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ORNL/TM-10078

Large-Scale Leaching of Low-Level Radioactive Wastes

C. W. Francis

Environmental Sciences Division
Publication No. 2737

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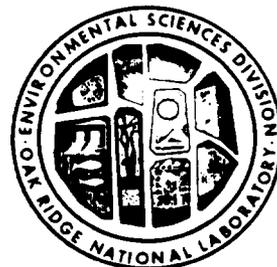
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ENVIRONMENTAL SCIENCES DIVISION
LARGE-SCALE LEACHING OF LOW-LEVEL RADIOACTIVE WASTES

C. W. Francis

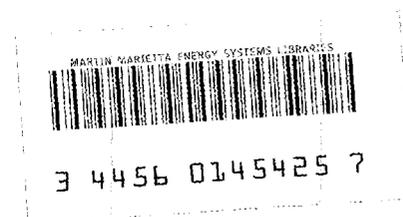
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ABSTRACT

FRANCIS, C. W. 1986. Large-scale leaching of low-level radioactive wastes. ORNL/TM-10078. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 80 pp.

The large-scale leaching of low-level radioactive wastes was conducted using 208- and 314-L (55- and 83-gal) drums containing radioactive wastes generated at Oak Ridge National Laboratory and Oak Ridge Gaseous Diffusion Plant. Ten 208-L drums containing low-level transuranic (TRU) wastes and four 314-L overpack drums containing compacted drums from a Westinghouse-Hittman drum compaction demonstration were leached with potable drinking water, using a unique design to simulate the flooded conditions of a shallow-land burial site. The TRU drums selected were those that contained less than 3.7 kBq/g (100 nCi/g) of transuranics and less than 5 mR/h gamma radiation at the surface of the drum. Only one of the ten drums generated a leachate that contained detectable levels of alpha activity over a 27-d leaching period, with concentrations ranging from approximately 200 to 1200 Bq/L. Concentrations of inorganic and organic constituents were also monitored in the drum leachates. Maximum cadmium concentrations in the leachates of all ten TRU drums were equal to and, in many cases, in excess of the National Interim Primary Drinking Water Standard (NIPDWS). However, cadmium concentrations were factors of ten below the maximum limit established by the Research Conservation and Recovery Act-extraction Procedure (RCRA-EP) leach test (1 mg/L), defining the toxicity characteristic of the waste. The major organic constituent detected in the TRU leachates

was phenol, at concentrations of 1 to 2 mg/L in leachates from two of the ten drums. Other organic compounds detected in TRU leachates were phthalates, bromodichloromethane, chlorodibromomethane, chloroform, and chlorinated ethanes and ethenes. Maximum concentrations of these organic compounds were quite low, usually on the order of 0.05 to 0.5 mg/L, indicating that the shallow-land disposal of these materials probably would not contaminate groundwater supplies with hazardous organic chemicals.

Only one of the overpack drums generated leachates containing detectable concentrations of ^{137}Cs , ^{60}Co , and ^{90}Sr (concentrations ranging from 130 Bq/L of ^{90}Sr to 3000 Bq/L of ^{137}Cs) over 20 d of leaching. Another showed detectable levels of ^{90}Sr (30 to 200 Bq/L) and another, detectable levels of alpha activity (up to 50 Bq/L) in their leachates. Leachates from these drums were analyzed for volatile organic compounds. Leachate collected from one drum contained concentrations of 1,1,1-trichloroethane and/or 1,2-dichloroethane in excess of 0.3 mg/L. Leachates from two of the other four drums contained from 0.05 to 0.1 mg/L of tetrachloroethene. Concentrations of volatile organic compounds decreased rapidly on continued leaching, indicating that disposing of these low-level radioactive wastes in a shallow-land burial site probably would not contaminate the groundwater.

A waste model was used to demonstrate how concentrations of leachable constituents from a waste can be estimated. With the use of leaching data from one of the TRU wastes, the total quantity of alpha activity available for leaching was estimated to be 10,620 Bq/kg of waste. The model can also be used to estimate leachable quantities of

inorganic and organic compounds from wastes. The model, coupled with this large-scale leaching method for wastes, is an excellent method of determining the leaching characteristics of large-volume, low-level radioactive wastes, when the subsampling of such wastes into 100-g representative samples as required for the RCRA-EP leach test is a difficult and seemingly impossible task.

1. INTRODUCTION

To evaluate potential releases from low-level radioactive wastes disposed of in the proposed Central Waste Disposal Facility (CWDF), a source term describing the leaching characteristics of the wastes, was needed for the pathways analysis of the Environmental Impact Statement. The proposed CWDF was a new low-level radioactive waste disposal facility where wastes from all three of the Martin Marietta Oak Ridge plants [Oak Ridge National Laboratory (ORNL), Oak Ridge Gaseous Diffusion Plant (ORGDP), and the Y-12 plant] could be disposed of. The types of waste, with respect to physical and chemical makeup, type of radionuclides, and amounts, vary greatly among the three plants. Because of the multidisciplinary nature of research conducted at ORNL, there are vast differences in the physical and chemical characteristics of the wastes generated by ORNL.

It is well known that the concentrations of radionuclides, as well as the nonradioactive inorganic and organic chemical constituents in the leachates of low-level radioactive wastes, are highly dependent on the chemical and physical characteristics of the waste. Consequently, one of the major problems in determining the characteristics of leachates generated on disposal of wastes from these three plants was the selection of "representative" wastes on which to conduct leaching tests. For example, the U.S. Environmental Protection Agency (USEPA) approved RCRA (Resource Conservation and Recovery Act) extraction procedure (called the EP) requires the leaching of 100 g of waste to determine if the waste's leachate is toxic (USEPA 1982). Subsampling the large volume of low-level radioactive wastes into 100-g samples

that are "representative" of the varied chemical and physical properties making up the waste streams generated at the three facilities is a difficult and probably impossible task.

Perhaps a better alternative to the leaching of 100-g subsamples of waste to determine a source term for leaching is the in situ leaching of wastes packed in 208-L (55-gal) drums. The leaching of wastes packed in drums was an unusually attractive method of determining the characteristics of leachates generated from wastes disposed of in shallow-land burial sites because a large volume of the wastes presently generated at ORNL is packed in drums.

To test the utility of in situ leaching of wastes packed in 208-L drums, ten drums were selected from approximately 1700 drums previously assayed by the TRU Waste Drum Assay Test Facility located in building 7824 at ORNL. These drums that contained less than 3.7 kBq/g (100 nCi/g) of transuranics (TRUs) had been classified as low-level wastes. All ten drums selected for leaching had been surveyed for gamma emitters (radiation level at the surface of the drum was less than 5 mR/h), and there was documentation of the type of waste, as well as of time and place (building, etc.) the waste was collected. The purpose of this experiment was to determine not only the concentrations of radionuclides, but also the concentrations of potentially hazardous inorganic and organic constituents present in the leachates.

As a follow-up to this experiment, the same facility and experimental design was used to determine the leaching characteristics of 20 waste drums that had been compacted during a demonstration at ORNL. These 20 drums originated both at ORNL and ORGDP, and following

compaction were contained in four 334-L (83-gal) "overpack" drums. The four overpack drums were leached in situ to determine the leaching rates of radionuclides from compacted low-level radioactive wastes.

2. SAFETY ASSESSMENT

The first step in the leaching study was the preparation of a safety assessment that addressed the potential hazards associated with the proposed experimental design (Horton 1985). An "Activities Description Memorandum" dated September 30, 1985, and entitled ORNL Large-Scale Radwaste Leach Studies, Buildings 7811 and 7863 (Oak Ridge National Laboratory, Oak Ridge, Tennessee) was also written. The potential hazards associated with the study consisted of possible airborne contamination and inhalation of radioactive material on opening the drums in preparation of the leaching. This hazard was mitigated by opening the drums in a negative-pressure room with high-efficiency particulate air (HEPA) filtration, within a doubly-contained building. The operators wore contamination-zone clothing and appropriate face respirators to protect against the inhalation of any airborne contamination. All work was done under supervision of the Environmental and Occupational Safety Division.

Any spillage of the leachate during the leaching operation, which might result in subsequent absorption of radioactive materials through the skin or possible drying of the liquid causing airborne contamination and potential inhalation of the radionuclides, was prevented by use of double-containment drums and connecting piping. No safety systems or administrative controls were found to be necessary beyond normal safety precautions routinely practiced in other similar work.

3. METHODS AND MATERIALS

Two sets of waste, each in 208-L and larger drums, were leached to determine concentrations of radionuclides and nonradioactive inorganic and organic constituents in their respective leachates. The initial set of drums was selected from the TRU Waste Drum Assay Test Facility (Phase I). As a follow-up to the leaching of these drums (Phase II), four drums containing the wastes from the compaction demonstration were leached, using a similar experimental design and the leaching facility established for leaching of the TRU wastes.

3.1. EXPERIMENTAL DESIGN

3.1.1. Phase I - TRU Wastes

A general description of the ten drums leached, flow rate of water used to leach the wastes, and the pH and total organic carbon concentration of the leachates are presented in Table 1. The "ATN" listed in Table 1 is the "Accountability Transfer Number" that is a number unique to ORNL-Solid Waste Storage Area (SWSA) operations used to track the date at which the waste was generated, building number from which it originated, and general descriptions of type of wastes and quantities as entered in the ORNL solid waste disposal log data management system. Seven of the ten drums were wastes generated at building 3508 from March 1972 to January 1980. The other three drums originated from buildings 5505, 3019, and 3028. The net weight in the drums ranged from a low of 7 kg (drum 2) to a high of 77 kg (drum 10 collected from building 3028 in July 1974).

Table 1. General characteristics of the drums used
in the TRU leaching experiment

Drum	ATN	Bldg.	Date	Net weight (kg)	Flow rate (mL/min)	pH ^a	TOC ^b (mg/L)	
1	400	3508	3/72	32	29	6.4	4.8	195.0
2	1915	3508	1/80	7	29	6.8	2.8	15.0
3	720	3508	7/73	23	27	6.8	3.6	10.0
4	1908	3508	12/79	10	26	6.3	4.2	54.0
5	952	5505	11/74	60	29	7.1	2.7	12.0
6	1391	3508	8/77	25	30	6.8	2.9	21.0
7	1451	3019	8/76	26	25	7.0	2.5	8.5
8	885	3508	6/74	72	30	6.6	13.0	443.0
9	455	3508	5/72	28	24	5.7	13.0	108.0
10	889	3028	7/74	77	27	6.7	4.9	189.0

^apH of the leachate sampled on day 27 of leaching.

^bTotal organic carbon of the leachate sampled on day 27 and 58, respectively.

After moving the ten drums to the double-containment room (inside Building 7863), the lids were removed from the drums and a lance approximately 80 cm long was used to manually perforate the plastic bags containing the radioactive wastes. This lance, which was connected to PTFE (polytetrafluoroethylene) tubing was left in the drum to deliver water to the bottom of the drum (see Fig. 1). To assure against leakage along the top of the new lid (a stainless steel lid identical to the one removed), an epoxy-type water-repelling sealant was used as caulking along the top seam of the drum. A piston-type laboratory metering pump (FMI Model RP-G150) on top of the stainless steel drum was used to deliver potable water to the bottom of each of the drums. An outlet, also placed in the new lid (see Fig. 1) and connected to a three-way valve, was used to flow leachate to the leachate collection drum as well as to a portal for sampling leachate. To avoid generating excess pressure within the drum and causing possible leakage around the top of the lid if the drum outlet became clogged, a relief valve set at approximately 10 psi and an overflow reservoir were included in the influent line (Fig. 1). The relief valves were never activated, and there was no leakage observed around the top of any of the ten drums.

After the new lids were placed on the 208-L stainless steel drums, the drums were moved to the building 7811 area and placed in 756-L seamless high-density polyethylene tanks. Leachate was collected in approximately 150-L plastic drums also contained in similar 756-L high-density polyethylene tanks as illustrated in Fig. 2. Potable water used for leaching was stored in a 1900-L polyethylene reservoir

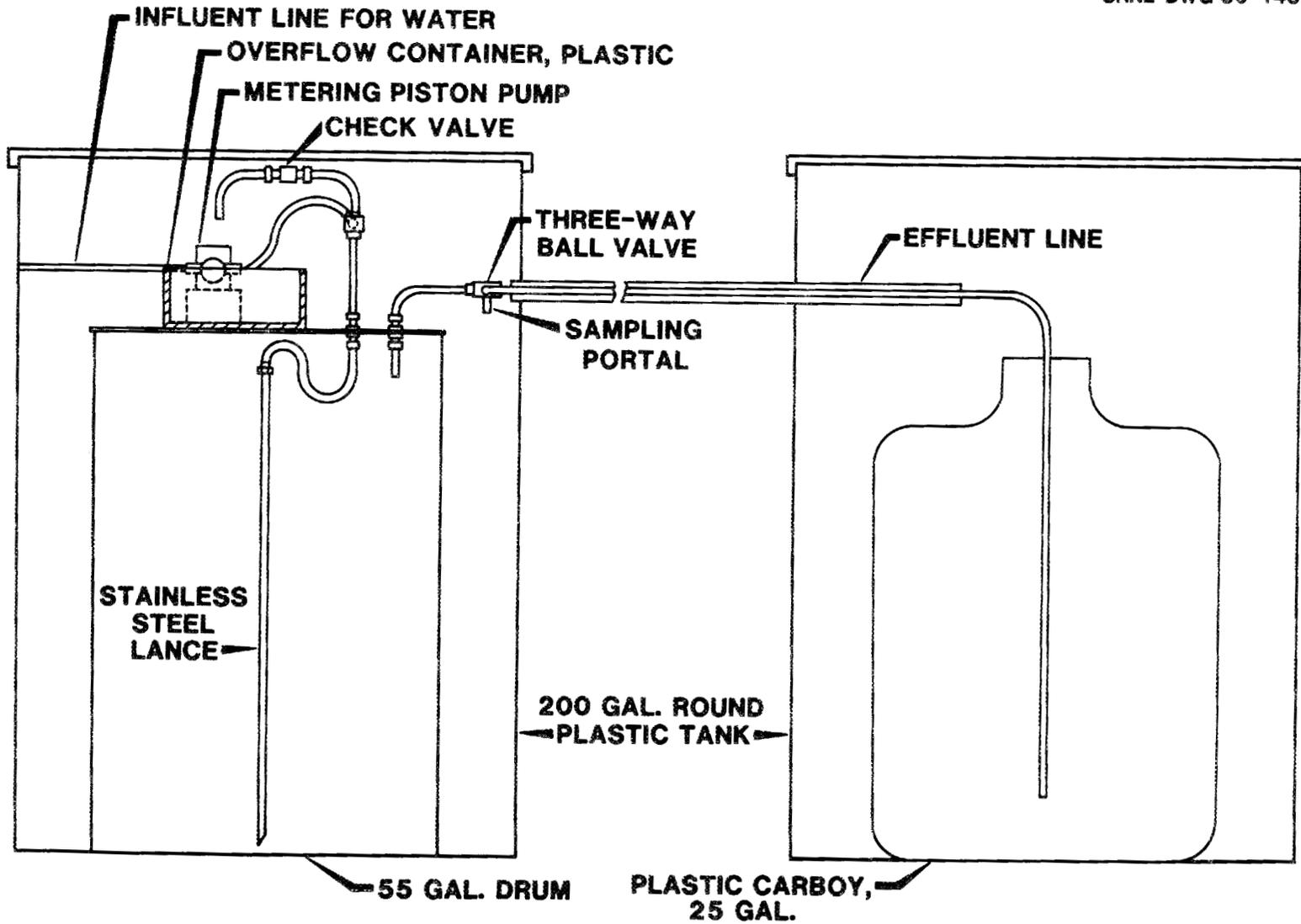


Fig. 1. Schematic of large-scale leaching method.

ORNL PHOTO 5992-85



Fig. 2. Overview of large-scale leaching facility.

adjacent to building 7811. This water was piped by gravity to a manifold system to which each of the ten laboratory pumps was connected.

3.1.2. Phase II - Wastes from the Drum Compaction Demonstration

In September 1985, 134 208-L drums of low-level radioactive wastes were compacted in a demonstration by Westinghouse-Hittman. The "acceptance criteria" for the demonstration included only those 208-L drums that contained no resins, sludges, or soil, drums with surface readings of <5 mR/h, and no drums from buildings known to generate alpha contaminated wastes. The drums used in the compaction demonstration (called overpack drums) originated at ORNL, ORGDP, and Y-12. The documentation of the building location and date of generation was not as extensive as that for the TRU drums. After compaction, one of the overpack drums (drum 8c) showed readings at its surface of approximately 10 mR/h. This drum and three other overpack drums were used to evaluate the leaching of waste drums following compaction. Each of these overpack drums was approximately 314 L in size and contained from three to seven compacted 208-L drums. A description of the drums leached and their respective net weights are presented in Table 2. Lids from the overpack drums were removed and replaced with lids that contained bulkheads for the influent and effluent lines (similar to the design illustrated in Fig. 1, but in this case flexible PTFE tubing was placed between the crushed drums and the inside of the overpack drum to deliver influent to the bottom of the overpack drum).

Table 2. Description and weights of drums used from the drum compaction demonstration

Overpack drum	55-gal drum	Plant and building	Net weight (kg)
7c			
	21	ORNL building 3028	28
	22	ORNL building 1505	87
	23	Unknown	114
	123	ORGDP (pipe)	152
	124	ORGDP (vacuum pump)	81
		Total net weight	463
8c			
	26	ORNL building 4505	97
	41	Unknown	18
	56	Unknown	26
	57	Unknown	29
	98	ORNL building 6000	6
	139	Geotek*	25
	140	Geotek	104
		Total net weight	305
9c			
	115	ORGDP	136
	116	ORGDP	106
	117	ORGDP	65
	118	ORGDP	86
	119	ORGDP	41
		Total net weight	435
10c			
	104	ORGDP (trash)	198
	105	ORGDP (aluminum compressor blades)	130
	106	ORGDP (aluminum compressor blades)	124
		Total net weight	452

*Subcontractor for ORNL.

3.2. LEACHATE COLLECTION AND ANALYSES

3.2.1. Phase I - TRU Wastes

Water was started pumping to the ten drums of TRU waste August 16, 1985, and leaching time in days was referenced to this date. Influent flow rates were checked randomly throughout the leaching period that continued over 27 d. The rates presented in Table 1 are those determined on day 26 of leaching. The mean flow rate to the 10 drums on day 26 was 27.7 ± 2.0 . Variation in flow rate to individual drums was generally less than 2.0 mL/min; however, these data are somewhat academic as power failure occurred at least three times, lasting at one time for as long as 2 d (over a weekend). After 27 d, the pumping of water to the drums was stopped. The drums remained idle until October 12 (58 d from the beginning of leaching) when the metering pumps were reversed and the interstitial leachate from each of the drums was pumped into an empty drum. This was done to remove any excess liquid from the waste drum for final disposal. The leachate collected in this manner was also analyzed for radionuclides as well as for inorganic and organic chemical constituents.

Leachate was collected at the outlet portal from each of the ten drums on days 7, 11, 14, 18, 21, and 27. Radiological analyses of the leachate included the counting of gross-alpha and gross-beta activity on 5 mL of leachate that was deposited and dried by a heat lamp on a counting planchet. Measurements were performed by counting for 30 min using a Tennelec LB5100 Series II detector. No corrections were made for self-absorption or for possible differences in weights of the

5-mL aliquots between drum leachates or sampling dates due to dissolved salts. Visual examination of the planchets did not show crystals of salts or suspended solids after drying. After 7 d of leaching, 20 mL of leachate from each drum was also counted for gamma activity using high-resolution germanium detectors.

For analyses of semivolatile organic constituents, leachate was collected in 1-L glass jars with PTFE inserts in the cap lids to protect against sorption of organic constituents. For volatile organic analyses, leachate was collected in no-head vials made especially for volatile organic analyses. Leachate was analyzed for acids, base neutrals, pesticides, and volatile organic compounds at days 7, 11, 14, and 18. The interstitial leachate pumped from the drums after standing 31 d was also analyzed for acids, base neutrals, and pesticides.

Leachate was collected in glass containers and immediately acidified to $\text{pH} < 2$ with special grade high-purity nitric acid for the determination of inorganic elements. As in the case for the analyses of organic compounds, the interstitial leachate pumped from the drums after standing 31 d was also analyzed for inorganic elements.

3.2.2. Phase II - Wastes from the Drum Compaction Demonstration

Leaching of the compacted drums began October 15, 1985. Potable water was pumped to each of the overpack drums (7c, 8c, 9c, and 10c, see Table 2) at a flow rate of approximately 29 mL/min. The first effluent sample was collected on day 3. Leaching was continued for 23 d, except for drum 7c, which developed a severe leak on day 15 and began filling up the containment drum. Influent to this drum was discontinued, and the overflow leachate was pumped from the containment drum.

The pH of the leachate was measured at the beginning and end of the experiment. The initial pH values were 6.76, 7.14, 6.97, and 10.14 for drums 7c, 8c, 9c, and 10c, respectively, and the final pH values, in the same order for each of the drums, were 8.20, 8.01, 8.28, and 8.75.

3.3. ANALYTICAL METHODS

3.3.1. Inorganic elements

The concentrations of inorganic elements (also referred to as metals in this report) in waste leachates were determined by inductively coupled plasma (ICP) spectroscopy.

3.3.2. Organic compounds

Organic compounds analyzed in the waste leachates can be classified as semivolatile compounds (which include acid and base neutral fractions as well as the pesticides) and volatile compounds. All semivolatile organic compounds were determined according to Environmental Protection Agency (EPA) Method 8270 (USEPA 1984). This is a gas chromatograph/mass spectrometry method in which a capillary column and multiple internal standards are employed. The semivolatile samples were prepared by EPA Method 3510, which is a liquid-liquid solvent extraction method. Normally, this method requires a 1-L aqueous sample; however, in the case of some leachate samples, <1-L (usually 400 to 600 mL) was used. Thus, the procedures were adjusted to accommodate the reduced amount of sample. Each sample was extracted

six times with methylene chloride (three times at pH 12 and three times at pH 2). The three extracts from each of the acid and base extractions were combined for the subsequent analysis of acid and base fractions according to EPA Method 8270.

Volatile organics were determined by either one of the two methods. The pentane extraction method was used early in the study. In this procedure, 20 mL of the aqueous leachate is extracted with 1 mL of pentane in a Mixxor extractor. This extract is then analyzed by capillary gas chromatography, with the injected sample being split between two capillary columns. The effluent from one column is directed to an electron capture detector, where halogenated volatiles are detected. The effluent from the second column is directed to a flame ionization detector, where all hydrocarbon (including halogenated species) volatiles are detected.

The second method of determining volatile organic compounds was EPA Method 8240 (USEPA 1984). This method employs a purge-and-trap inlet associated with a gas chromatograph/mass spectrometry system. In this method, a small aliquot (generally 5 mL) of the sample was purged onto a trap and then thermally desorbed onto a packed column.

4. RESULTS AND DISCUSSION

4.1. PHASE I - TRU WASTES

4.1.1. Radiological analyses

As a first step in the radiological analyses of the leachates collected, gross-alpha and gross-beta determinations were made for each sampling date. These measurements can be conducted rapidly and with little expense relative to radiochemical (e.g., ^{90}Sr) or alpha spectra analyses (for U, Th, or Pu isotopes). For leachates showing high levels of alpha or beta activities, further analyses for individual isotopes can be conducted if so desired. The objective in the initial phase of the analyses was to determine the general magnitude and type of radioactivity being leached from the wastes. Listed in Table 3 are the gross-alpha and gross-beta activity measurements in each of the leachates sampled from the ten drums over the 27-d leaching period. The measurements are presented in terms of number of days since leaching was started, as well as in terms of the respective liquid-to-solid ratio for each of the drums. The term liquid-to-solid ratio is defined as the volume of leachate generated up to that sampling date (in liters) divided by the mass of waste leached (in kilograms). The liquid-to-solid ratio is used to normalize the differences between drums containing small and large quantities of waste as well as possible differences in flow of water to each of the drums. Note that drum 2, which has only 7 kg of waste, has a liquid-to-solid ratio of 163 on day 27 of leaching, compared with a liquid-to-solid ratio of 18.5 for drum 5, which has 60 kg of waste but

Table 3. Gross-alpha and gross-beta activity measured in TRU leachates

Drum		Day					
		7	11	14	18	21	27
1	L/S Ratio ^a	9.2	14.5	18.4	23.7	27.7	35.6
	Alpha ^c	24	7.2	10.6	<4	<4	<4
	Beta	<9.4	<9.4	<9.4	<9.4	<9.4	<9.4
2	L/S Ratio	42.2	66.3	84.3	108	127	163
	Alpha	<4	<4	<4	<4	<4	<4
	Beta	<9.4	<9.4	<9.4	<9.4	<9.4	<9.4
3	L/S Ratio	11.8	18.6	23.7	30.4	35.5	45.7
	Alpha	8.4	5.4	5.6	6.6	<4	<4
	Beta	<9.4	<9.4	<9.4	<9.4	<9.4	<9.4
4	L/S Ratio	26.2	41.1	52.4	67.4	78.6	101
	Alpha	<4	5.4	<4	<4	<4	<4
	Beta	<9.4	<9.4	64	<9.4	<9.4	<9.4
5	L/S Ratio	4.8	7.5	9.6	12.3	14.4	18.5
	Alpha	<4	<4	<4	<4	<4	<4
	Beta	<9.4	<9.4	<9.4	<9.4	<9.4	<9.4
6	L/S Ratio	12.2	19.1	24.3	31.3	36.5	47
	Alpha	6.6	<4	<4	<4	<4	<4
	Beta	<9.4	<9.4	<9.4	<9.4	<9.4	22
7	L/S Ratio	ns	15.6	19.8	25.5	29.8	38.2
	Alpha	ns	<4	<4	<4	<4	<4
	Beta	ns	<9.4	<9.4	<9.4	<9.4	<9.4
8	L/S Ratio	4.1	6.5	8.3	10.7	12.5	16
	Alpha	1140	900	580	280	200	220
	Beta	<9.4	<9.4	<9.4	<9.4	<9.4	<9.4
9	L/S Ratio	8.6	13.6	17.3	22.2	25.9	33.3
	Alpha	5.4	<4	<4	5.2	<4	4.6
	Beta	<9.4	<9.4	<9.4	<9.4	<9.4	<9.4
10	L/S Ratio	3.5	5.6	7.1	9.1	10.6	13.6
	Alpha	5.4	20	5.6	<4	9	5.8
	Beta	10.6	<9.4	<9.4	<9.4	<9.4	<9.4

^aL/S ratio is the liquid-to-solid ratio defined as the volume of leachate generated to that date sampled (in liters) divided by the mass of waste leached (in kilograms).

^bns = not sampled.

^cAlpha and beta are given in Bq/L.

leached at the same flow rate (29 mL/min). Obviously, the direct comparison of the leaching between the two drums would not be equivalent on a day-to-day basis. To make comparisons among the drums more equal, the leaching is expressed in terms of the liquid-to-solid ratio.

From the standpoint of beta activity, only two samples showed counts in excess of the detection level (9.4 Bq/L). This included a moderately high and likely spurious count on day 14 of sampling the leachate from drum 4 (based on the activity measured in the leachate at other sampling dates from the same drum, the 64 Bq/L is highly suspect), and a measurement slightly greater than the detection level in the first sampling from drum 7 (10.6 Bq/L compared with the detection level of 9.4 Bq/L). Neither of these measurements was considered to be important enough to justify analysis for ^{90}Sr by radiochemical procedures.

Detectable quantities of alpha activity were measured in leachate generated in all drums except drums 2, 5, and 7. Leachate from drum 8 contained by far the highest concentration of alpha activity, a concentration in excess of 1000 Bq/L on day 7 of leaching. Alpha spectra analyses indicated the activity to be largely ^{234}U , with detectable quantities of ^{228}Th and ^{237}Np .

For the most part, the concentration of alpha activity in the leachates was at or below the detection level (4 Bq/L) after 14 d of leaching, the exception being leachate from drum 8. However, there were large differences in liquid-to-solid ratios, with values ranging from 7.1 for drum 10 to 84.3 for drum 2.

No detectable gamma-emitting radionuclides were measured in 20 mL of leachate collected from each of the drums on day 7 of leaching. These data generally confirmed the absence of measurable quantities of

gamma-emitting radionuclides, as none of the waste drums showed gamma radiation in excess of 5 mR/h. Thus, the counting of leachates for gamma-emitting radionuclides was discontinued after the first leachate sampling.

After leaching for 27 d, the drums were left standing for 31 d. Analyses of the interstitial leachate did not reveal detectable alpha activity in any of the interstitial leachate except those leachates sampled from drums 8 and 10 (a very high activity of 2600 Bq/L in leachate from drum 8 and 19 Bq/L in the leachate from drum 10). Leachate from drum 6 was the only leachate that showed detectable levels of beta activity (approx. 230 Bq/L).

4.1.2. Leaching of Metals

Toxic metals leached from wastes contaminate groundwater and create a potential health hazard. Concentration limits for various metals in water have been established for drinking water, and these limits as well as other guidelines are being used to evaluate potential contamination of groundwater by shallow-land burial of wastes. Listed in Table 4 are the concentrations of various metals that, if detected in the groundwater adjacent to a burial site, may classify the site as a hazardous waste landfill probably requiring remedial action to control discharge.

To evaluate the potential of each of the ten wastes to leach toxic metals, leachate samples were analyzed for metals using ICP spectroscopy. This technique provides general information on concentrations of nearly 30 elements in one analysis. Many of these metals are not RCRA regulatory metals, but their concentrations in the leachate are useful in evaluating general water quality. The major

Table 4. Water quality criteria for metals

Metals	Characteristics required for	
	Groundwater ^a	Leachate ^b
	(mg/L)	
Arsenic	0.05	5
Barium	1.00	100
Cadmium	0.01	1
Chromium (VI)	0.05	5
Copper	1.00	ND
Lead	0.05	5
Mercury	0.00	2.0
Nickel	0.20	ND
Selenium	0.01	1
Silver	0.05	5
Zinc	5.0	ND

^aWater quality of groundwater established at concentrations set by the National Interim Primary Drinking Water Standards (USEPA 1980), except for copper, nickel, and zinc, which are guidelines established by the State of Tennessee (personal communication to T. A. Perry, Martin Marietta, Energy Systems, Inc., Oak Ridge National Laboratory, May 21, 1985, from L. W. Gregory, Division of Solid Waste Management, Tennessee Department of Health and Environment).

^bResource Conservation Recovery Act Extraction Procedure maximum limits (USEPA 1980). ND = Not defined.

disadvantages of the ICP analyses methodology are that mercury concentrations are not determined and that the detection levels for arsenic, lead, and selenium are not low enough to detect concentrations at the groundwater quality criteria level listed in Table 4. The detection levels, however, are adequate to determine concentrations of these metals that are in excess of the RCRA-EP leaching test (see Table 4).

Leachate concentrations measured in this leaching study have no regulatory implications with respect to the classification of a waste as hazardous or nonhazardous. The purpose here is to determine a source term for leaching to be used in the pathways analysis model of the Environmental Impact Statement for the proposed CWDF. However leachate concentrations determined in this study may be useful in determining wastes whose leachate might result in the contamination of groundwater in excess of the primary drinking water standard or other criteria established by a state or federal regulatory agency, making the disposal of the waste in a shallow-land burial site subject to question. Obviously, metal concentrations in the waste leachates at or below the groundwater quality criteria listed in Table 4 are not an environmental concern; however, if the leachate concentrations were in excess of these criteria by factors of 10 to 100, or even greater, then the degree of attenuation by soil and/or dilution by uncontaminated groundwater will dictate the concentration in groundwater downgradient from the burial site.

For the present, only those metals whose concentration in the waste leachate measured in excess of the water quality criteria listed in Table 4 will be addressed. The metal concentrations in the leachates from the ten drums sampled at days 7, 14, and 21 over the

leaching period are presented in Appendix A. A summary of the maximum metal concentrations observed in the leachates of the TRU wastes is listed in Table 5.

Concentrations of barium and silver measured in TRU leachates never exceeded the maximum limit established for the RCRA-EP leaching test or even the levels established for National Interim Primary Drinking Water Standards (NIPDWS). Limits of detection for arsenic, lead, and selenium were in excess of the NIPDWS; however, leachate concentrations for these elements were never in excess of limits for the RCRA-EP leach test.

Maximum cadmium concentrations in the leachates from all ten TRU drums were equal to and, in many cases, in excess of the NIPDWS. Cadmium concentrations, however, never exceeded RCRA-EP limits (1 mg/L). The highest cadmium concentrations (0.12 and 0.11 mg/L) were observed in leachates from drums 7 and 9, respectively. Except for chromium concentrations in leachate from drum 1, all chromium concentrations were below maximum limits defined for the RCRA-EP leach test as well as the NIPDWS. The chromium concentration in the leachate from drum 1 on day 7 of leaching (0.15 mg/L) was in excess of the NIPDWS (0.05 mg/L) but well below the RCRA-EP limit (5 mg/L). Chromium concentrations on days 14 and 21 of leaching were below detection limits by ICP spectroscopy (0.04 mg/L). Copper concentrations measured in TRU waste leachates were less than 0.02 mg/L, considerably less than the 1.0 mg/L guideline suggested by the State of Tennessee. A maximum nickel concentration of 0.47 mg/L was measured in the leachate from drum 1 (see Table 5). This was in excess of the Tennessee suggested

Table 5. Summary of maximum concentrations (in mg/L) of metals measured in TRU waste leachates

Metal	Influent	Drum										
		1	2	3	4	5	6	7	8	9	10	
Aluminum	<0.02	0.29	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Antimony	<0.20	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Arsenic	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Barium	0.02	0.06	0.07	0.07	0.69	0.07	0.10	0.15	0.54	0.13	0.18	
Boron	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	0.63	<0.08	
Cadmium	<0.005	0.02 ^a	0.02 ^a	0.04 ^a	0.06 ^a	0.01	0.01	0.12 ^a	0.01	0.11 ^a	0.03 ^a	
Calcium	42	50	50	38	50	41	36	39	53	55	47	
Chromium	<0.04	0.15 ^a	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	
Cobalt	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	5.60	<0.01	
Copper	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	
Iron	<0.03	35	0.24	0.62	0.24	0.32	0.07	0.34	0.99	0.71	2.70	
Lead	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
Lithium	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
Magnesium	11	10	14	9	18	10	9	9	10	13	10	
Manganese	<0.005	0.30	0.03	0.03	0.02	0.03	0.03	0.17	0.04	0.04	0.05	
Molybdenum	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	
Nickel	<0.06	0.47 ^a	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	0.09	<0.06	
Phosphorous	<0.30	4.40	<0.03	1.30	0.40	<0.03	<0.03	<0.03	26.00	1.60	6.90	
Selenium	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
Silicon	2.60	3.40	8.20	2.70	10.00	3.60	2.10	3.00	4.20	5.10	4.20	
Silver	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	
Sodium	6.10	17.0	5.4	9.8	5.9	5.3	4.9	5.8	130	9.8	43.0	
Strontium	0.09	0.11	0.09	0.08	0.10	0.08	0.72	0.08	0.15	0.25	0.09	
Titanium	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	
Vanadium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Zinc	<0.02	3.40	0.10	6.40 ^a	0.46	0.13	0.46	0.48	2.00	5.10 ^a	1.50	
Zirconium	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	

^aConcentrations are in excess of the water quality criteria for groundwater, see Table 4.

guideline for nickel in groundwater (0.2 mg/L). No defined limits for nickel have been established for the NIPDWS or the RCRA-EP leach test. Two drums (drums 3 and 9) generated leachate that contained zinc concentrations (6.4 and 5.1 mg/L, respectively) in excess of the Tennessee suggested guideline for zinc in groundwater (5.0 mg/L). As for nickel, NIPDWS or RCRA-EP leach test limits for zinc have not been defined.

The metal concentrations in the interstitial leachate sampled 31 d after the leaching had been stopped (Table 11A, in Appendix A) revealed only concentrations of cadmium and zinc to be in excess of those groundwater quality criteria established for metals in Table 4. The concentrations of cadmium in the interstitial leachate of drums 3 and 7 were similar to those concentrations measured on day 7 of leaching (see Appendix A). On the other hand, zinc concentrations in the interstitial leachate of drums 3 and 9 (37 and 140 mg/L, respectively) were much higher than the maximum zinc concentrations measured during the 27 d of leaching (see Appendix A, approximately 6 mg/L). The data in Table 11A indicate that the solubility of zinc in these drums (drums 3 and 9) increased on continued leaching and time. (Note in Table 1 that the pH of the leachate sampled from drum 9 on day 27 of leaching was 5.7, the lowest of all drums sampled.)

In summary, the major concern with respect to metal concentrations in the leachates of the ten drums of TRU wastes leached appears to be cadmium levels. These levels, though in excess of the NIPDWS, are factors of ten below the maximum limit established by the RCRA-EP leach test. These concentrations were observed in the early stages of

leaching (generally day 7 of leaching) and only one drum (drum 7) generated a leachate that contained cadmium concentrations in excess of NIPDWS on day 21 of leaching (see leaching concentrations in Appendix A).

4.1.3. Leaching of Organic Compounds

Considerable effort, in terms of time and expense, was made to determine concentrations of organic constituents in leachates of the TRU low-level radioactive wastes. This was undertaken because little is known about the character of organic compounds in radwastes leachates. For example, most leaching studies have confined analyses of leachates to radionuclides, and to some extent, hazardous inorganic constituents. Thus, the type and quantity of organic compounds in leachates of low-level radioactive wastes have been largely speculation.

A list of all organic compounds assayed in the leachates collected on day 7 of leaching is presented in Table 6. This included analysis for 15 acids, 54 base neutral compounds, 17 pesticides, and 22 volatile organic compounds. These are organic compounds identified by USEPA as potential contaminants to groundwater and drinking water supplies (USEPA 1983). Initial inspection of Table 6 reveals that the concentration of most of these compounds in the TRU leachates were below detection levels. The exceptions were phenol in leachate from drums 1, 3, 4, and 9 and some volatile organics in leachates of the other drums. The concentrations of detectable organic compounds in the leachates from all TRU drums over the duration of the experiment are presented in Table 12A (Appendix A). A summary of the maximum

Table 6. Concentrations (in µg/L) of organic compounds in TRU waste leachates after 7 d of leaching

Chemical	Detection limit	Drum Number										
		1	2	3	4	5	6	7	8	9	10	
<u>Acids</u>												
Benzoic acid	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Pentachlorophenol	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Phenol	<10	1398	<10	429	427	<10	<10	<10	<10	<10	222	<10
p-Chloro-m-cresol	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
2,4,5-Trichlorophenol	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
2,4,6-Trichlorophenol	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
2,4-Dichlorophenol	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
2,4-Dimethylphenol	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
2,4-Dinitrophenol	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
2-Chlorophenol	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
2-Methylphenol	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
2-Nitrophenol	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
4,6-Dinitro-2-methylphenol	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
4-Methylphenol	<10	23	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
4-Nitrophenol	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
<u>Base neutrals</u>												
Acenaphthene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Acenaphthylene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Aniline	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Anthracene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Benzidine	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Benzo(a)anthracene	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Benzo(a)pyrene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Benzo(b)fluoranthene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Benzo(g,h)perylene	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Benzo(k)fluoranthene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Benzyl alcohol	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Benzyl butyl phthalate	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Bis(2-chloroethoxy)methane	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Bis(2-chloroethyl)ether	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Bis(2-chloroisopropyl)ether	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Bis(2-ethylhexyl)phthalate	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Chrysene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Di-N-butyl phthalate	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Di-N-octyl phthalate	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Dibenzo(a,h)anthracene	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Dibenzofuran	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10

Table 6 (continued)

Chemical	Detection limit	Drum Number										
		1	2	3	4	5	6	7	8	9	10	
<u>Base neutrals</u>												
Diethyl phthalate	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Dimethyl phthalate	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Fluoranthene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Fluorene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Hexachlorobenzene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Hexachlorobutadiene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Hexachlorocyclopentadiene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Hexachloroethane	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Indeno(1,2,3-cd)pyrene	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Isophorone	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
N-Nitrosodimethylamine	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
N-Nitrosodiphenylamine	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
N-Nitrosodipropylamine	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Naphthalene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Nitrobenzene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Phenanthrene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Pyrene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
1,2,4-Trichlorobenzene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
1,2-Dichlorobenzene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
1,2-Diphenylhydrazine	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
1,3-Dichlorobenzene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
1,4-Dichlorobenzene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
2,4-Dinitrotoluene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
2,6-Dinitrotoluene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
2-Chloronaphthalene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
2-Methylnaphthalene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
2-Nitroaniline	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
3,3-Dichlorobenzidine	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
3-Nitroaniline	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
4-Bromophenyl phenyl ether	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
4-Chlorophenyl phenyl ether	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
4-Nitroaniline	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
4-Chloroaniline	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
<u>Pesticides</u>												
Aldrin	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Alpha-BHC	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Beta-BHC	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Chlordane	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10

Table 6 (continued)

Chemical	Detection limit	Drum Number										
		1	2	3	4	5	6	7	8	9	10	
<u>Pesticides</u>												
Delta-BHC	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Dieldrin	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Endosulfan I	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Endosulfan II	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Endosulfan sulfate	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Endrin	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Endrin aldehyde	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Gamma-BHC (Lindane)	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Heptachlor	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Heptachlor epoxide	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
4,4'-DDD	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
4,4'-DDE	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
4,4'-DDT	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
<u>Volatiles</u>												
Benzene	<4.4	<4.4	<4.4	<4.4	<4.4	<4.4	<4.4	<4.4	<4.4	<4.4	ND ^a	ND
Bromodichloromethane	<4.7	21	21	10	7	7	18	<4.7	<2.2	ND	ND	ND
Bromodichloromethane	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	ND	ND	ND
Bromoform	<4.7	<4.7	<4.7	<4.7	<4.7	<4.7	<4.7	<4.7	<4.7	ND	ND	ND
Carbon tetrachloride	<2.8	<2.8	<2.8	<2.8	<2.8	<2.8	<2.8	<2.8	<2.8	ND	ND	ND
Chlorobenzene	<5	<5	<5	<5	<5	<5	<5	<5	<5	ND	ND	ND
Chlorodibromomethane	<5	<5	<5	<5	<5	<5	<5	<5	<5	ND	ND	ND
Chloroform	<1.6	61	52	35	41	27	40	17	13	ND	ND	ND
Methylene chloride	<2.8	<2.8	<2.8	<2.8	<2.8	<2.8	<2.8	<2.8	<2.8	ND	ND	ND
Tetrachloroethene	<4.1	<4.1	<4.1	<4.1	<4.1	<4.1	<4.1	<4.1	<4.1	ND	ND	ND
Toluene	<5	<5	<5	<5	<5	<5	<5	<5	<5	ND	ND	ND
Trichloroethene	<1.9	21	21	10	7	7	18	2	<1.9	ND	ND	ND
cis-1,3-Dichloropropene	<5	<5	<5	<5	<5	<5	<5	<5	<5	ND	ND	ND
trans-1,2-Dichloroethene	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	ND	ND	ND
trans-1,3-Dichloropropene	<5	<5	<5	<5	<5	<5	<5	<5	<5	ND	ND	ND
1,1,1-Trichloroethane	<3.8	25	68	8	28	8	6	10	4	ND	ND	ND
1,1,2,2-Tetrachloroethane	<6.9	<6.9	<6.9	<6.9	<6.9	<6.9	<6.9	<6.9	<6.9	ND	ND	ND
1,1,2-Trichloroethane	<5	17	<5	<5	<5	<5	<5	<5	<5	ND	ND	ND
1,1-Dichloroethane	<4.7	<4.7	<4.7	<4.7	<4.7	<4.7	<4.7	<4.7	<4.7	ND	ND	ND
1,1-Dichloroethene	<2.8	<2.8	<2.8	<2.8	<2.8	<2.8	<2.8	<2.8	<2.8	ND	ND	ND
1,2-Dichloroethane	<2.8	25	68	8	28	8	6	10	4	ND	ND	ND
1,2-Dichloropropane	<6	<6	<6	<6	<6	<6	<6	<6	<6	ND	ND	ND

^aND = Not determined.

concentration of the organic compounds measured in the leachates is presented in Table 7.

The major organic constituent detected, using the above analyses, in the TRU leachates was phenol at concentrations of 1 to 2 mg/L in leachates from drums 1 and 10. Leachates from other drums contained detectable amounts of volatile organics; most prominent was leachate from drum 7 that contained concentrations of bromodichloromethane, chloroform, and others in excess of 0.1 mg/L (Table 7). Measurements of organic compounds in the influent (potable drinking water) were not made. Analyses of all leachates collected from the TRU drums revealed that concentrations of all compounds were below the detection level for at least one sampling (see Table 12A). The one organic compound found most consistently at levels of 20 to 60 ug/L was chloroform, indicating that chloroform may have been in the influent at those levels. The intent was to determine if leachates contained significant concentrations of organic constituents that could pollute groundwater. These data indicate, with the possible exception of phenol, that leachates from the TRU low-level radioactive wastes examined would not be a threat to groundwater quality.

4.2. PHASE II - WASTES FROM THE DRUM COMPACTION DEMONSTRATION

4.2.1. Radiological Analyses

The primary interest, as in the case of the TRU waste leachates, was to determine the general character of radioactivity in the leachates by gross-alpha and gross-beta measurements (Table 8). Leachate was also analyzed for gamma activity (see Table 9) by counting

Table 7. Summary of maximum concentrations (in µg/L) of organic compounds measured in TRU waste leachates

Chemical	Detection Level											
		1	2	3	4	5	6	7	8	9	10	
Bis(2-ethylhexyl)phthalate	<10	<10	<10	<10	<10	<10	<10	<10	<10	34	18	39
Bromodichloromethane	<1	21	21	42	7	22	20	226	25	2	9	
Chlorodibromomethane	<1	1	1	1	<1	1	1	28	2	<1	<1	
Chloroform	<1	61	63	65	41	61	44	133	55	19	40	
Diethylphthalate	<10	<10	<10	21	<10	<10	<10	<10	<10	<10	<10	
Phenol	<10	1398	<10	504	427	<10	<10	<10	242	516	1315	
Tetrachloroethene	<1	<1	<1	<1	<1	<1	<1	3	<1	<1	<1	
Trichloroethene	<1	21	21	42	7	22	20	226	25	2	9	
1,1,1-Trichloroethane	<10	25	68	<10	28	12	<10	184	43	271	915	
1,1,2-Trichloroethane	<10	17	<10	<10	<10	<10	<10	<10	<10	<10	<10	
1,2-Dichloroethane	<10	25	68	8	28	12	<10	184	43	271	915	

Table 8. Gross-alpha and gross-beta activity
measured in leachates from
compacted waste drums

Drum	Day	Alpha	Beta
		Bq/L	
7c	3	BD ^a	351
	6	BD	167
	9	BD	83
	13	BD	45
8c	3	BD	1871
	6	BD	3391
	9	BD	2191
	13	BD	1871
	16	BD	1671
	20	BD	991
	23	BD	1451
9c	3	BD	13
	6	BD	80
	9	BD	80
	13	BD	80
	16	BD	80
	20	BD	80
	23	BD	31
10c	3	6	80
	6	11	5
	9	7	80
	13	33	9
	16	21	7
	20	41	29
	23	41	17

^aBD = below detection

Table 9. Concentrations of radionuclides in leachates from compacted waste drums

Crushed Drum	Day	Radionuclide				
		^{90}Sr	^{137}Cs	^{134}Cs	^{60}Co	^{54}Mn
7c	3	188	37	BD ^a	80	80
	6	88	80	80	80	80
	9	40	80	80	80	80
	13	29	80	80	80	80
8c	3	254	1211	48	342	80
	6	427	2738	85	309	80
	9	280	1711	55	221	80
	13	272	1163	70	471	206
	16	236	1104	80	272	88
	20	129	471	80	294	129
9c	3	4	80	80	80	80
	6	2	80	80	80	80
	9	80	80	80	80	80
	13	1	80	80	80	80
	16	80	80	80	80	80
	20	80	80	80	80	80
10c	3	7	80	80	80	80
	6	4	80	80	80	80
	9	3	80	80	80	80
	13	0	80	80	80	80
	16	11	80	80	80	80
	20	17	80	80	80	80

^aBD = below detection.

20-mL aliquots in high-resolution germanium detectors (Larsen and Cutshall 1981). The activity of ^{90}Sr in the leachates (Table 9) was estimated using Cerenkov radiation counting techniques (Larsen 1981).

As expected, based on the initial radiological surveys, leachates from drum 8c contained the highest activity (Tables 8 and 9). Leachates from drum 7c also contained significant beta activity, and low levels of alpha activity were detected in leachates from drum 10c (Table 8). In general, the initial guideline limiting the selection of drums to those with surface readings <5 mR/h precluded the measurement of significant quantities of radioactivity in the leachates generated.

4.2.2. Leaching of Metals

Leachates collected for gross-alpha and gross-beta analysis were archived for possible metal analysis (see Table 8 for frequency of sample collection). For example, aliquots of leachate were acidified to pH <2 with high-purity concentrated nitric acid and stored for metal analyses. To conserve funding, metal analyses were not planned for these leachates until the leachates generated from the TRU wastes were analyzed. The TRU wastes represented a larger variety and a more representative sample of wastes generated over a longer time range than those used in the compaction demonstration. For example, the wastes that were compacted in the Westinghouse-Hittman demonstration were the formerly non-compactible wastes that were placed in 208-L drums starting in June 1985. Prior to June 1985, these non-compactible wastes were "dumped" into trenches. Also, documentation of the source

of the TRU wastes and their general characterization in terms of telemeter scans was better than the wastes used in the compaction demonstration. Thus, if significant concentrations of hazardous metals were detected in the TRU waste leachates, the possible sources of these metals could be determined from these wastes better than from the wastes used in the compaction demonstration. Since the concentrations of metals in the leachates of TRU wastes were not excessive (except in a few cases where concentrations of cadmium exceeded the NIPDWS in the early stages of leaching), it was not considered necessary to determine the metal concentrations in the leachates of the compacted drums.

4.2.3. Leaching of Organic Compounds

When the lids of the overpack drums were replaced with lids containing the influent and effluent bulkheads, a strong pungent odor suggestive of volatile organic compounds was detected emanating from drum 7c. In spite of the fact that the replacement of the drum lids was conducted outside in the open air with an accompanying light breeze, the odor was enough of a concern that the operation was finished with the operators wearing face respirators equipped to strip organic solvents from the air. For this reason, the leachates from these drums were sampled and analyzed for volatile organic compounds. The volatile compounds detected in the leachates are listed in Table 10. The predominant volatile organic compounds found to be present in the leachate from drum 7c were 1,1,1-trichloroethane and 1,2-dichloroethane. Concentrations of each compound were estimated to range from 100 to 300 ug/L (identical concentrations of each compound

Table 10. Concentrations (in $\mu\text{g/L}$) of volatile organic compounds detected in leachate from compacted waste drums

Drum and Chemical	Day				
	3	6	9	20	23
Drum 7c					
Bromodichloromethane	<1	2	1	ND ^a	ND
Chloroform	6	19	16	ND	ND
Trichloroethene	<1	2	1	ND	ND
1,1,1-Trichloroethane	109	336	134	ND	ND
1,2-Dichloroethane	109	336	134	ND	ND
Drum 8c					
Bromodichloromethane	1	2	2	<2.2	<2.2
Chloroform	6	17	15	22	11
Tetrachloroethene	38	<1	<1	<4.1	<4.1
Trichloroethene	1	2	2	<1.9	<1.9
Drum 9c					
Bromodichloromethane	<1	2	2	<2.2	<2.2
Chloroform	6	16	16	18	12
Tetrachloroethene	<1	48	91	10	9
Trichloroethene	<1	2	2	<1.9	<1.9
Drum 10c					
Bromodichloromethane	<1	1	2	<2.2	<2.2
Chloroform	6	15	14	22	12
Trichloroethene	<1	1	2	<1.9	<1.9

^aND = not determined.

are reported as the compounds eluted together from the pentane extraction method; i.e., the maximum value is reported--see chemical analyses in Sect. 3.3.2). Traces of bromodichloromethane, tri- and tetra-chloroethene, and chloroform were detected in leachates from the compacted waste drums during the 23 d of leaching. The chloroform concentrations, ranging from 6 to 22 ug/L, may represent influent concentrations.

4.3. WASTE LEACH MODEL

The primary purpose for conducting the leaching study was to determine a source term characteristic of the leaching of wastes disposed of in the CWF. The selection of waste drums for low radioactivity, from the standpoint of safety considerations, no doubt precluded the representativeness of the waste with respect to their concentrations of radionuclides. However, it is not anticipated that selection of low-activity drums biases the representativeness of the drums with respect to their concentrations of nonradioactive constituents. The important point is that the study offers an opportunity to demonstrate the utility of such large-scale leaching studies to characterize the leaching properties of wastes.

Drum 8 (see Table 3) was one of the few drums with leachate containing radioactivity adequate to provide sufficient data to be used in a proposed waste leach model. If one assumes that the leaching of constituents from waste by water takes the general form

$$A/A_0 = e^{-kr} ,$$

where

A = amount of the leachable radionuclide remaining on the waste in Bq/kg,

A_0 = total leachable radionuclide on the waste in Bq/kg,

k = a partition coefficient,

r = liquid-to-solid ratio (i.e., the ratio of leachate to mass of waste in L/kg),

then the leaching of alpha activity from drum 8 can be used to demonstrate the potential use of the model. For example, the alpha activity when plotted against time takes a general first-order leaching rate (see Figs. 3 and 4). However, to estimate the quantity of A_0 above, the same data can be expressed as a function of the liquid-to-solid ratio in the following manner:

$$A_0 - A = B_0(1 - e^{-Br})$$

The coefficients of B_0 and B can be estimated by nonlinear regression analysis using the leaching data over the range of liquid-to-solid ratios (see Fig. 5). The smooth curve fitted to the leaching data (illustrated by the stars in Fig. 5), is used to estimate the maximum leachable amount of activity (B_0 in units of Bq/kg) and a partition coefficient (B, which has units of kg/L). For this example, B_0 was estimated to be 10620 ± 943 Bq/kg and B to be 0.15 ± 0.03 kg/L, using the NLIN procedure of SAS (1982). At large r, $A_0 = B_0$. Since A_0 is now known, the percentage of the waste remaining can be determined (Fig. 6) as well as the partition coefficient (k) in the leach model. In this manner, not only is the total quantity of leachable radionuclide determined (estimated at 10,620 Bq/kg), but also the

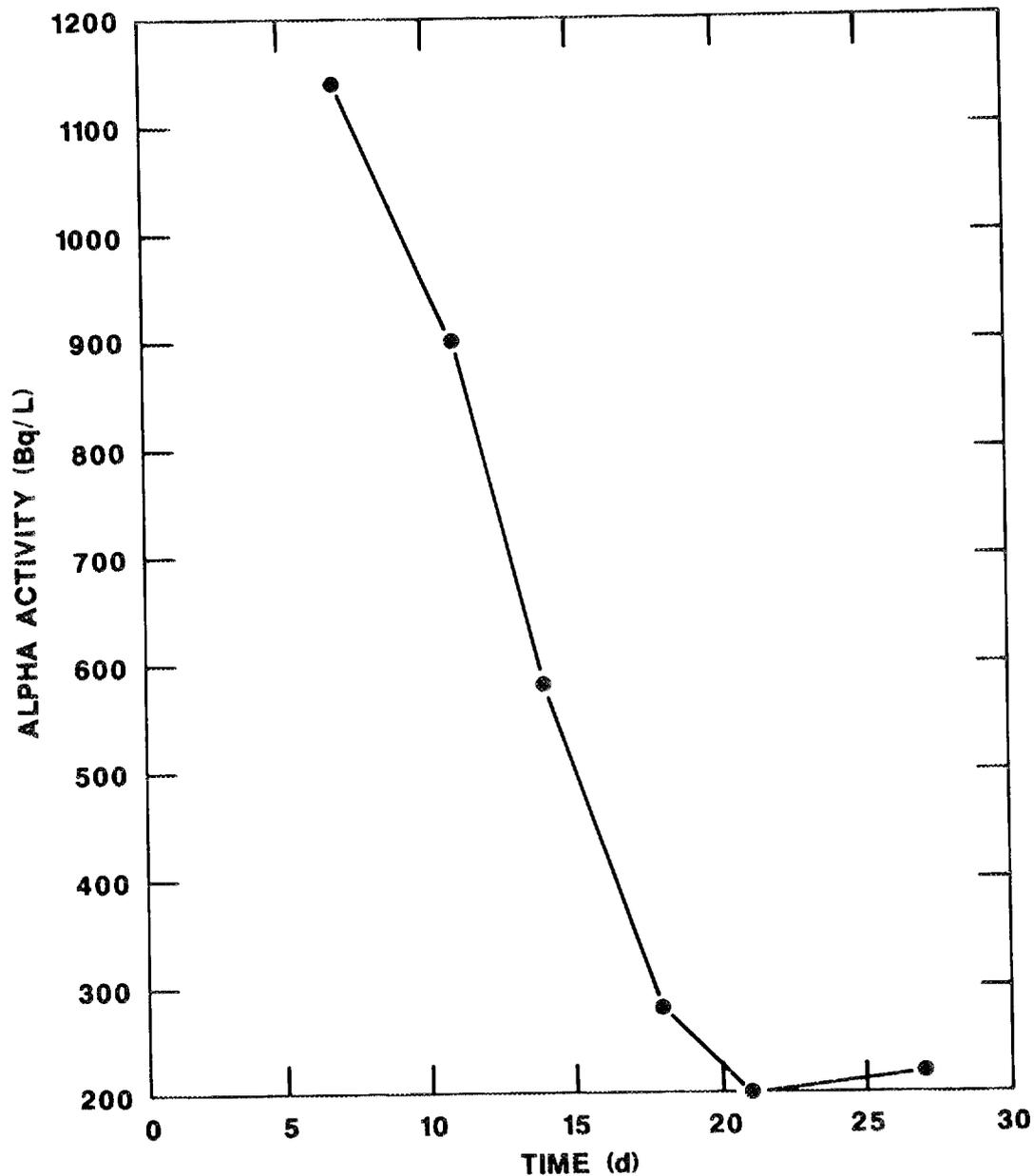


Fig. 3. Leaching of alpha activity from drum 8.

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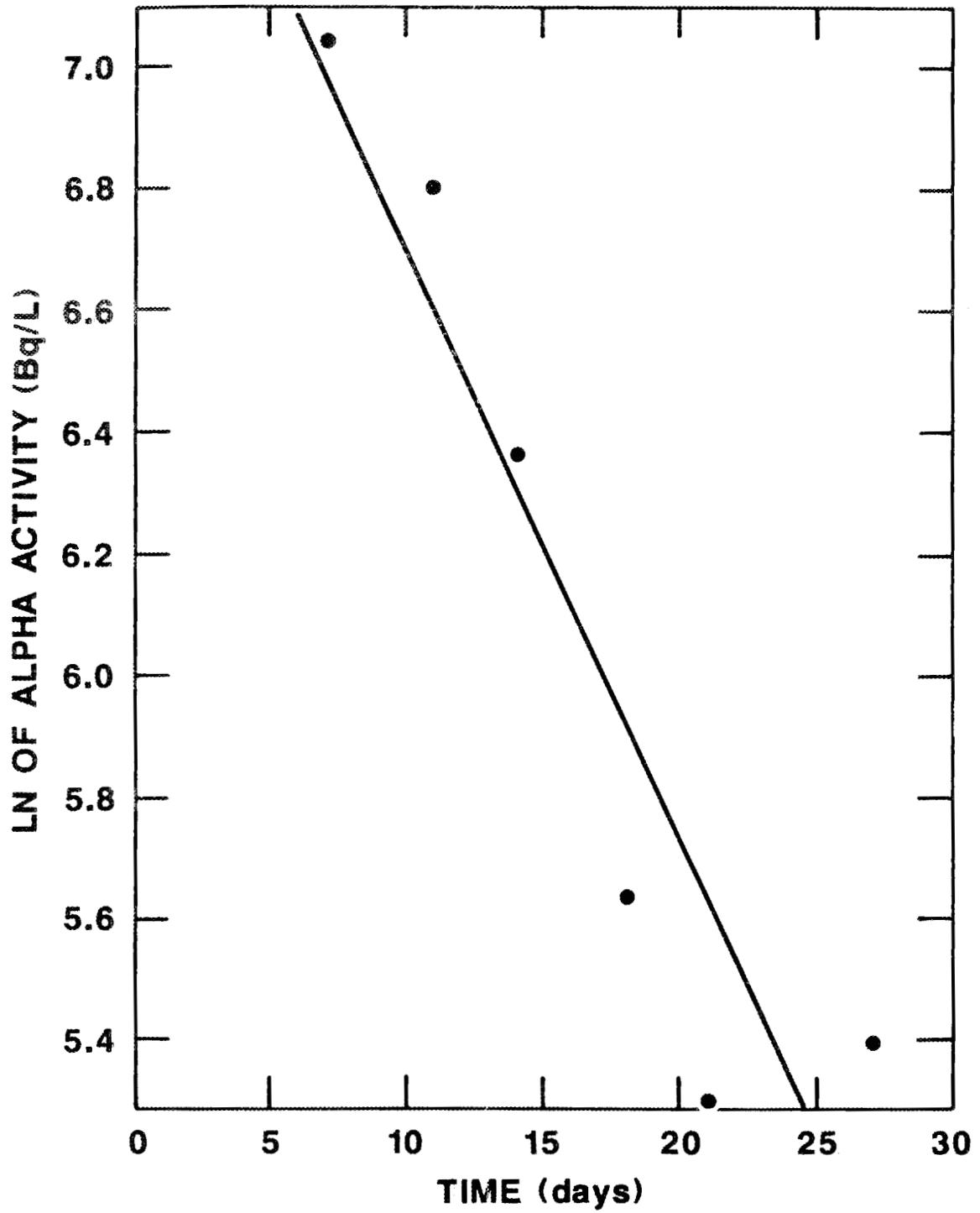


Fig. 4. First-order leaching kinetics of alpha activity from drum 8.

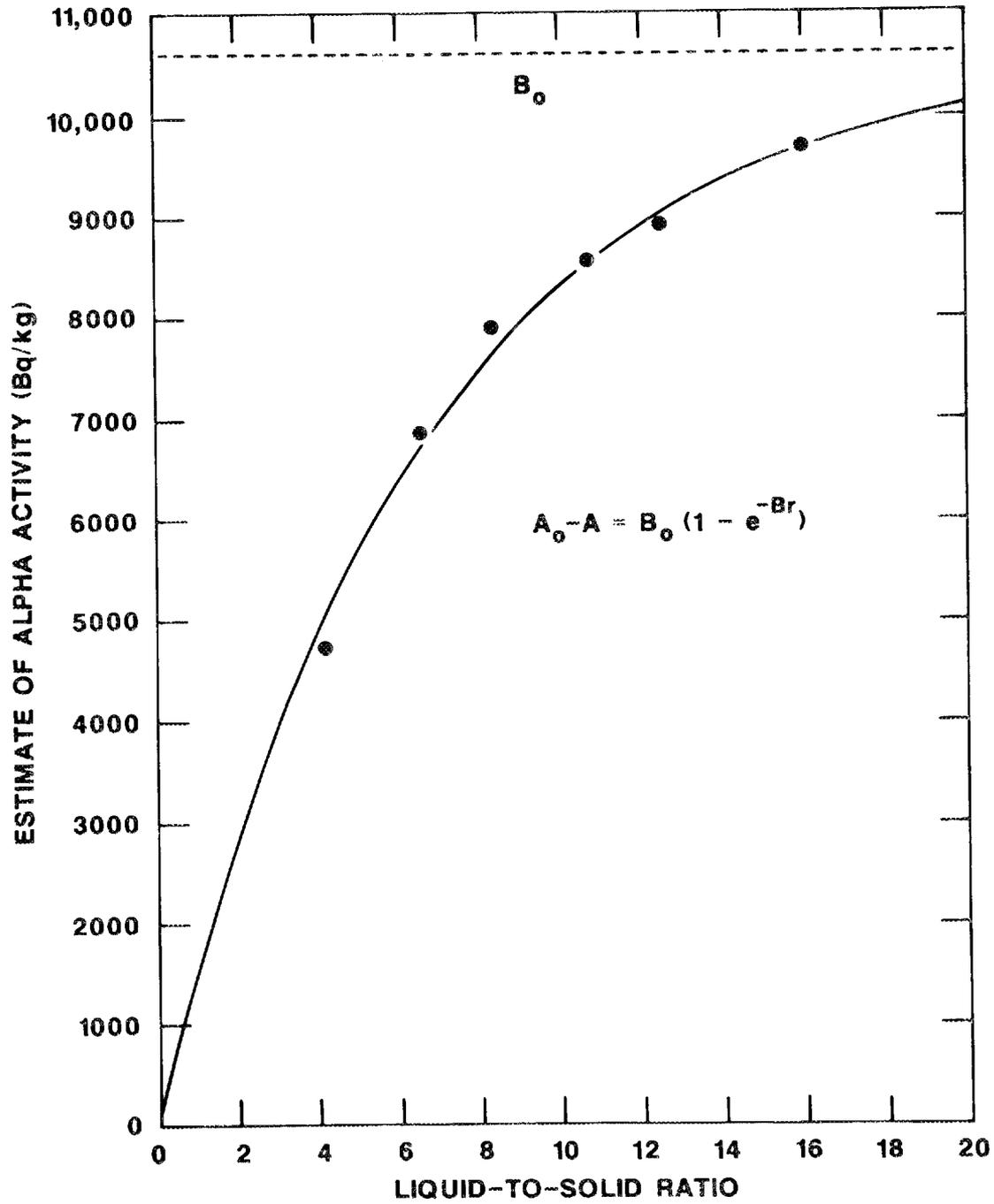


Fig. 5. Estimate of leachable alpha activity in drum 8.

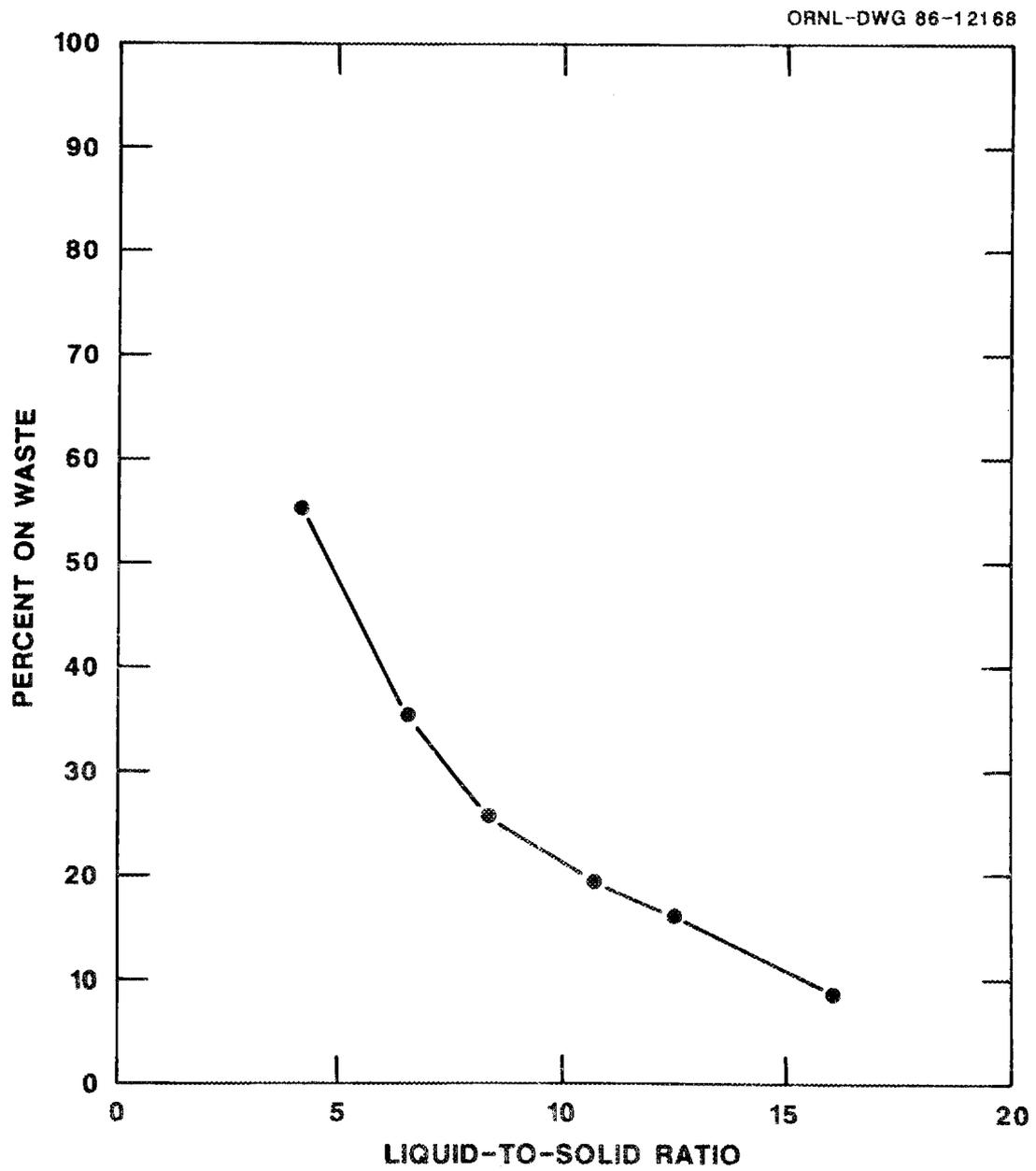


Fig. 6. Percent of leachable alpha activity remaining in drum 8.

partition coefficient needed to describe the rate at which the radionuclide is released from the waste. From an analytical standpoint, if the rate of water movement through a waste or a trench containing this waste is known, the value of k_r at $A/A_0 = 0.5$ can be used to estimate the time at which half of a soluble constituent will be leached from the waste. For the case of drum 8, over half of the alpha-emitting activity was lost from the waste at a liquid-to-solid ratio of less than five. Thus, these data indicate that the alpha activity from this waste would be leached relatively rapidly if water were allowed to move through the waste. It also implies that if the waste is buried in a shallow-land burial site that is occasionally saturated, any in situ monitoring would have to be conducted shortly after disposal to effectively estimate the source term for leaching of that waste. This assumes no containment of leachate by the drums or by any other waste container that might be used. The intent here is to describe the leaching characteristics of waste per se, not the leaching that would result as breachment of the waste container occurs.

The same leach model can be used to estimate the leachable quantities of ^{90}Sr , ^{137}Cs , and ^{60}Co from the compacted waste contained in drum 8c. There were, however, two important differences between the leaching of the TRU and compacted waste. First, accessibility of water to the wastes in the compacted drums was much more limited than it was in the case for the TRU wastes. Consequently, the kinetics of leaching constituents from the interstitial regions of the compacted wastes would be slower, owing to the diffusion of soluble constituents from the interstitial regions to regions of convectional

flow of water, than in the case for the TRU wastes, where water could move freely around the noncompacted waste (convectonal flow patterns). Second, the quantity of waste leached in the case of the compacted waste was significantly greater than it was for the TRU wastes [305 and 72 kg, respectively, for the compacted and TRU wastes (drum 8 in Table 1 and drum 8c in Table 2, respectively)]. For example, even though leaching was continued for 23 d, in terms of the liquid-to-solid ratio, the compacted waste (drum 8c) was leached only to a liquid-to-solid ratio of approximately 3 compared with 16 for the TRU wastes (drum 8).

Concentrations of ^{137}Cs and ^{90}Sr in the leachate collected from drum 8c (Table 9) peaked on day 6 of leaching and decreased on continued leaching. On the other hand, concentrations of ^{60}Co remained relatively constant over the 20 d the leachate was monitored. These data, transformed in terms of the amount of radioactivity leached per kilogram and expressed as a function of liquid-to-solid ratio, are illustrated in Figs. 7, 8, and 9 for ^{60}Co , ^{137}Cs , and ^{90}Sr , respectively. The leaching rate of ^{60}Co is constant to the liquid-to-solid ratio of three, and it is clear that further leaching would be required to use the model to predict the total leachable quantity of this isotope from the waste. Extrapolation of the leach curves for ^{137}Cs and ^{90}Sr gave estimates of 5700 and 1400 Bq/kg, respectively. However, these are only preliminary estimates, and leaching to at least a liquid-to-solid ratio of 15, or preferably to 20:1, should be conducted for estimates of higher precision.

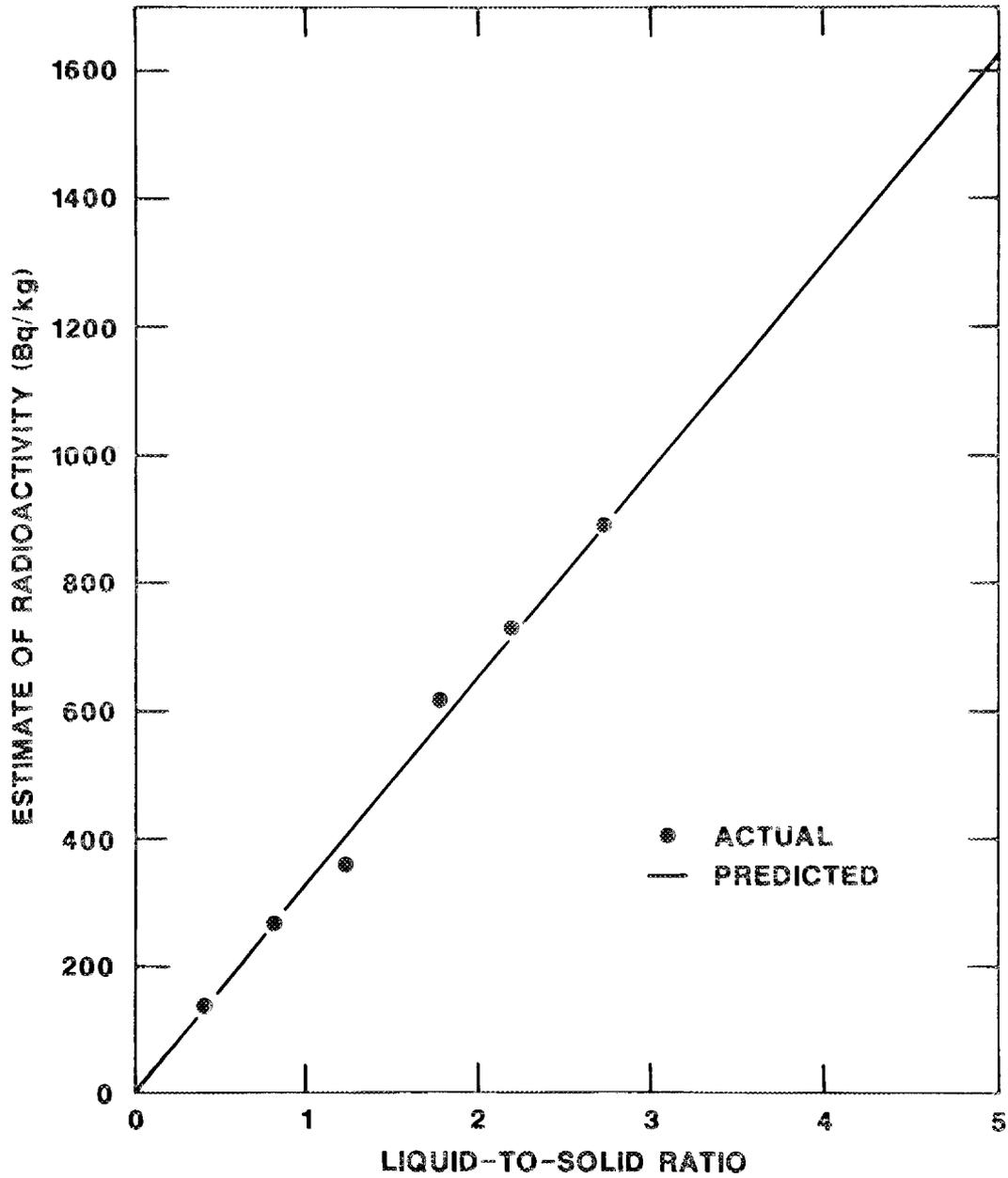


Fig. 7. Estimate of leachable ⁶⁰Co in drum 8c.

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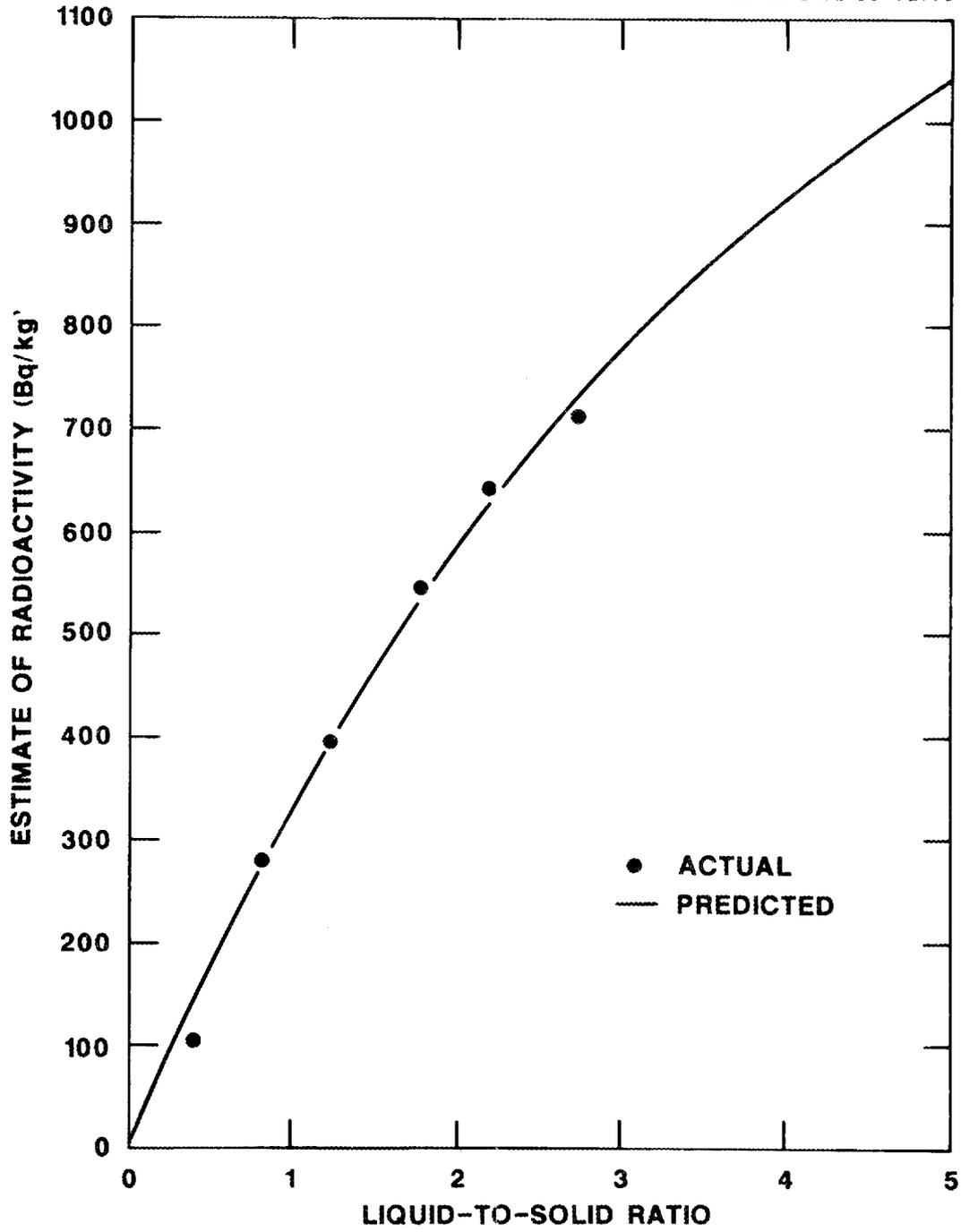


Fig. 8. Estimate of leachable ¹³⁷Cs in drum 8c.

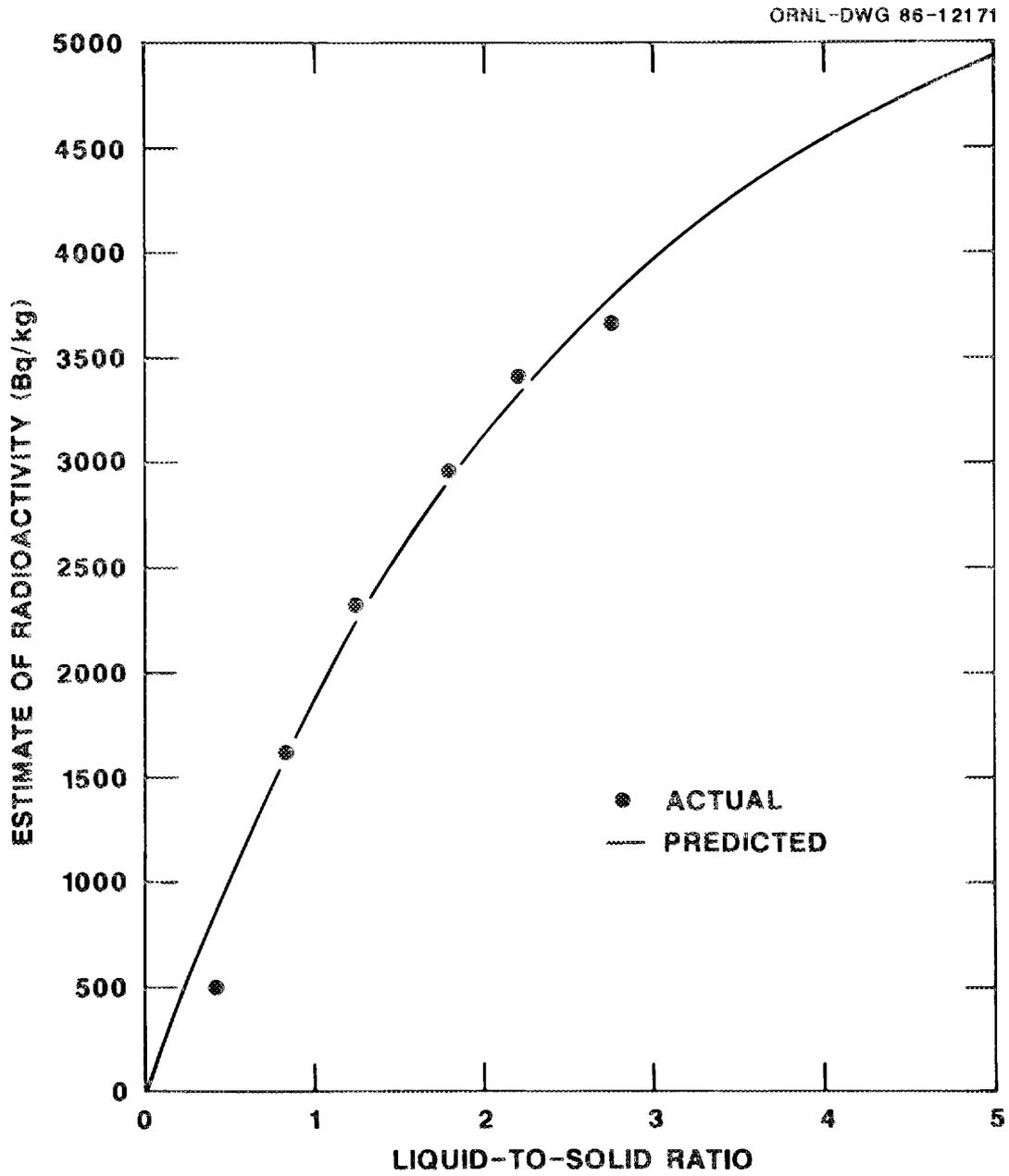


Fig. 9. Estimate of leachable ⁹⁰Sr in drum Bc.

5. SUMMARY AND CONCLUSIONS

The large-scale leaching of low-level radioactive wastes was conducted using 208- and 314-L (55- and 83-gal) drums containing radioactive wastes generated at ORNL and ORGDP. Ten 208-L drums containing low-level TRU wastes were leached with potable drinking water using a unique design to simulate the possible flooded conditions of a shallow-land burial site. The drums selected were those that contained less than 3.7 kBq/g (100 nCi/g) of transuranics and less than 5 mR/h gamma radiation at the surface of the drum. These steps were taken as a safety measure because this was the first attempt to leach drums in such a manner. For example, it was necessary to open the drums and replace the drum lids to assure that influent water was delivered to the bottom of the drum. A laboratory safety assessment committee concurred with the experimental design only if the drums selected were those that contained a minimum of alpha and gamma activity.

The rigorous selection requirement for drums of waste precluded the opportunity to observe detectable concentrations of radioactivity in the leachates of all drums. For example, only one of the ten drums generated a leachate that contained detectable levels of alpha activity over a 27 d leach period: concentrations ranging from approximately 1200 to 200 Bq/L. Using these data as input, the proposed leach model predicted that the waste contained approximately 11,000 Bq/kg of leachable alpha activity.

In addition to measurements of radioactivity in the leachates generated from each of the ten 208-L drums of TRU waste, concentrations

of inorganic and organic constituents were monitored. The concern with respect to metal concentrations in the TRU leachates was the concentration of cadmium. For example, maximum cadmium concentrations in the leachates of all ten TRU drums were equal to, and in many cases in excess of, the National Interim Primary Drinking Water Standard (NIPDWS). However, cadmium concentrations were factors of ten below the maximum limit established by the RCRA-EP leach test (1 mg/L), defining the toxicity characteristic of the waste. The high concentrations of cadmium were observed in the early stages of leaching, generally day 7 of leaching, and only one drum generated a leachate that contained cadmium concentrations in excess of the NIPDWS after 21 d of leaching.

Considerable effort, with respect to time and expense, was made to determine the concentrations of potentially hazardous organic chemicals in the leachates of the TRU wastes, as relatively little is known about concentrations of such organic compounds in leachates of laboratory-derived low-level radioactive wastes. The major organic constituent detected in the TRU leachates was phenol at concentrations of 1 to 2 mg/L in leachates from two of the ten drums. Other organic compounds detected in TRU leachates were some phthalates, bromodichloromethane, chlorodibromomethane, chloroform, and some chlorinated ethanes and ethenes. Maximum concentrations of these organic compounds were quite low, usually on the order of 0.05 to 0.5 mg/L, indicating that the shallow-land disposal of these materials would not likely contaminate groundwater supplies with hazardous organic chemicals.

Four overpack drums containing compacted drums from a Westinghouse-Hittman drum compaction demonstration at ORNL were leached to determine concentrations of radionuclides in their leachates. Each of these four 314-L overpack drums contained from three to seven crushed 208-L waste drums originating at either ORNL or ORGDP. The net weights of crushed wastes in the drums ranged from 300 to nearly 500 kg. The quantity of radioactivity in the wastes was expected to be low because one of the acceptance criteria was only those 208-L waste drums with surface readings of <5 mR/h. However, one of the resulting overpack drums did show gamma radiation levels on the order of 10 mR/h at the drum surface. This drum generated leachates containing detectable concentrations of ^{137}Cs , ^{60}Co , and ^{90}Sr (concentrations ranging from 3000 Bq/L of ^{137}Cs to 130 Bq/L of ^{90}Sr) over 20 d of leaching. Another showed detectable levels of ^{90}Sr (200 to 30 Bq/L) and another, detectable levels of alpha activity (<50 Bq/L) in their leachates. Leaching, although conducted for 23 d, had not yet reached a liquid-to-solid ratio greater than 3 (because of the large mass being leached); thus, precise estimates of the quantities of total leachable radioactivity could not be determined using the proposed leach model.

On preparation of the overpack drums for leaching, a strong odor indicative of volatile organic compounds was noted emanating from one of the drums. Thus, leachates from these drums were analyzed for volatile organic compounds. Leachate collected from the drum that generated the strong odor contained concentrations of 1,1,1-trichloroethane and/or 1,2-dichloroethane in excess of 0.3 mg/L.

Leachates from two of the other four drums contained from 0.05 to 0.1 mg/L of tetrachloroethene. The source of these organic compounds is unknown; however, these compounds are known to be present in degreasing solvents. Chloroform and bromodichloromethane were also detected in the leachates but only at levels <0.02 mg/L. Other than the concentrations of 1,1,1-trichloroethane in leachates of one of the drums, the analysis of the leachates for the large array of volatile organic compounds revealed that groundwater probably would not be contaminated with volatile organics on disposal of these low-level radioactive wastes in a shallow-land burial site.

A waste model was used to demonstrate how concentrations of leachable constituents from a waste can be estimated. Using the leaching data from one of the TRU wastes, the total quantity of alpha activity available for leaching was estimated to be 10,620 Bq/kg of waste. The model can also be used to estimate leachable quantities of inorganic and organic compounds from wastes. The model, coupled with this large-scale leaching method for wastes, is an excellent method to determine the leaching characteristics of large-volume low-level radioactive wastes where the subsampling of such wastes into 100-g "representative" samples is a difficult and probably impossible task.

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APPENDIX A

LEACHATE CHARACTERISTICS

Table 1A. Concentrations (in mg/L) of metals in leachate collected from drum 1

Element	Day		
	7	14	21
Ag	<0.05	<0.05	<0.05
Al	0.29	<0.20	<0.20
As	<0.10	<0.10	<0.10
B	<0.08	<0.08	<0.08
Ba	0.06	0.04	0.04
Ca	50	43	50
Cd	0.019 ^a	<0.005	<0.005
Co	0.011	<0.005	<0.060
Cr	0.15 ^a	<0.04	<0.04
Cu	<0.02	<0.02	<0.02
Fe	28	22	35
Li	<0.20	<0.20	<0.20
Mg	10	9.6	8.5
Mn	0.3	0.22	0.23
Mo	<0.04	<0.04	<0.04
Na	17	12	11
Ni	0.47 ^a	0.28	<0.06
P	4.4	1.2	2
Pb	<0.20	<0.20	<0.20
Sb	<0.20	<0.20	<0.20
Se	<0.20	<0.20	<0.20
Si	2.4	2.3	3.4
Sr	0.11	0.1	0.095
Ti	<0.02	<0.02	<0.02
V	<0.01	<0.01	<0.01
Zn	3.4	<0.02	0.08
Zr	<0.02	<0.02	<0.02

^aConcentration in excess of the groundwater quality criteria for metals listed in Table 4.

Table 2A. Concentrations (in mg/L) of metals in leachate collected from drum 2

Element	Day		
	7	14	21
Ag	<0.05	<0.05	<0.05
Al	<0.20	<0.10	<0.20
As	<0.10	<0.10	<0.10
B	<0.08	<0.08	<0.08
Ba	0.073	0.034	0.045
Ca	33	50	40
Cd	0.015 ^a	<0.005	<0.005
Co	<0.01	<0.01	<0.01
Cr	<0.04	<0.04	<0.04
Cu	<0.02	<0.02	<0.02
Fe	<0.03	0.24	0.12
Li	<0.20	<0.20	<0.20
Mg	8.7	14	8.2
Mn	0.017	0.019	0.026
Mo	<0.04	<0.04	<0.04
Na	5.2	5.3	5.4
Ni	<0.06	<0.06	<0.06
P	<0.30	<0.30	<0.30
Pb	<0.20	<0.20	<0.20
Sb	<0.20	<0.20	<0.20
Se	<0.20	<0.20	<0.20
Si	1.9	8.2	3.2
Sr	0.082	0.086	0.078
Ti	<0.02	<0.02	<0.02
V	<0.01	<0.01	<0.01
Zn	0.1	0.1	0.06
Zr	<0.02	<0.02	<0.02

^aConcentration in excess of the groundwater quality criteria for metals listed in Table 4.

Table 3A. Concentrations (in mg/L) of metals in leachate collected from drum 3

Element	Day		
	7	14	21
Ag	<0.05	<0.05	<0.05
Al	<0.20	<0.20	<0.20
As	<0.10	<0.10	<0.10
B	<0.08	<0.08	<0.08
Ba	0.066	0.043	0.034
Ca	31	34	38
Cd	0.038 ^a	0.014 ^a	0.0072
Co	<0.01	<0.01	<0.01
Cr	<0.04	<0.04	<0.04
Cu	<0.02	<0.02	<0.02
Fe	0.5	0.44	0.62
Li	<0.20	<0.20	<0.20
Mg	8.5	9.1	8.8
Mn	0.032	0.029	0.025
Mo	<0.04	<0.04	<0.04
Na	9.8	7.3	5.6
Ni	<0.06	<0.06	<0.06
P	1.3	0.71	0.38
Pb	<0.20	<0.20	<0.20
Sb	<0.20	<0.20	<0.20
Se	<0.20	<0.20	<0.20
Si	2	2.1	2.7
Sr	0.08	0.079	0.074
Ti	<0.02	<0.02	<0.02
V	<0.01	<0.01	<0.01
Zn	5.4 ^a	6.4 ^a	5.6 ^a
Zr	<0.02	<0.02	<0.02

^aConcentration in excess of the groundwater quality criteria for metals listed in Table 4.

Table 4A. Concentrations (in mg/L) of metals in leachate collected from drum 4

Element	Day		
	7	14	21
Ag	<0.05	<0.05	<0.05
Al	<0.20	<0.20	<0.20
As	<0.10	<0.10	<0.10
B	<0.08	<0.08	<0.08
Ba	0.69	0.24	0.14
Ca	41	42	50
Cd	0.056 ^a	0.0057	<0.005
Co	<0.01	<0.01	<0.01
Cr	<0.04	<0.04	<0.04
Cu	<0.02	<0.02	<0.02
Fe	0.075	0.11	0.24
Li	<0.20	<0.20	<0.20
Mg	18	14	14
Mn	0.018	0.013	0.019
Mo	<0.04	<0.04	<0.04
Na	5.9	5.2	5.3
Ni	<0.06	<0.06	<0.06
P	0.4	<0.30	<0.30
Pb	<0.20	<0.20	<0.20
Sb	<0.20	<0.20	<0.20
Se	<0.20	<0.20	<0.20
Si	10	7.5	8.2
Sr	0.1	0.085	0.086
Ti	<0.02	<0.02	<0.02
V	<0.01	<0.01	<0.01
Zn	0.46	0.17	0.1
Zr	<0.02	<0.02	<0.02

^aConcentration in excess of the groundwater quality criteria for metals listed in Table 4.

Table 5A. Concentrations (in mg/L) of metals in leachate collected from drum 5

Element	Day		
	7	14	21
Ag	<0.05	<0.05	<0.05
Al	<0.20	<0.10	<0.20
As	<0.10	<0.10	<0.10
B	<0.08	<0.08	<0.08
Ba	0.06	0.051	0.049
Ca	32	35	41
Cd	0.011 ^a	<0.005	<0.005
Co	<0.01	<0.01	<0.01
Cr	<0.04	<0.04	<0.04
Cu	<0.04	<0.02	<0.02
Fe	0.092	0.27	0.32
Li	<0.20	<0.20	<0.20
Mg	8.8	9.9	7.7
Mn	0.0067	0.026	0.031
Mo	<0.04	<0.04	<0.04
Na	4.8	5	5.3
Ni	<0.06	<0.06	<0.06
P	<0.30	<0.30	<0.30
Pb	<0.20	<0.20	<0.20
Sb	<0.20	<0.20	<0.20
Se	<0.20	<0.20	<0.20
Si	2	2.1	3.6
Sr	0.076	0.073	0.074
Ti	<0.02	<0.02	<0.02
V	<0.01	<0.01	<0.01
Zn	0.1	0.13	0.086
Zr	<0.02	<0.02	<0.02

^aConcentration in excess of the groundwater quality criteria for metals listed in Table 4.

Table 6A. Concentrations (in mg/L) of metals in leachate collected from drum 6

Element	Day		
	7	14	18
Ag	<0.05	<0.05	<0.05
Al	<0.20	<0.20	<0.20
As	<0.10	<0.10	<0.10
B	<0.08	<0.08	<0.08
Ba	0.097	0.034	0.034
Ca	32	36	36
Cd	0.011 ^a	<0.005	<0.005
Co	<0.01	<0.01	<0.01
Cr	<0.04	<0.04	<0.04
Cu	<0.02	<0.02	<0.02
Fe	0.067	<0.03	0.049
Li	<0.20	<0.20	<0.20
Mg	8.6	9.4	9.4
Mn	0.033	0.025	0.03
Mo	<0.04	<0.04	<0.04
Na	4.7	4.9	4.9
Ni	<0.06	<0.06	<0.06
P	<0.30	<0.30	<0.30
Pb	<0.20	<0.20	<0.20
Sb	<0.20	<0.20	<0.20
Se	<0.20	<0.20	<0.20
Si	1.9	2.1	2.1
Sr	0.079	0.073	0.72
Ti	<0.02	<0.02	<0.02
V	<0.01	<0.01	<0.01
Zn	0.46	0.12	0.051
Zr	<0.02	<0.02	<0.02

^aConcentration in excess of the groundwater quality criteria for metals listed in Table 4.

Table 7A. Concentrations (in mg/L) of metals in leachate collected from drum 7

Element	Day		
	7	14	21
Ag	<0.05	<0.05	<0.05
Al	<0.20	<0.20	<0.20
As	<0.10	<0.10	<0.10
B	<0.08	<0.08	<0.08
Ba	0.15	0.13	0.085
Ca	32	35	39
Cd	0.1 ^a	0.12 ^a	0.083 ^a
Co	<0.01	<0.01	<0.01
Cr	<0.04	<0.01	<0.04
Cu	<0.02	<0.02	<0.02
Fe	0.34	0.11	0.3
Li	<0.20	<0.20	<0.20
Mg	8.7	9.3	8.2
Mn	0.023	0.17	0.023
Mo	<0.04	<0.04	<0.04
Na	5.8	5.8	5.6
Ni	<0.06	<0.06	<0.06
P	<0.30	<0.30	<0.30
Pb	<0.20	<0.20	<0.20
Sb	<0.20	<0.20	<0.20
Se	<0.20	<0.20	<0.20
Si	1.9	2	3
Sr	0.078	0.074	0.074
Ti	<0.02	<0.02	<0.02
V	<0.01	<0.01	<0.01
Zn	0.48	0.43	0.21
Zr	<0.02	<0.02	<0.02

^aConcentration in excess of the groundwater quality criteria for metals listed in Table 4.

Table 8A. Concentrations (in mg/L) of metals in leachate collected from drum 8

Element	Day		
	7	14	21
Ag	<0.05	<0.05	<0.05
Al	<0.20	<0.20	<0.20
As	<0.10	<0.10	<0.10
B	<0.08	<0.08	<0.08
Ba	0.54	0.034	0.048
Ca	48	50	53
Cd	0.011 ^a	0.011 ^a	0.0058
Co	0.011	<0.01	<0.01
Cr	<0.04	<0.04	<0.04
Cu	<0.02	<0.02	<0.02
Fe	0.99	0.62	0.65
Li	<0.20	<0.20	<0.20
Mg	10	10	6.9
Mn	0.039	0.04	0.036
Mo	<0.04	<0.04	<0.04
Na	130	64	32
Ni	<0.06	<0.06	<0.06
P	26	13	4.9
Pb	<0.20	<0.20	<0.20
Sb	<0.20	<0.20	<0.20
Se	<0.20	<0.20	<0.20
Si	3.2	2.6	4.2
Sr	0.15	0.11	0.098
Ti	<0.02	<0.02	<0.02
V	<0.01	<0.01	<0.01
Zn	2	1.5	0.85
Zr	<0.02	<0.02	<0.02

^aConcentration in excess of the groundwater quality criteria for metals listed in Table 3.

Table 9A. Concentrations (in mg/L) of metals in leachate collected from drum 9

Element	Day		
	7	14	21
Ag	<0.05	<0.05	<0.05
Al	<0.20	<0.20	<0.20
As	<0.10	<0.10	<0.10
B	0.081	0.63	<0.08
Ba	0.13	0.098	0.12
Ca	47	55	53
Cd	0.11 ^a	0.02 ^a	0.0058
Co	5.6	1.2	<0.04
Cr	<0.04	<0.04	<0.04
Cu	<0.02	<0.02	<0.02
Fe	0.17	0.33	0.71
Li	<0.20	<0.20	<0.20
Mg	13	12	10
Mn	0.041	0.043	0.028
Mo	<0.04	<0.04	<0.04
Na	9.8	7.5	6.8
Ni	0.094	<0.06	<0.06
P	1.6	1.1	0.52
Pb	<0.20	<0.20	<0.20
Sb	<0.20	<0.20	<0.20
Se	<0.20	<0.20	<0.20
Si	4.6	4.4	5.1
Sr	0.25	0.21	0.16
Ti	<0.02	<0.02	<0.02
V	<0.01	<0.01	<0.01
Zn	0.82	2.2	5.1 ^a
Zr	<0.02	<0.02	<0.02

^aConcentration in excess of the groundwater quality criteria for metals listed in Table 4.

Table 10A. Concentrations (in mg/L) of metals in leachate collected from drum 10

Element	Day		
	7	14	21
Ag	<0.05	<0.05	<0.05
Al	<0.20	<0.20	<0.20
As	<0.10	<0.10	<0.10
B	<0.08	<0.08	<0.08
Ba	0.18	0.1	0.11
Ca	40	44	47
Cd	0.025 ^a	0.012 ^a	<0.005
Co	<0.01	<0.01	<0.01
Cr	<0.04	<0.04	<0.04
Cu	<0.02	<0.02	<0.02
Fe	1.1	2.2	2.7
Li	<0.20	<0.20	<0.20
Mg	9.1	9.8	6.7
Mn	0.052	0.048	0.048
Mo	<0.04	<0.04	<0.04
Na	43	21	15
Ni	<0.06	<0.06	<0.06
P	6.9	3.5	1.7
Pb	<0.20	<0.20	<0.20
Sb	<0.20	<0.20	<0.20
Se	<0.20	<0.20	<0.20
Si	2.8	2.5	4.2
Sr	0.09	0.092	0.086
Ti	<0.02	<0.02	<0.02
V	<0.01	<0.01	<0.01
Zn	1.5	1	0.42
Zr	<0.02	<0.02	<0.02

^aConcentration in excess of the groundwater quality criteria for metals listed in Table 4.

Table 11A. Metal concentrations (mg/L) in interstitial leachate of the TRU wastes after standing for 31 d

Element	Drum									
	1	2	3	4	5	6	7	8	9	10
Ag	<0.05	<0.05	<0.10	<0.05	<0.05	<0.05	<0.05	<0.05	<0.30	<0.05
Al	<0.20	<0.20	<0.40	0.37	<0.20	<0.20	<0.20	<0.20	<1.2	<0.20
As	<0.10	<0.10	<0.20	<0.10	<0.10	<0.10	<0.10	<0.10	<0.60	<0.10
B	<0.08	<0.08	<0.16	<0.08	<0.08	<0.08	0.11	<0.08	<0.48	<0.08
Ba	0.077	0.32	0.72	0.16	0.11	0.081	0.29	0.16	0.52	0.11
Ca	61	41	40	64	35	40	37	140	77	80
Cd	<0.005	<0.005	0.022 ^a	<0.005	<0.005	<0.005	0.17 ^a	0.006	<0.03	0.006
Co	<0.01	<0.01	<0.02	<0.01	<0.01	<0.01	<0.01	0.014	3.7	<0.01
Cr	<0.04	<0.04	<0.08	<0.04	<0.04	<0.04	<0.04	0.058	<0.24	<0.04
Cu	<0.02	<0.02	<0.04	<0.02	<0.02	<0.02	<0.02	<0.02	<0.12	<0.02
Fe	220	26	5.1	2.4	7.7	2.3	4.5	7	7.3	31
Li	<0.20	<0.20	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<1.2	<0.20
Mg	0.69	8.8	8.4	20	12	9.4	8.4	<0.20	14	10
Mn	<0.04	0.24	0.04	0.072	0.11	0.99	0.053	0.14	0.11	0.3
Mo	<0.04	<0.04	<0.08	<0.04	<0.04	<0.04	<0.04	<0.04	<0.24	<0.04
Na	10	8.2	4.7	5.2	5.4	5.3	8	180	9.1	92
Ni	0.067	<0.06	<0.12	<0.06	<0.06	<0.06	<0.06	0.063	<0.36	<0.06
P	4.1	0.57	1.5	1.4	0.79	0.61	0.47	45	3.4	16
Pb	<0.20	<0.20	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<1.2	0.20
Sb	0.35	<0.20	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<1.2	0.20
Se	<0.20	<0.20	<0.40	<0.20	<0.20	<0.20	<0.20	<0.20	<1.2	0.20
Si	3.2	3	2.6	16	3.1	2.5	2.4	4.7	8	5.8
Sr	0.18	0.12	0.08	0.1	0.081	0.0086	0.085	0.3	0.26	0.17
Ti	<0.02	<0.02	<0.04	<0.02	<0.02	<0.02	<0.02	<0.02	<0.12	<0.02
Zn	0.12	0.51	37 ^a	0.64	0.59	0.073	0.26	0.38	140 ^a	0.13
Zr	<0.02	<0.02	<0.04	<0.02	<0.02	<0.02	<0.02	<0.02	<0.12	<0.02

^aConcentration in excess of the groundwater quality criteria for metals listed in Table 4.

Table 12A. Concentrations ($\mu\text{g/L}$) of organic compounds detected in leachate collected from TRU wastes

Drum and chemical	Day				
	7	11	14	18	58 ^a
Drum 1					
Bromodichloromethane	21	<1	10	18	ND ^b
Chlorodibromomethane	<1	<1	<1	1	ND
Chloroform	61	<1	31	57	ND
Phenol	1398	<10	904	468	>200
Trichloroethene	21	<1	10	18	ND
1,1,1-Trichloroethane	25	<10	<10	<10	ND
1,1,2-Trichloroethane	17	<10	<10	<10	ND
1,2-Dichloroethane	25	<10	<10	<10	ND
Drum 2					
Bromodichloromethane	21	21	8	20	ND
Chlorodibromomethane	<1	1	<1	1	ND
Chloroform	52	63	28	62	ND
Trichloroethene	21	21	8	20	ND
1,1,1-Trichloroethane	68	26	<10	16	ND
1,2-Dichloroethane	68	26	<10	16	ND
Drum 3					
Bromodichloromethane	10	14	5	42	ND
Chlorodibromomethane	<1	<1	<1	1	ND
Chloroform	35	46	20	65	ND
Diethylphthalate	<10	<10	21	14	<10
Phenol	429	<10	504	282	305
Trichloroethene	10	14	5	42	ND
1,1,1-Trichloroethane	8	<10	<10	<10	ND
1,2-Dichloroethane	8	<10	<10	<10	ND
Drum 4					
Bromodichloromethane	7	2	<1	<1	ND
Chloroform	41	44	24	41	ND
Phenol	427	<10	162	87	151
Trichloroethene	7	2	<1	<1	ND
1,1,1-Trichloroethane	28	10	<10	<10	ND
1,2-Dichloroethane	28	10	<10	<10	ND

Table 12A. (continued)

Drum and chemical	Day				
	7	11	14	18	58 ^a
Drum 5					
Bromodichloromethane	7	21	14	22	ND
Chlorodibromomethane	<1	1	<1	1	ND
Chloroform	27	61	36	58	ND
Phenol	<10	<10	<10	<10	>200
Trichloroethene	7	21	14	22	ND
1,1,1-Trichloroethane	8	12	12	12	ND
1,2-Dichloroethane	8	12	12	12	ND
Drum 6					
Bromodichloromethane	18	6	8	20	ND
Chloroform	40	23	27	44	ND
Trichloroethene	18	6	8	20	ND
1,1,2-Trichloroethane	<5	<10	<10	<10	ND
1,2-Dichloroethane	6	<10	<10	<10	ND
Drum 7					
Bromodichloromethane	<4.7	5	226	10	ND
Chlorodibromomethane	<1	<1	28	<1	ND
Chloroform	17	22	133	29	ND
Tetrachloroethene	<1	<1	3	<1	ND
Trichloroethene	2	5	226	10	ND
1,1,1-Trichloroethane	10	<10	184	<10	ND
1,2-Dichloroethane	10	<10	184	<10	ND
Drum 8					
Bis(2-ethylhexyl)phthalate	<10	34	24	<10	<10
Bromodichloromethane	<2.2	5	25	3	ND
Chlorodibromomethane	<1	<1	2	<1	ND
Chloroform	13	24	55	21	ND
Phenol	<10	73	348	242	153
Trichloroethene	<1.9	5	25	3	ND
1,1,1-Trichloroethane	4	<10	43	<10	ND
1,2-Dichloroethane	4	<10	43	<10	ND

Table 12A. (continued)

Drum and Chemical	Day				
	7	11	14	18	58 ^a
Drum 9					
Bis(2-ethylhexyl)phthalate	<10	<10	18	<10	<10
Bromodichloromethane	ND	2	<1	2	ND
Chloroform	ND	18	<1	19	ND
Phenol	222	320	516	416	>200
Trichloroethene	ND	2	<1	2	ND
1,1,1-Trichloroethane	ND	<10	<10	271	ND
1,2-Dichloroethane	ND	<10	<10	271	ND
Drum 10					
Bis(2-ethylhexyl)phthalate	<10	<10	39	17	<10
Bromodichloromethane	ND	2	9	4	ND
Chloroform	ND	19	40	25	ND
Phenol	<10	416	1315	964	>200
Trichloroethene	ND	2	9	4	ND
1,1,1-Trichloroethane	ND	271	915	317	ND
1,2-Dichloroethane	ND	271	915	317	ND

^aConcentrations reported for day 58 are those concentrations in the interstitial leachate after standing for 31 days without fresh influent pumped into the drum.

^bND = not determined.

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