the nitrate equal to 1.2 times the estimated insolubles in the sludge.

15. The cation totals for both supernate and sludge are determined from selenium, thallium, boron, and arsenic.

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