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PROPERTIES OF RADIOACTIVE WASTES
AND WASTE CONTAINERS

QUARTERLY PROGRESS REPORT

APRIL-JUNE 1980

MASTER

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ABSTRACT

A study was initiated to determine the effect of varying V/S (the ratio of the waste form volume to its surface area) on the leachability of radioisotopes incorporated in cement forms. Cesium-137 and strontium-85 mixed with a simulated formulation of waste derived from forced recirculation evaporator bottoms of LWR's were solidified in portland II cement. The V/S ratios of the forms varied from 0.41 to 2.77. The resulting forms were leached using a modified IAEA procedure. Leaching data indicate an inverse relationship between the amount of leached radioactivity and V/S value.

Experiments were undertaken to determine the degree of desorption of Cs-137 initially adsorbed on cation organic ion exchange resins upon mixing with cement paste and during the plastic phase of the curing process. Portland II and lumnite cements were used as the solidification agents. Twenty seven percent of the Cs-137 was removed from the ion exchange resins after two hours of contact with portland II cement, whereas, 43 % of the activity was removed from the resins after the same contact period with lumnite cement.

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1. EFFECTS OF SPECIMEN DIMENSIONS ON LEACHABILITY

1.1 Introduction

Several theoretical and empirical methods have been developed to predict the leachability of radioisotopes incorporated in cement composites.⁽¹⁻⁵⁾ A method has been recommended by the International Atomic Energy Agency (IAEA) for leaching samples and for the analysis of the leaching data.⁽⁶⁾ The method assumes a semi-infinite plane source model of diffusion for the radioisotopes from the waste composites. The solution for the rate equation describing the model is:

$$M = 2C_0 \left(\frac{Dt}{\pi} \right)^{1/2} \quad (1.1)$$

where M = amount of substance diffused out of the form during time t (in days) per unit surface,
 C_0 = initial concentration of substance incorporated into the cement form,
 D = effective diffusion coefficient of the substance.

The total amount of the substance leached from the whole form is $M \times S$ where S is the total surface of the solid. Furthermore, if the leaching method is such that the sample is leached daily with fresh leachant, then $M \times S = a_n$ (cumulative fraction released), where a_n = the amount of the substance observed to diffuse out of the form each elution period. Equation 1.1 may be rewritten as

$$\sum_{i=1}^t a_n = 2 \cdot S \cdot C_0 \left(\frac{Dt}{\pi} \right)^{1/2} \quad (1.2)$$

For the special case where the specimen used for leaching is a cylinder, with volume V , and the total amount of substance incorporated in A_0 , the initial concentration of the incorporated substance is:

$$C_0 = \frac{A_0}{V} \quad (1.3)$$

Substituting for C_0 in equation 1.2 and rearranging yields:

$$\frac{V}{S} \cdot \left(\frac{\sum_{i=1}^t a_n}{A_0} \right) = 2 \left(\frac{Dt}{\pi} \right)^{1/2} \quad (1.4)$$

Equation 1.4 is the solution for the semi-infinite model for mass transport by diffusion from a homogeneous cylindrical medium having a zero surface concentration at any time $t > 0$. It can be directly applied to radioactive substances

if their decay can be neglected during the leaching process. Correcting for the decay of the radionuclide under study, Eq. 1.4 becomes:

$$\frac{V}{S} \left(\sum_{i=1}^t \frac{a_n}{A_0 e^{-\lambda \Delta t_i}} \right) = 2 \left(\frac{Dt}{\pi} \right)^{\frac{1}{2}} \quad (1.5)$$

where λ = the decay constant of the radioisotope,
 Δt_i = the time elapsed between the time the form was made, and the time of measurement of the leached activity of the i^{th} sample.

The cumulative (total) fractional release of a given species from a solid during leaching is:

$$f = \frac{\sum a_n}{A_0} \quad (1.6)$$

Hence, Eq. 1.4 can be rewritten as:

$$f \left(\frac{V}{S} \right)_i = 2 \left(\frac{D_i t}{\pi} \right)^{\frac{1}{2}} \quad (1.7)$$

where $\left(\frac{V}{S} \right)_i$ = the ratio of the volume to surface for a specific waste form i ,
 D_i = effective diffusion coefficient for the specific matrix material and its structure in waste form i .

Consider two waste forms fabricated under identical conditions, from the same material and with different V/S ratios. If the diffusion coefficient of a given element is the same in both forms, hence from Eq. 1.7:

$$f_1 \left(\frac{V}{S} \right)_1 = f_2 \left(\frac{V}{S} \right)_2 \quad (1.8)$$

Furthermore, the time required to leach the same fraction of a substance from these two identical matrices (i.e., $D_1 = D_2$), having differing volume-to-surface ratios is given by:

$$t_1 = t_2 \left[\left(\frac{V}{S} \right)_2 \right]^2 \cdot \left[\left(\frac{S}{V} \right)_1 \right]^2 \text{ or } t_1/t_2 = \left[\left(\frac{V}{S} \right)_1 / \left(\frac{V}{S} \right)_2 \right]^2 \quad (1.9)$$

Equation 1.9 indicates that the ratio of the times required to leach the same fraction of radioactivity from these two waste forms is proportional to the ratio of the square of their respective (V/S). This relationship infers that the larger the (V/S) ratio is, the longer it would take to diffuse its content to the environment. This relationship is often used to predict the environmental impact of the leachability of radioisotopes from large waste forms (55-gallon drums and larger) based on data obtained from laboratory bench scale forms (1" diameter x 2" height to 2" diameter by 4" height).

Preliminary experiments were conducted to verify this relationship and to determine the effects of varying the (V/S) ratio on leachability of radioactive tracers from waste forms.

1.2 Experimental

Portland II cement specimens containing simulated BWR chemical regenerative wastes were prepared. The waste formulations are representative of those found in forced circulation evaporator bottoms of commercial power reactors. The waste to cement ratio was 0.8 by weight, and the waste composition was adjusted to 2.0 weight percent NaCl, 22.9 weight percent Na₂SO₄, and 7.5 weight percent deionized water. Strontium-85 and Cs-137 tracers were added to this water. The specific activities of all the forms were approximately equal. The forms were cured for a ten day period prior to the initiation of leaching. The leachant volume to specimen surface area ratio was 10 cm, and a modified IAEA leaching procedure⁽⁷⁾ was followed. The volume to surface area ratio of the studied specimens ranged from 0.41 cm to 2.77 cm. Table 1.1 summarizes the compositions, dimensions, V/S ratios and leachant volumes used for each specimen.

Table 1.1
Sample Preparation and Dimensions

Series	Cement (gm)	Waste			free H ₂ O (gm)	dia (cm)	ht (cm)	V/S (cm)	V leachant (mL)
		Na ₂ SO ₄ (gm)	NaCl (gm)	H ₂ O ^a (gm)					
1	12.2	2.2	0.2	7.3	---	2.36	2.60	0.41	330
2	166.7	30.5	2.7	100.0	b	4.56	9.00 ^b	0.91	2085
3	430.6	78.9	6.9	258.3	20.7	6.50	12.00	1.28	3489
4	944.4	173.0	15.1	566.7	3.0 ^c	9.20	14.90 ^c	1.76	4741
5	388.9	71.2	6.2	233.3	---	6.80	10.30	1.28	3134
6	1055.6	193.4	16.9	633.3	---	9.20	14.80	1.75	6073
7	1777.8	325.7	28.4	1066.7	---	11.60	15.40	2.11	8811
8	4000.0	732.8	61.0	2400.0	---	15.00	21.10	2.77	13942

^aIncluding ⁸⁵Sr and ¹³⁷Cs tracer solutions.

^b0.25 cm of wet crystals on top.

^c0.70 cm of wet crystals on top.

The specimens were removed from the leachants at 24 hour intervals (excluding weekends and holidays), the leachates were stirred and 10-mL aliquots were removed for analyses. The pH of each aliquot was measured.

Analysis of the Sr-85 and Cs-137 tracers was performed by gamma-ray spectroscopy using a Searle (Model 1185) automatic gamma counter with a three inch by three inch true well sodium iodide detector. Each aliquot was counted for ten minutes. The counting data were reduced to counts per minute and corrected for background and peak overlap. The incremental fractional release (f) of a given radionuclide at anytime (t) was determined by the ratio of the activity in the aliquot to that of a standard, containing an activity equal to the activity initially incorporated in the waste form. These standards were prepared at the same time as the original waste forms and had a volume of 10 mL.

1.3 Results

The incremental fractional release data calculated for each leachant together with their measured pH are tabulated in Appendix 1. After attempts at fitting the incremental fractional release data with simple exponential and polynomial approximations (up to the ninth order) failed, a smooth fit was hand-drawn through the data. This line was used to read the incremental fractional release values for each leaching period to minimize the total error due to fluctuations in the individual activity assays when the incremental fractional release data is integrated.

The integrals of the incremental fractional release data (cumulative fraction release data) for each form are plotted as a function of leaching period and are shown in Figures 1.1 and 1.2 for Sr-85 and Cs-137, respectively.

The experimental error for the Cs-137 cumulative fraction release was measured for form 1 and is shown at the end of the data curve for this form in Figure 1.2. The magnitude of this error was arrived at by comparing the initial activity incorporated into the form to the activity remaining in the form at the end of the leaching study. This remaining activity was measured by dissolving the form in aqua regia at the end of the study, and assaying the final solution for Cs-137.

The cumulative fractional release data for Sr-85 and Cs-137, corrected for (V/S) of each different waste form, are tabulated in Appendix 1 and shown in Figures 1.3 and 1.4, respectively. The cumulative fraction release, as a function of the square root of leaching time in days, are shown in Figures 1.5 and 1.6 for Sr-85 and Cs-137, respectively. The variations of leachant pH, as a function of leaching period for each form studied, are shown in Figures 1.7 through 1.12.

1.4 Discussion

The dispersion of radioactivity from cement waste forms in an aqueous medium can be attributed to a complicated system of physical and chemical processes. In addition to diffusion mechanisms, the surface condition and dissolution of the waste form influence the rate of migration of the radioactivity

incorporated in the waste form. Godbee, et al.⁽³⁾ and Matsuzuru, et al.⁽⁸⁾ have attributed the primary mode of dispersion of radioactivity from waste forms to diffusion, and approximate the process with a semi-infinite plane source model. More recently, Godbee, et al.⁽⁹⁾ have shown that the effective diffusion coefficient, in the general relationship derived from the semi-infinite model, varies with the leaching periodicity and, hence, point out that other mechanisms for release of the radioactivity may be involved.

The primary objective of this study was to determine the relative effect of varying the waste form V/S ratio on leachability. Although the data from this experiment does not lend itself to quantification of the differences, we can qualitatively state that the cumulative fractional releases of radioactivity from the waste forms are inversely proportional to their respective V/S ratios, as shown in Figures 1.1 and 1.2, for a specific leach period.

According to the semi-infinite diffusion model (as shown in Eq. 1.8), the cumulative fraction released from one sample, multiplied by its (V/S) ratio, should be equal to the fraction released from another sample multiplied by its respective V/S ratio, provided that both samples are identical composites. The cumulative fractional release curves corrected for V/S should therefore be congruent. This is not the case, as shown in Figures 1.3 and 1.4, and we therefore postulate that mechanisms other than diffusion are involved in the leaching of radioactivity from the waste forms.

Equation 1.7 above can be rearranged as:

$$f = \left[2 \left(\frac{S}{V} \right) \cdot \left(\frac{D}{\pi} \right)^{\frac{1}{2}} \right] \cdot t^{\frac{1}{2}} \quad (1.10)$$

where the terms in the square brackets can be substituted by a constant (M). If we assume that the diffusion coefficient (D) remains constant, then $f = M \times t^{1/2}$. This relationship indicates a linear dependence of (f) on the square root of the leaching time, with a slope of (M). The cumulative fraction release data as a function of the square root of leaching time is shown in Figures 1.5 and 1.6 for Sr-85 and Cs-137, respectively. A seemingly linear relationship is observed for samples with V/S ratios larger than 0.81 for Sr-85, and not for Cs-137, further indicating that the diffusion coefficient is not a constant.

Data obtained from experiments with larger sample populations are expected to provide more quantitative results for evaluating the above tentative conclusions.

Figure 1.1 Sr-85 cumulative fractional release data.

Figure 1.2 Cs-137 cumulative fractional release data.

Figure 1.3 Sr-85 cumulative fractional release data corrected for V/S.

Figure 1.4 Cs-137 cumulative fractional release data corrected for v/s .

Figure 1.5 Sr-85 cumulative fractional release data as a function of $\sqrt{t}$.

Figure 1.6 Cs-137 cumulative fractional release data as a function of $\sqrt{t}$.

Figure 1.7 Leachate pH form #1.

Figure 1.8 Leachate pH form #2.

Figure 1.9 Leachate pH form #3.

Figure 1.10 Leachate pH form #4.

Figure 1.11 Leachate pH form #5.

Figure 1.12 Leachate pH form #6.

2. DISPLACEMENT OF ADSORBED MONOVALENT CATIONS (Cs-137) FROM ORGANIC ION EXCHANGE RESINS DURING SOLIDIFICATION IN CEMENT

2.1 Introduction

Organic ion exchange resins from power plants are currently disposed in shallow land burial sites in the dewatered state. A preliminary draft of 10CFR part 61⁽¹³⁾ stipulates that "ion exchange resins shall be immobilized by solidification". In addition, the commercial burial sites operators have indicated that after July 1981, some unsolidified dewatered organic resins will not be acceptable for burial in their facilities.⁽¹⁴⁾

Several solidification agents including cement, bitumen, urea formaldehyde, and vinyl ester-styrene are compatible with organic ion exchange resins. Barletta, et al., have recently published a status report on the solidification of organic ion exchange resins in cement and point out difficulties associated with this method. The problems encountered include poor integrity of the waste forms when immersed in water and subsequent release of Cs-137.

Most cation organic resins have a higher affinity for divalent and trivalent cations than for monovalent cations, and most cements used in the solidification of wastes contain an overwhelming amount of polyvalent cations. These cations present in cement paste used for the solidification of organic resins loaded with monovalent cations (Cs-137), will displace a portion of the radiocesium from the resins. This displacement will affect the leachability of this isotope from the ensuing waste form. Therefore, as part of our ongoing program to characterize the chemical properties of solidified wastes, and to determine their efficiency in immobilization of the incorporated radioactive species, we initiated studies to determine the partition of Cs-137 adsorbed on organic ion exchange resins when mixed with cement paste and during the plastic phase of the curing process. Portland II and lumnite cements at two different waste to cement ratios were evaluated, and the fraction of Cs-137 desorbed from the ion exchange resins was measured.

We define the terms used as follows:

Incorporated waste: The weight of incorporated waste is the weight of dry waste. When referring to organic ion exchange resins, the weight is that of the dewatered resins (where the interstitial water between particles is at a minimum).

Water: The weight of water used to fabricate the waste form (excluding the water entrapped within organic ion exchange resins).

2.2 Experimental

Samples of Amberlite cation exchange resin (Rohm and Haas IRN-77) H⁺ form were batch loaded with tracer Cs-137, slurried in water and mixed with portland II cement or lumnite (HAC) cement. After contact times ranging from five minutes to two hours, the resins were separated from the cement mixture and washed with deionized water. The mixture of cement and water was allowed to

solidify and reserved for subsequent leaching studies. The amount of radioactivity (Cs-137) lost from the resins into the cement was determined. Control samples of resins loaded in a similar fashion were not mixed with cement, but were rinsed with an equal volume of water as those contacted with cement. Another set of resin samples were solidified in cement for leaching studies. The details of the procedure are described below.

The ratios by weight of waste/cement/water, used for both portland II and lumnite (HAC) cements were 1/1/0.8, respectively. These ratios were selected from previously determined optimum process parameters for waste solidification.⁽¹⁰⁾ The composition of these mixtures are shown in Table 2.1. The compositions of the two cements are shown in Table 2.2.

Batches of Amberlite (IRN-77) cation exchange resins (H^+ form), weighing 85.71 grams each were placed in individual containers and covered with deionized water. One microcurie of Cs-137 tracer was added to each container. The radioactivity was adsorbed onto the resins overnight. After equilibration, the resins were rinsed with deionized water. The activity on each batch of resin was then quantitatively determined by counting each sample.

The proper amounts of water and cements, as shown in Table 2.1, were added to the individual resin samples, mixed and allowed to stand for the contact times shown in Table 2.3. The resins were then separated from the cement by placing the mixture in an appropriate sieve, and rinsing away the cement with deionized water. The separated resin fractions were assayed again for their radioactivity contents, and the fractions of Cs-137 remaining on the resins were determined.

Table 2.1
Composition of Mixture

Component	Weight (g)
Cation exchange resin	
IRN-77 H^+ form	87.51
Water	68.58
Cement	85.71

Table 2.2
Composition of Cements⁽¹¹⁾

Cement Type	Composition (weight percent)						
	CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	Si ₂ O ₃	Other
Portland II	63.3	22.4	4.6	4.3	2.5	1.7	1.2
Lumnite (HAC)	36.5	8.5	40.5	5.5	1.0	0.2	7.8 ^a

^aIncludes Fe₂O₃ 5.5% and TiO₂ 2%.

2.3 Results

The fraction of Cs-137 remaining on the cation exchange resins relative to that loaded onto the resins was measured as a function of contact time with portland II and lumnite cements. The average of five samples for each contact time was computed, and the data are summarized in Table 2.3.

Table 2.3
Activity Remaining on Cation Resins (IRN-77)
as a Function of Contact Time With Portland II and Lumnite Cements

Cement Type	Contact Time	Cs-137 fraction left on cation exchange resins (percent)
Portland II	5 min	83.0 ± 12.3
	1 hr	73.0 ± 7.4
	2 hrs	73.0 ± 12.3
Lumnite (HAC)	5 min	87.3 ± 11.3
	1 hr	61.1 ± 9.5
	2 hrs	57.4 ± 12.9

2.4 Conclusions

The data in table 2.3 indicates that when portland II cement is mixed with Amberlite (IRN-77) cation resin loaded with Cs-137, in a proportion of resin to cement to water of 1.0/1.0/0.8, it displaces approximately a fourth of the activity from the resin, whereas, lumnite (HAC) cement, under the same conditions, displaces approximately a third of the adsorbed radioactivity from the ion

exchange resins. The control samples of resins loaded with Cs-137 and left for 50 days in deionized water showed no loss of activity. Organic cation exchange resins have a stronger affinity for polyvalent than for monovalent cations. The greater displacement of Cs-137 from the resin by lumnite cement is a consequence of the lumnite cement containing a higher concentration of trivalent cations, namely Al^{+3} and Fe^{+3} than portland II cement, as shown in Table 2.2.

The desorbed amount of Cs-137 steadily increased for the samples mixed with Lumnite cement (Table 2.3) whereas, for those mixed with portland II cement, the loss occurred within the first five minutes. This effect may be due to the fact that the diffusion of larger cations (trivalent) into the exchange resins is slower than that for smaller cations (monovalent).⁽¹²⁾ Work is in progress to evaluate the effects of radioisotope displacement from the resins on the leachability of the finished cement form.

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APPENDIX 1

LEACHING DATA Form #1 V/S = 0.41 cm

Leach Time (Days)	Incremental Fractional Release				pH of Leachant
	Sr-85		Cs-137		
	Measured Fraction	Fraction xV/S ^a	Measured Fraction	Fraction xV/S ^a	
1	1.40E-02	1.40E-02	1.79E-01	1.79E-01	
2	5.59E-03	5.05E-03	5.93E-02	5.93E-02	11.60
3	3.95E-03	3.95E-03	3.71E-02	3.71E-02	11.54
4	3.11E-03	3.20E-03	2.60E-02	2.60E-02	11.45
5		2.55E-03		2.00E-02	
6		2.30E-03		1.60E-02	
7	5.32E-03	2.00E-03	4.64E-02	1.35E-02	11.58
8	1.73E-03	1.75E-03	1.18E-02	1.10E-02	
9		1.60E-03		9.00E-03	
10	2.21E-03	1.45E-03	1.46E-02	7.15E-03	11.39
11	1.37E-03	1.30E-03	6.32E-03	6.20E-03	10.96
12		1.20E-03		5.40E-03	
13		1.05E-03		4.85E-03	
14	1.83E-03	9.50E-04	1.37E-02	4.35E-03	11.40
15	1.24E-03	9.00E-04	3.99E-03	3.85E-03	10.86
16	7.35E-04	8.00E-04	3.46E-03	3.45E-03	10.54
17	6.65E-04	7.50E-04	3.02E-03	3.05E-03	10.70
18	7.86E-04	7.00E-04	2.64E-03	2.75E-03	10.46
19		6.00E-04		2.50E-03	
20		5.50E-04		2.30E-03	
21	8.72E-04	5.00E-04	6.58E-03	2.10E-03	11.00
22	5.19E-04	5.00E-04	2.20E-03	1.90E-03	10.28
23	6.40E-04	4.50E-04	1.82E-03	1.75E-03	9.77
24	3.82E-04	4.50E-04	1.51E-03	1.65E-03	9.17
25	2.12E-04	4.50E-04	1.49E-03	1.50E-03	8.90
26		4.50E-04		1.40E-03	
27		4.50E-04		1.30E-03	
28	4.71E-04	4.50E-04	3.21E-03	1.20E-03	9.73
29	2.83E-04	4.00E-04	1.31E-03	1.15E-03	8.77
30	2.65E-04	4.00E-04	1.26E-03	1.05E-03	9.84
31	3.41E-04	4.00E-04	1.24E-03	1.00E-03	9.67
32	5.16E-04	4.00E-04	1.22E-03	9.00E-04	10.10
33		4.00E-04		8.50E-04	
34		4.00E-04		8.00E-04	
35	6.69E-04	4.00E-04	2.19E-03	7.50E-04	10.59
36	3.75E-04	4.00E-04	7.65E-04	7.00E-04	9.58
37	2.87E-04	4.00E-04	6.74E-04	6.50E-04	9.60
38	3.55E-04	4.00E-04	7.29E-04	6.50E-04	9.72
39	4.89E-04	4.00E-04	6.37E-04	6.00E-04	9.85
40		4.00E-04		5.50E-04	
41		4.00E-04		5.00E-04	
42	8.01E-04	4.00E-04	1.51E-03	5.00E-04	10.31

^aFraction values are read from the hand smoothed curves as explained in the text.

APPENDIX 1, Continued

LEACHING DATA Form #1 V/S = 0.41 cm

43	4.15E-04	4.00E-04	6.37E-04	4.50E-04	9.44
44	3.61E-04	4.00E-04	2.73E-04	4.50E-04	9.54
45	3.25E-04	4.00E-04	3.64E-04	4.00E-04	9.92
46	2.02E-04	4.00E-04	3.64E-04	4.00E-04	9.45
47		4.00E-04		3.50E-04	
48		4.00E-04		3.50E-04	
49		3.50E-04		3.00E-04	
50	6.53E-04	3.50E-04	1.11E-03	3.00E-04	10.06
51	4.08E-04	3.50E-04	2.91E-04	2.50E-04	9.16
52	2.44E-04	3.50E-04	2.18E-04	2.50E-04	9.45
53	3.43E-04	3.50E-04	2.18E-04	2.50E-04	9.22
54		3.50E-04		2.00E-04	
55		3.50E-04		2.00E-04	
56	5.72E-04	3.50E-04	5.64E-04	2.00E-04	9.68
57	3.16E-04	3.50E-04	2.37E-04	2.00E-04	9.28
58	2.78E-04	3.50E-04	1.46E-04	2.00E-04	9.37
59	2.56E-04	3.50E-04	1.27E-04	2.00E-04	9.32
60	3.00E-04	3.50E-04	1.64E-04	2.00E-04	9.30
61		3.50E-04		2.00E-04	
62		3.50E-04		2.00E-04	
63	5.94E-04	3.50E-04	3.82E-04	2.00E-04	9.52
64	3.00E-04	3.50E-04	1.64E-04	2.00E-04	8.53
65	2.35E-04	3.50E-04	9.09E-05	2.00E-04	9.30
66	2.31E-04	3.50E-04	1.27E-04	2.00E-04	9.26
67	2.51E-04	3.50E-04	1.64E-04	2.00E-04	9.12
68		3.50E-04		2.00E-04	
69		3.00E-04		2.00E-04	
70		3.00E-04		2.00E-04	
71		3.00E-04		2.00E-04	
72	8.65E-04	3.00E-04	3.82E-04	2.00E-04	10.60
73	3.99E-04	3.00E-04	1.64E-04	2.00E-04	9.31
74	4.82E-04	3.00E-04	9.08E-05	2.00E-04	8.79
75		3.00E-04		2.00E-04	
76		3.00E-04		2.00E-04	
77	6.61E-04	3.00E-04	2.36E-04	2.00E-04	8.45
78	4.98E-04	3.00E-04	1.64E-04	2.00E-04	8.56
79	2.31E-04	3.00E-04	1.27E-04	2.00E-04	8.49
80	1.68E-04	3.00E-04	3.63E-05	2.00E-04	8.25
81	2.60E-04	3.00E-04	9.09E-05	2.00E-04	8.06
82		3.00E-04		2.00E-04	
83		3.00E-04		2.00E-04	
84	4.24E-04	3.00E-04	1.64E-04	1.50E-04	8.49
85	3.27E-04	3.00E-04	1.46E-04	1.50E-04	8.73
86	2.82E-04	3.00E-04	1.09E-04	1.50E-04	8.98
87	3.32E-04	3.00E-04	1.09E-04	1.50E-04	8.94
88	4.16E-04	3.00E-04	9.11E-05	1.50E-04	8.96
89		3.00E-04		1.50E-04	
90		3.00E-04		1.50E-04	
91	6.16E-04	3.00E-04	1.82E-04	1.50E-04	8.56
92	4.19E-04	3.00E-04	7.28E-05	1.50E-04	8.79
93	3.47E-04	3.00E-04	7.29E-05	1.50E-04	8.59
94	4.49E-04	3.00E-04	1.09E-04	1.50E-04	8.71

APPENDIX 1, Continued

LEACHING DATA Form #1 V/S = 0.41 cm

95	3.41E-04	3.00E-04	1.09E-04	1.50E-04	8.79
96		3.00E-04		1.50E-04	
97		3.00E-04		1.50E-04	
98	6.19E-04	3.00E-04	1.64E-04	1.50E-04	8.61
99	4.09E-04	3.00E-04	1.23E-04	1.50E-04	8.92
100	3.44E-04	3.00E-04	9.11E-05	1.50E-04	8.98
101	3.47E-04	3.00E-04	7.29E-05	1.50E-04	8.87
102	3.44E-04	3.00E-04	9.11E-05	1.50E-04	9.10
103		3.00E-04		1.50E-04	
104		3.00E-04		1.50E-04	
105	6.97E-04	3.00E-04	1.27E-04	1.50E-04	9.37
106	4.81E-04	3.00E-04	1.28E-04	1.50E-04	9.18
107	2.69E-04	3.00E-04	1.09E-04	1.50E-04	9.04
108	3.05E-04	3.00E-04	1.09E-04	1.50E-04	9.11
109	2.72E-04	3.00E-04	9.12E-05	1.50E-04	8.87
110		3.00E-04		1.50E-04	
111		3.00E-04		1.00E-04	
112	9.89E-04	3.00E-04	1.09E-04	1.00E-04	9.28
113	6.29E-04	3.00E-04	1.09E-04	1.00E-04	8.95
114	3.11E-04	3.00E-04	7.29E-05	1.00E-04	8.69
115	3.08E-04	3.00E-04	9.12E-05	1.00E-04	8.27
116	4.55E-04	3.00E-04	2.74E-04	1.00E-04	8.18
117		3.00E-04		1.00E-04	
118		3.00E-04		1.00E-04	
119	6.42E-04	3.00E-04	3.62E-05	1.00E-04	8.76
120	3.86E-04	3.00E-04	5.46E-05	1.00E-04	8.22
121	6.32E-04	3.00E-04	9.10E-05	1.00E-04	

APPENDIX 1, Continued

LEACHING DATA Form #2 V/S = 0.81 cm

Leach Time (Days)	Incremental Fractional Release				pH of Leachant
	Sr-85		Cs-137		
	Measured Fraction	Fraction xV/S ^a	Measured Fraction	Fraction xV/S ^a	
1	1.28E-02	1.47E-02	1.61E-01	1.61E-01	11.90
2	1.12E-02	1.12E-02	7.14E-02	7.14E-02	11.63
3	7.24E-03	9.60E-03	5.03E-02	5.03E-02	11.57
4	5.19E-03	5.55E-03	3.72E-02	3.72E-02	11.54
5		4.60E-03		3.32E-02	
6		4.00E-03		2.91E-02	
7	9.47E-03	3.40E-03	8.49E-02	2.50E-02	11.68
8	3.42E-03	3.00E-03	2.16E-02	2.11E-02	
9		2.65E-03		1.73E-02	
10	3.43E-03	2.40E-03	2.92E-02	1.41E-02	11.54
11	2.31E-03	2.15E-03	1.37E-02	1.24E-02	11.35
12		1.95E-03		1.13E-02	
13		1.80E-03		1.05E-02	
14	3.78E-03	1.65E-03	3.17E-02	9.80E-03	11.64
15	1.78E-03	1.55E-03	8.79E-03	9.20E-03	11.13
16	1.78E-03	1.40E-03	8.66E-03	8.65E-03	11.04
17	1.51E-03	1.35E-03	7.98E-03	8.20E-03	11.15
18	1.47E-03	1.30E-03	8.43E-03	7.80E-03	10.92
19		1.20E-03		7.45E-03	
20		1.15E-03		7.10E-03	
21	2.07E-03	1.10E-03	2.04E-02	6.75E-03	11.43
22	1.37E-03	1.05E-03	6.92E-03	6.45E-03	10.70
23	1.40E-03	1.00E-03	6.12E-03	6.15E-03	10.36
24	7.58E-04	1.00E-03	5.08E-03	5.90E-03	9.95
25	6.46E-04	9.50E-04	4.98E-03	5.70E-03	10.04
26		9.50E-04		5.45E-03	
27		9.00E-04		5.25E-03	
28	1.61E-03	9.00E-04	1.41E-02	5.05E-03	
29	8.24E-04	9.00E-04	4.80E-03	4.90E-03	9.91
30	8.64E-04	9.00E-04	4.37E-03	4.75E-03	10.70
31	1.29E-03	9.00E-04	4.78E-03	4.60E-03	10.72
32	1.50E-03	9.00E-04	5.04E-03	4.45E-03	10.87
33		9.00E-04		4.30E-03	
34		8.50E-04		4.15E-03	
35	1.97E-03	8.50E-04	1.14E-02	4.05E-03	11.24
36	9.82E-04	8.50E-04	3.60E-03	3.90E-03	10.57
37	7.80E-04	8.50E-04	3.39E-03	3.80E-03	10.33
38	1.08E-03	8.50E-04	3.65E-03	3.70E-03	10.55
39	1.02E-03	8.50E-04	3.83E-03	3.55E-03	10.67
40		8.00E-04		3.45E-03	
41		8.00E-04		3.35E-03	
42	1.97E-03	8.00E-04	1.02E-02	3.25E-03	11.08

^a Fraction values are read from the hand smoothed curves as explained in the text.

APPENDIX 1, Continued

LEACHING DATA
Form #2 V/S = 0.81 cm

43	1.04E-03	8.00E-04	3.40E-03	3.15E-03	10.64
44	8.74E-04	8.00E-04	2.86E-03	3.05E-03	10.46
45	7.51E-04	8.00E-04	2.93E-03	2.95E-03	10.67
46	6.63E-04	8.00E-04	2.59E-03	2.85E-03	10.37
47		8.00E-04		2.80E-03	
48		8.00E-04		2.70E-03	
49		8.00E-04		2.60E-03	
50	1.70E-03	8.00E-04	9.65E-03	2.55E-03	11.11
51	8.71E-04	8.00E-04	2.67E-03	2.45E-03	10.19
52	7.16E-04	7.50E-04	2.29E-03	2.40E-03	10.36
53	6.88E-04	7.50E-04	2.25E-03	2.30E-03	10.26
54		7.50E-04		2.25E-03	
55		7.50E-04		2.20E-03	
56	1.60E-03	7.50E-04	6.35E-03	2.15E-03	10.77
57	8.42E-04	7.50E-04	2.21E-03	2.10E-03	10.12
58	5.59E-04	7.50E-04	1.94E-03	2.05E-03	10.17
59	5.87E-04	7.50E-04	2.09E-03	2.00E-03	10.27
60	7.83E-04	7.50E-04	2.12E-03	1.95E-03	10.33
61		7.50E-04		1.90E-03	
62		7.00E-04		1.85E-03	
63	1.40E-03	7.00E-04	5.07E-03	1.80E-03	10.91
64	6.22E-04	7.00E-04	1.68E-03	1.75E-03	9.40
65	6.89E-04	7.00E-04	1.72E-03	1.70E-03	10.22
66	6.19E-04	7.00E-04	1.70E-03	1.70E-03	10.23
67	6.11E-04	7.00E-04	1.75E-03	1.65E-03	9.88
68		7.00E-04		1.65E-03	
69		7.00E-04		1.60E-03	
70		7.00E-04		1.60E-03	
71		7.00E-04		1.55E-03	
72	2.21E-03	7.00E-04	7.35E-03	1.50E-03	11.04
73	9.42E-04	7.00E-04	1.75E-03	1.50E-03	10.56
74	5.21E-04	6.50E-04	1.32E-03	1.45E-03	10.12
75		6.50E-04		1.45E-03	
76		6.50E-04		1.40E-03	
77	1.49E-03	6.50E-04	3.72E-03	1.40E-03	10.80
78	5.69E-04	6.50E-04	1.56E-03	1.35E-03	9.81
79	5.57E-04	6.50E-04	1.33E-03	1.35E-03	9.79
80	4.93E-04	6.50E-04	1.27E-03	1.30E-03	9.24
81	2.89E-04	6.50E-04	1.38E-03	1.25E-03	9.48
82		6.00E-04		1.25E-03	
83		6.00E-04		1.20E-03	
84	1.04E-03	6.00E-04	3.26E-03	1.20E-03	10.34
85	5.92E-04	6.00E-04	1.23E-03	1.15E-03	10.19
86	5.73E-04	6.00E-04	1.33E-03	1.15E-03	10.29
87	5.78E-04	6.00E-04	1.20E-03	1.10E-03	10.17
88	3.36E-04	6.00E-04	8.86E-04	1.10E-03	10.09
89		6.00E-04		1.05E-03	
90		5.50E-04		1.05E-03	
91	1.48E-03	5.50E-04	2.79E-03	1.05E-03	10.34
92	5.73E-04	5.50E-04	1.11E-03	1.00E-03	9.55
93	6.66E-04	5.50E-04	9.61E-04	1.00E-03	9.88
94	6.03E-04	5.50E-04	9.99E-04	1.00E-03	9.87

APPENDIX 1, Continued

LEACHING DATA
Form #2 V/S = 0.81 cm

95	5.32E-04	5.50E-04	1.00E-03	1.00E-03	10.23
96		5.50E-04		9.50E-04	
97		5.50E-04		9.50E-04	
98	1.20E-03	5.50E-04	2.52E-03	9.50E-04	10.57
99	5.44E-04	5.50E-04	9.14E-04	9.00E-04	10.31
100	6.64E-04	5.50E-04	9.70E-04	9.00E-04	10.24
101	6.98E-04	5.00E-04	9.42E-04	9.00E-04	10.19
102	6.56E-04	5.00E-04	8.95E-04	8.50E-04	10.17
103		5.00E-04		8.50E-04	
104		5.00E-04		8.50E-04	
105	1.05E-03	5.00E-04	2.28E-03	8.50E-04	10.61
106	7.17E-04	5.00E-04	9.70E-04	8.00E-04	10.19
107	4.17E-04	5.00E-04	7.82E-04	8.00E-04	10.01
108	4.87E-04	5.00E-04	7.16E-04	8.00E-04	10.07
109	6.58E-04	5.00E-04	7.82E-04	8.00E-04	10.09
110		5.00E-04		7.50E-04	
111		5.00E-04		7.50E-04	
112	1.05E-03	5.00E-04	1.87E-03	7.00E-04	10.56
113	5.73E-04	5.00E-04	8.01E-04	7.00E-04	9.88
114	4.02E-04	5.00E-04	7.35E-04	7.00E-04	9.63
115	5.48E-04	5.00E-04	7.91E-04	7.00E-04	9.31
116	4.70E-04	5.00E-04	6.78E-04	6.50E-04	9.26
117		5.00E-04		6.50E-04	
118		5.00E-04		6.00E-04	
119	8.48E-04	4.50E-04	1.51E-03	6.00E-04	10.03
120	4.00E-04	4.50E-04	8.48E-04	6.00E-04	9.24
121	3.23E-04	4.50E-04	6.22E-04	5.50E-04	9.11

APPENDIX 1, Continued

LEACHING DATA Form #3 V/S = 1.76 cm

Leach Time (Days)	Incremental Fractional Release				pH of Leachant
	Sr-85		Cs-137		
	Measured Fraction	Fraction xV/S ^a	Measured Fraction	Fraction xV/S ^a	
1	2.07E-02	2.07E-02	2.59E-01	2.55E-01	11.92
2	8.28E-03	1.30E-02	8.06E-02	8.06E-02	11.73
3	6.66E-03	6.40E-03	5.87E-02	5.87E-02	11.67
4	5.31E-03	5.00E-03	4.53E-02	4.53E-02	11.63
5		4.15E-03		3.90E-02	
6		3.55E-03		3.50E-02	
7	8.91E-03	3.15E-03	9.87E-02	3.16E-02	11.81
8	3.05E-03	2.85E-03	2.92E-02	2.82E-02	
9		2.60E-03		2.44E-02	
10	3.70E-03	2.40E-03	4.00E-02	2.13E-02	11.72
11	2.23E-03	2.15E-03	1.95E-02	1.83E-02	11.55
12		2.00E-03		1.62E-02	
13		1.85E-03		1.49E-02	
14	4.08E-03	1.75E-03	4.38E-02	1.40E-02	11.80
15	1.91E-03	1.65E-03	1.34E-02	1.32E-02	11.46
16	1.65E-03	1.55E-03	1.28E-02	1.27E-02	11.41
17	1.39E-03	1.45E-03	1.16E-02	1.21E-02	11.42
18	1.38E-03	1.40E-03	1.18E-02	1.17E-02	11.31
19		1.35E-03		1.13E-02	
20		1.30E-03		1.09E-02	
21	2.96E-03	1.25E-03	3.15E-02	1.05E-02	11.68
22	1.67E-03	1.25E-03	1.05E-02	1.02E-02	11.24
23	1.34E-03	1.20E-03	9.24E-03	9.80E-03	11.20
24	9.30E-04	1.20E-03	8.52E-03	9.50E-03	11.12
25	1.20E-03	1.15E-03	8.55E-03	9.25E-03	11.14
26		1.15E-03		8.95E-03	
27		1.10E-03		8.75E-03	
28	1.99E-03	1.10E-03	2.22E-02	8.50E-03	11.54
29	1.11E-03	1.10E-03	8.22E-03	8.25E-03	11.07
30	1.07E-03	1.10E-03	7.36E-03	8.05E-03	11.17
31	1.54E-03	1.10E-03	8.24E-03	7.85E-03	11.18
32	1.71E-03	1.05E-03	8.10E-03	7.65E-03	11.18
33		1.05E-03		7.45E-03	
34		1.05E-03		7.30E-03	
35	1.92E-03	1.05E-03	1.88E-02	7.10E-03	11.54
36	1.18E-03	1.00E-03	6.58E-03	6.95E-03	11.19
37	1.14E-03	1.00E-03	6.49E-03	6.80E-03	11.14
38	1.18E-03	1.00E-03	8.11E-03	6.60E-03	11.17
39	1.09E-03	1.00E-03	7.14E-03	6.45E-03	11.17
40		1.00E-03		6.30E-03	
41		1.00E-03		6.15E-03	
42	2.16E-03	9.50E-04	1.95E-02	6.00E-03	11.48

^aFraction values are read from the hand smoothed curves as explained in the text.

APPENDIX 1, Continued

LEACHING DATA Form #3 V/S = 1.76 cm

43	1.19E-03	9.50E-04	5.94E-03	5.85E-03	11.17
44	9.16E-04	9.50E-04	5.43E-03	5.70E-03	11.11
45	8.49E-04	9.50E-04	5.23E-03	5.55E-03	11.15
46	7.29E-04	9.50E-04	5.19E-03	5.40E-03	11.11
47		9.00E-04		5.25E-03	
48		9.00E-04		5.15E-03	
49		9.00E-04		5.00E-03	
50	1.97E-03	9.90E-04	1.79E-02	4.90E-03	11.56
51	1.24E-03	9.00E-04	5.31E-03	4.80E-03	11.13
52	1.00E-03	9.00E-04	4.31E-03	4.70E-03	11.08
53	9.28E-04	9.00E-04	4.15E-03	4.60E-03	11.06
54		8.50E-04		4.50E-03	
55		8.50E-04		4.40E-03	
56	1.67E-03	8.50E-04	1.18E-02	4.30E-03	11.42
57	9.44E-04	8.50E-04	4.05E-03	4.20E-03	11.08
58	7.90E-04	8.50E-04	3.91E-03	4.10E-03	11.03
59	8.08E-04	8.00E-04	3.65E-03	4.05E-03	11.06
60	7.49E-04	8.00E-04	4.31E-03	3.95E-03	11.08
61		8.00E-04		3.85E-03	
62		8.00E-04		3.80E-03	
63	1.18E-03	8.00E-04	1.08E-02	3.70E-03	11.42
64	8.77E-04	8.00E-04	3.24E-03	3.65E-03	11.04
65	7.57E-04	8.00E-04	3.65E-03	3.60E-03	10.69
66	7.66E-04	8.00E-04	3.30E-03	3.50E-03	10.71
67	9.30E-04	8.00E-04	3.68E-03	3.45E-03	10.95
68		8.00E-04		3.40E-03	
69		8.00E-04		3.35E-03	
70		8.00E-04		3.30E-03	
71		7.50E-04		3.25E-03	
72	2.27E-03	7.50E-04	1.51E-02	3.20E-03	11.49
73	1.07E-03	7.50E-04	3.93E-03	3.15E-03	11.15
74	6.92E-04	7.50E-04	2.83E-03	3.10E-03	10.97
75		7.50E-04		3.05E-03	
76		7.50E-04		3.00E-03	
77	1.54E-03	7.00E-04	8.24E-03	2.95E-03	11.34
78	6.35E-04	7.00E-04	3.32E-03	2.90E-03	10.88
79	6.00E-04	7.00E-04	2.78E-03	2.85E-03	10.69
80	6.04E-04	7.00E-04	2.60E-03	2.80E-03	10.62
81	5.10E-04	7.00E-04	3.01E-03	2.75E-03	10.66
82		7.00E-04		2.70E-03	
83		7.00E-04		2.65E-03	
84	1.14E-03	7.00E-04	7.88E-03	2.60E-03	11.04
85	7.47E-04	7.00E-04	2.80E-03	2.55E-03	10.78
86	7.75E-04	7.00E-04	2.94E-03	2.50E-03	10.87
87	6.29E-04	6.50E-04	2.60E-03	2.45E-03	10.76
88	6.09E-04	6.50E-04	2.06E-03	2.40E-03	10.62
89		6.50E-04		2.40E-03	
90		6.50E-04		2.35E-03	
91	1.68E-03	6.50E-04	6.94E-03	2.30E-03	10.89
92	6.67E-04	6.50E-04	2.43E-03	2.30E-03	10.40
93	7.31E-04	6.50E-04	2.32E-03	2.25E-03	10.47
94	5.39E-04	6.00E-04	2.34E-03	2.25E-03	10.42

APPENDIX 1, Continued

LEACHING DATA Form #3 V/S = 1.76 cm

95	5.99E-04	6.00E-04	2.40E-03	2.25E-03	10.53
96		6.00E-04		2.20E-03	
97		6.00E-04		2.20E-03	
98	1.11E-03	6.00E-04	6.53E-03	2.20E-03	11.06
99	6.93E-04	6.00E-04	2.17E-03	2.20E-03	10.72
100	6.33E-04	6.00E-04	2.26E-03	2.20E-03	10.73
101	7.40E-04	6.00E-04	1.97E-03	2.20E-03	10.70
102	7.64E-04	6.00E-04	2.18E-03	2.20E-03	10.70
103		5.50E-04		2.20E-03	
104		5.50E-04		2.20E-03	
105	1.17E-03	5.50E-04	5.81E-03	2.20E-03	11.05
106	6.80E-04	5.50E-04	2.22E-03	2.20E-03	10.72
107	5.96E-04	5.50E-04	2.11E-03	2.20E-03	10.53
108	4.77E-04	5.50E-04	1.84E-03	2.25E-03	10.59
109	7.22E-04	5.50E-04	3.26E-03	2.25E-03	10.67
110		5.50E-04		2.30E-03	
111		5.00E-04		2.35E-03	
112	1.03E-03	5.00E-04	6.99E-03	2.40E-03	11.04
113	6.64E-04	5.00E-04	3.04E-03	2.45E-03	10.66
114	4.14E-04	5.00E-04	2.10E-03	2.50E-03	10.44
115	6.27E-04	5.00E-04	2.74E-03	2.60E-03	10.41
116	5.33E-04	5.00E-04	2.98E-03	2.65E-03	10.45
117		5.00E-04		2.75E-03	
118		5.00E-04		2.85E-03	
119	1.02E-03	4.50E-04	6.31E-03	3.00E-03	11.05
120	5.51E-04	4.50E-04	4.11E-03	3.15E-03	10.52
121	3.47E-04	4.50E-04	2.67E-03	3.30E-03	10.38

APPENDIX 1, Continued

LEACHING DATA Form #4 V/S = 1.75 cm

Leach Time (Days)	Incremental Fractional Release				pH of Leachant
	Sr-85		Cs-137		
	Measured Fraction	Fraction xV/S ^a	Measured Fraction	Fraction xV/S ^a	
1	1.59E-02	1.59E-02	1.94E-01	1.94E-01	11.89
2	6.24E-03	8.50E-03	6.66E-02	6.66E-02	11.69
3	5.76E-03	5.40E-03	5.36E-02	5.36E-02	11.60
4	4.68E-03	4.50E-03	4.78E-02	4.78E-02	11.61
5		3.85E-03		3.65E-02	
6		3.30E-03		3.30E-02	
7	7.60E-03	2.85E-03	9.61E-02	2.96E-02	11.76
8	2.58E-03	2.45E-03	2.67E-02	2.23E-02	
9		2.20E-03		1.90E-02	
10	3.07E-03	1.95E-03	3.74E-02	1.72E-02	11.69
11	1.98E-03	1.60E-03	1.78E-02	1.61E-02	11.53
12		1.65E-03		1.51E-02	
13		1.55E-03		1.41E-02	
14	2.97E-03	1.45E-03	4.24E-02	1.33E-02	11.75
15	1.55E-03	1.35E-03	1.36E-02	1.26E-02	11.44
16	1.28E-03	1.25E-03	1.22E-02	1.19E-02	11.38
17	1.31E-03	1.20E-03	1.20E-02	1.14E-02	11.39
18	1.42E-03	1.15E-03	1.14E-02	1.09E-02	11.30
19		1.10E-03		1.09E-02	
20		1.10E-03		1.04E-02	
21	2.50E-03	1.05E-03	3.18E-02	9.95E-03	11.65
22	1.44E-03	1.05E-03	1.06E-02	9.55E-03	11.18
23	1.19E-03	1.00E-03	9.39E-03	9.15E-03	11.18
24	9.81E-04	1.00E-03	8.32E-03	8.80E-03	11.12
25	1.06E-03	1.00E-03	8.61E-03	8.45E-03	11.11
26		1.00E-03		8.20E-03	
27		1.00E-03		8.05E-03	
28	1.96E-03	1.00E-03	2.19E-02	8.00E-03	11.49
29	9.03E-04	1.00E-03	7.77E-03	8.00E-03	11.08
30	1.14E-03	1.00E-03	7.92E-03	8.05E-03	11.19
31	1.17E-03	1.00E-03	8.26E-03	8.15E-03	11.14
32	1.34E-03	1.00E-03	8.31E-03	8.40E-03	11.14
33		1.00E-03		8.70E-03	
34		9.50E-04		8.95E-03	
35	2.14E-03	9.50E-04	2.61E-02	9.25E-03	11.55
36	1.11E-03	9.50E-04	9.22E-03	9.50E-03	11.20
37	1.12E-03	9.50E-04	9.76E-03	9.65E-03	11.16
38	1.34E-03	9.50E-04	1.07E-02	9.60E-03	11.17
39	1.24E-03	9.50E-04	8.62E-03	9.30E-03	11.13
40		9.50E-04		8.65E-03	
41		9.50E-04		8.15E-03	
42	2.09E-03	9.50E-04	2.28E-02	7.65E-03	11.48

^a Fraction values are read from the hand smoothed curves as explained in the text.

APPENDIX 1, Continued

LEACHING DATA Form #4 V/S = 1.75 cm

43	1.30E-03	9.50E-04	7.77E-03	7.20E-03	11.16
44	6.79E-04	9.00E-04	5.93E-03	6.85E-03	11.12
45	9.31E-04	9.00E-04	6.38E-03	6.50E-03	
46	9.39E-04	9.00E-04	5.84E-03	6.20E-03	11.11
47		9.00E-04		5.95E-03	
48		9.00E-04		5.75E-03	
49		9.00E-04		5.50E-03	
50	1.68E-03	9.00E-04	1.92E-02	5.35E-03	11.55
51	1.19E-03	9.00E-04	5.16E-03	5.15E-03	11.13
52	8.66E-04	9.00E-04	4.90E-03	5.00E-03	11.11
53	8.02E-04	9.00E-04	4.88E-03	4.85E-03	11.07
54		9.00E-04		4.75E-03	
55		8.50E-04		4.65E-03	
56	1.34E-03	8.50E-04	1.31E-02	4.55E-03	11.40
57	9.91E-04	8.50E-04	4.56E-03	4.45E-03	11.09
58	7.75E-04	8.50E-04	4.17E-03	4.35E-03	11.05
59	9.15E-04	8.50E-04	4.00E-03	4.30E-03	11.05
60	7.53E-04	8.50E-04	4.66E-03	4.20E-03	11.08
61		8.50E-04		4.10E-03	
62		8.50E-04		4.05E-03	
63	1.62E-03	8.00E-04	1.23E-02	4.00E-03	11.40
64	9.09E-04	8.00E-04	3.79E-03	3.90E-03	10.99
65	8.15E-04	8.00E-04	3.95E-03	3.80E-03	11.04
66	7.05E-04	8.00E-04	4.07E-03	3.75E-03	10.89
67	7.89E-04	8.00E-04	3.97E-03	3.70E-03	11.02
68		8.00E-04		3.65E-03	
69		8.00E-04		3.60E-03	
70		8.00E-04		3.50E-03	
71		8.00E-04		3.45E-03	
72	2.31E-03	8.00E-04	1.79E-02	3.40E-03	11.56
73	1.24E-03	8.00E-04	4.16E-03	3.40E-03	11.15
74	6.82E-04	7.50E-04	3.21E-03	3.35E-03	10.96
75		7.50E-04		3.30E-03	
76		7.50E-04		3.25E-03	
77	1.33E-03	7.50E-04	9.18E-03	3.25E-03	11.34
78	8.10E-04	7.50E-04	3.48E-03	3.20E-03	10.92
79	6.36E-04	7.00E-04	3.47E-03	3.20E-03	10.80
80	5.84E-04	7.00E-04	3.02E-03	3.15E-03	10.43
81	5.36E-04	7.00E-04	3.78E-03	3.15E-03	10.65
82		7.00E-04		3.10E-03	
83		7.00E-04		3.10E-03	
84	1.07E-03	7.00E-04	8.66E-03	3.10E-03	11.05
85	7.34E-04	7.00E-04	3.04E-03	3.05E-03	10.80
86	8.04E-04	6.50E-04	3.39E-03	3.00E-03	10.86
87	6.96E-04	6.50E-04	3.01E-03	2.95E-03	10.72
88	5.01E-04	6.50E-04	2.28E-03	2.95E-03	10.64
89		6.50E-04		2.90E-03	
90		6.50E-04		2.90E-03	
91	1.34E-03	6.50E-04	8.31E-03	2.90E-03	10.94
92	7.07E-04	6.50E-04	3.34E-03	2.85E-03	10.47
93	7.09E-04	6.00E-04	2.84E-03	2.85E-03	10.52
94	4.81E-04	6.00E-04	2.60E-03	2.85E-03	10.49

APPENDIX 1, Continued

LEACHING DATA Form #4 V/S = 1.75 cm

95	7.27E-04	6.00E-04	2.89E-03	2.80E-03	10.60
96		6.00E-04		2.80E-03	
97		6.00E-04		2.80E-03	
98	1.24E-03	6.00E-04	7.73E-03	2.80E-03	11.10
99	6.35E-04	5.50E-04	2.50E-03	2.80E-03	10.74
100	6.80E-04	5.50E-04	2.70E-03	2.80E-03	10.76
101	4.60E-04	5.50E-04	2.44E-03	2.80E-03	10.72
102	7.09E-04	5.50E-04	2.84E-03	2.80E-03	10.75
103		5.50E-04		2.80E-03	
104		5.50E-04		2.85E-03	
105	1.27E-03	5.00E-04	7.12E-03	2.85E-03	11.07
106	6.41E-04	5.00E-04	2.48E-03	2.85E-03	10.76
107	4.80E-04	5.00E-04	2.24E-03	2.90E-03	10.60
108	3.72E-04	5.00E-04	2.03E-03	2.90E-03	10.64
109	4.93E-04	5.00E-04	2.81E-03	2.95E-03	10.70
110		5.00E-04		2.95E-03	
111		4.50E-04		3.00E-03	
112	9.21E-04	4.50E-04	7.71E-03	3.05E-03	11.05
113	6.54E-04	4.50E-04	3.17E-03	3.10E-03	10.71
114	4.20E-04	4.50E-04	3.08E-03	3.15E-03	10.49
115	2.38E-04	4.50E-04	2.43E-03	3.20E-03	10.43
116	3.78E-04	4.50E-04	3.99E-03	3.25E-03	10.47
117		4.50E-04		3.30E-03	
118		4.00E-04		3.40E-03	
119	1.03E-03	4.00E-04	1.26E-02	3.45E-03	11.09
120	5.87E-04	4.00E-04	5.29E-03	3.50E-03	10.54
121	3.06E-04	4.00E-04	2.91E-03	3.60E-03	10.42

APPENDIX 1, Continued

LEACHING DATA Form #5 V/S = 2.11 cm

Leach Time (Days)	Incremental Fractional Release				pH of Leachant
	Sr-85		Cs-137		
	Measured Fraction	Fraction xV/S ^a	Measured Fraction	Fraction xV/S ^a	
1	2.94E-02	2.94E-02	2.34E-01	2.34E-01	11.93
2	1.25E-02	1.25E-02	8.89E-02	8.89E-02	11.70
3	6.45E-03	6.50E-03	6.43E-02	6.43E-02	11.59
4	5.43E-03	5.00E-03	5.14E-02	5.14E-02	11.63
5		4.20E-03		4.19E-02	
6		3.70E-03		3.85E-02	
7	9.84E-03	3.20E-03	1.06E-01	3.54E-02	11.77
8	3.59E-03	2.95E-03	3.31E-02	3.20E-02	
9		2.70E-03		2.85E-02	
10	4.84E-03	2.50E-03	4.98E-02	2.55E-02	11.71
11	2.33E-03	2.30E-03	2.26E-02	2.15E-02	11.48
12		2.15E-03		1.88E-02	
13		2.05E-03		1.76E-02	
14	3.97E-03	1.90E-03	5.16E-02	1.67E-02	11.70
15	2.16E-03	1.80E-03	1.66E-02	1.61E-02	11.43
16	1.68E-03	1.70E-03	1.53E-02	1.54E-02	11.42
17	1.43E-03	1.65E-03	1.41E-02	1.48E-02	11.41
18	1.66E-03	1.60E-03	1.44E-02	1.41E-02	11.32
19		1.55E-03		1.35E-02	
20		1.50E-03		1.28E-02	
21	3.10E-03	1.50E-03	3.57E-02	1.22E-02	11.65
22	1.79E-03	1.45E-03	1.26E-02	1.17E-02	11.19
23	1.59E-03	1.45E-03	1.14E-02	1.11E-02	11.25
24	9.39E-04	1.40E-03	9.97E-03	1.05E-02	11.17
25	1.28E-03	1.40E-03	1.06E-02	1.00E-02	11.13
26		1.35E-03		9.55E-03	
27		1.35E-03		9.25E-03	
28	2.80E-03	1.35E-03	2.74E-02	9.25E-03	11.54
29	1.15E-03	1.30E-03	9.56E-03	9.50E-03	11.02
30	1.39E-03	1.30E-03	9.53E-03	9.65E-03	11.23
31	1.78E-03	1.25E-03	1.01E-02	9.80E-03	11.18
32	1.04E-03	1.25E-03	1.02E-02	9.85E-03	11.10
33		1.20E-03		9.90E-03	
34		1.20E-03		9.95E-03	
35	2.67E-03	1.20E-03	2.83E-02	1.00E-02	11.57
36	1.59E-03	1.15E-03	1.04E-02	9.95E-03	11.26
37	1.36E-03	1.15E-03	9.97E-03	9.90E-03	11.20
38	1.24E-03	1.15E-03	1.01E-02	9.80E-03	11.16
39	1.53E-03	1.10E-03	9.50E-03	9.60E-03	11.20
40		1.10E-03		9.30E-03	
41		1.10E-03		8.95E-03	
42	2.32E-03	1.05E-03	2.40E-02	8.45E-03	11.52

^aFraction values are read from hand smoothed curves as explained in the text.

APPENDIX 1, Continued

LEACHING DATA Form #5 V/S = 2.11 cm

43	1.54E-03	1.05E-03	8.66E-03	7.90E-03	11.12
44	9.78E-04	1.05E-03	6.77E-03	7.50E-03	11.12
45	1.16E-03	1.00E-03	7.20E-03	7.20E-03	11.17
46	8.08E-04	1.00E-03	6.41E-03	6.95E-03	11.14
47		1.00E-03		6.70E-03	
48		1.00E-03		6.50E-03	
49		9.50E-04		6.30E-03	
50	1.88E-03	9.50E-04	2.28E-02	6.10E-03	11.59
51	1.26E-03	9.50E-04	6.10E-03	5.95E-03	11.18
52	8.19E-04	9.50E-04	5.39E-03	5.80E-03	11.15
53	8.32E-04	9.00E-04	5.59E-03	5.65E-03	11.12
54		9.00E-04		5.55E-03	
55		9.00E-04		5.40E-03	
56	1.81E-03	9.00E-04	1.52E-02	5.30E-03	11.44
57	1.02E-03	9.00E-04	5.44E-03	5.20E-03	11.12
58	7.30E-04	9.00E-04	5.10E-03	5.10E-03	11.12
59	8.23E-04	9.00E-04	4.83E-03	5.05E-03	11.08
60	7.83E-04	8.50E-04	5.33E-03	4.95E-03	11.09
61		8.50E-04		4.90E-03	
62		8.50E-04		4.80E-03	
63	1.79E-03	8.50E-04	1.41E-02	4.75E-03	11.44
64	9.99E-04	8.50E-04	4.36E-03	4.70E-03	10.81
65	9.21E-04	8.50E-04	4.67E-03	4.65E-03	10.94
66	7.48E-04	8.50E-04	4.45E-03	4.60E-03	10.91
67	7.57E-04	8.50E-04	4.94E-03	4.55E-03	11.02
68		8.00E-04		4.50E-03	
69		8.00E-04		4.45E-03	
70		8.00E-04		4.40E-03	
71		8.00E-04		4.35E-03	
72	1.95E-03	8.00E-04	1.94E-02	4.30E-03	11.59
73	1.10E-03	8.00E-04	4.97E-03	4.30E-03	11.18
74	6.58E-04	8.00E-04	3.76E-03	4.25E-03	10.99
75		8.00E-04		4.25E-03	
76		8.00E-04		4.20E-03	
77	2.01E-03	8.00E-04	1.18E-02	4.20E-03	11.30
78	9.63E-04	8.00E-04	4.56E-03	4.15E-03	10.95
79	5.49E-04	7.50E-04	4.53E-03	4.15E-03	10.84
80	4.67E-04	7.50E-04	3.78E-03	4.15E-03	10.61
81	6.04E-04	7.50E-04	4.61E-03	4.15E-03	10.85
82		7.50E-04		4.10E-03	
83		7.50E-04		4.10E-03	
84	1.12E-03	7.50E-04	1.22E-02	4.10E-03	11.08
85	7.54E-04	7.50E-04	4.15E-03	4.10E-03	10.84
86	8.20E-04	7.50E-04	4.31E-03	4.10E-03	10.92
87	6.95E-04	7.50E-04	4.22E-03	4.10E-03	10.75
88	6.70E-04	7.50E-04	3.57E-03	4.05E-03	10.70
89		7.00E-04		4.05E-03	
90		7.00E-04		4.00E-03	
91	1.72E-03	7.00E-04	1.10E-02	4.00E-03	11.00
92	8.82E-04	7.00E-04	4.22E-03	3.95E-03	10.52
93	5.52E-04	7.00E-04	3.63E-03	3.90E-03	10.56
94	4.19E-04	7.00E-04	3.75E-03	3.85E-03	10.57

APPENDIX 1, Continued

LEACHING DATA Form #5 V/S = 2.11 cm

95	5.90E-04	7.00E-04	4.02E-03	3.80E-03	10.67
96		7.00E-04		3.70E-03	
97		6.50E-04		3.65E-03	
98	1.80E-03	6.50E-04	1.09E-02	3.55E-03	11.14
99	6.14E-04	6.50E-04	3.52E-03	3.50E-03	10.77
100	6.64E-04	6.50E-04	3.73E-03	3.50E-03	10.82
101	3.68E-04	6.50E-04	2.87E-03	3.50E-03	10.77
102	5.24E-04	6.50E-04	3.88E-03	3.50E-03	10.79
103		6.50E-04		3.55E-03	
104		6.50E-04		3.60E-03	
105	1.49E-03	6.00E-04	8.99E-03	3.70E-03	11.09
106	5.95E-04	6.00E-04	3.33E-03	3.85E-03	10.85
107	4.87E-04	6.00E-04	3.75E-03	4.00E-03	10.64
108	1.65E-04	6.00E-04	4.08E-03	4.10E-03	10.73
109	5.57E-04	6.00E-04	4.96E-03	4.20E-03	10.85
110		6.00E-04		4.30E-03	
111		6.00E-04		4.40E-03	
112	1.63E-03	6.00E-04	1.21E-02	4.45E-03	11.14
113	7.96E-04	6.00E-04	5.23E-03	4.50E-03	10.83
114	7.16E-04	6.00E-04	5.42E-03	4.55E-03	10.62
115	5.10E-04	6.00E-04	4.88E-03	4.60E-03	10.56
116	4.07E-04	6.00E-04	4.61E-03	4.65E-03	10.55
117		5.50E-04		4.70E-03	
118		5.50E-04		4.75E-03	
119	1.35E-03	5.50E-04	1.20E-02	4.80E-03	11.14
120	6.82E-04	5.50E-04	5.55E-03	4.80E-03	10.69
121	4.01E-04	5.50E-04	4.23E-03	4.85E-03	10.50

APPENDIX 1, Continued

LEACHING DATA Form #6 V/S = 2.77 cm

Leach Time (Days)	Incremental Fractional Release				pH of Leachant
	Sr-85		Cs-137		
	Measured Fraction	Fraction xV/S ^a	Measured Fraction	Fraction xV/S ^a	
1	1.56E-02	1.58E-02	1.48E-01	1.48E-01	11.95
2	1.07E-02	1.08E-02	8.31E-02	8.31E-02	11.76
3	6.27E-03	6.30E-03	6.44E-02	6.44E-02	11.69
4	5.08E-03	4.20E-03	5.24E-02	5.24E-02	11.64
5		3.60E-03		4.25E-02	
6		3.20E-03		3.79E-02	
7	8.10E-03	2.90E-03	1.09E-01	3.52E-02	11.78
8	2.97E-03	2.65E-03	3.33E-02	3.25E-02	
9		2.40E-03		2.99E-02	
10	4.04E-03	2.25E-03	5.38E-02	2.73E-02	11.74
11	2.06E-03	2.10E-03	2.49E-02	2.47E-02	11.60
12		1.95E-03		2.21E-02	
13		1.85E-03		1.95E-02	
14	3.17E-03	1.80E-03	4.70E-02	1.76E-02	11.70
15	1.73E-03	1.70E-03	1.65E-02	1.66E-02	11.50
16	1.28E-03	1.65E-03	1.58E-02	1.57E-02	11.44
17	1.31E-03	1.60E-03	1.43E-02	1.49E-02	11.45
18	1.46E-03	1.55E-03	1.58E-02	1.41E-02	11.34
19		1.50E-03		1.34E-02	
20		1.45E-03		1.28E-02	
21	2.24E-03	1.40E-03	3.66E-02	1.23E-02	11.66
22	1.30E-03	1.35E-03	1.32E-02	1.18E-02	11.23
23	1.27E-03	1.30E-03	1.25E-02	1.14E-02	11.22
24	1.05E-03	1.25E-03	1.10E-02	1.10E-02	11.21
25	9.38E-04	1.20E-03	1.04E-02	1.06E-02	11.19
26		1.20E-03		1.02E-02	
27		1.20E-03		9.85E-03	
28	1.83E-03	1.15E-03	2.63E-02	9.55E-03	11.59
29	8.73E-04	1.15E-03	9.01E-03	9.30E-03	11.13
30	1.16E-03	1.10E-03	8.51E-03	9.05E-03	11.19
31	1.07E-03	1.10E-03	9.58E-03	8.85E-03	11.19
32	1.35E-03	1.05E-03	9.70E-03	8.65E-03	11.14
33		1.05E-03		8.45E-03	
34		1.00E-03		8.25E-03	
35	1.77E-03	1.00E-03	2.25E-02	8.05E-03	11.50
36	8.96E-04	1.00E-03	7.74E-03	7.90E-03	11.16
37	9.34E-04	9.50E-04	7.65E-03	7.70E-03	11.16
38	1.22E-03	9.50E-04	8.13E-03	7.60E-03	11.18
39	1.08E-03	9.50E-04	8.14E-03	7.45E-03	11.19
40		9.00E-04		7.30E-03	
41		9.00E-04		7.15E-03	
42	1.88E-03	9.00E-04	2.24E-02	7.00E-03	11.50

^aFraction values are read from the hand smoothed curves as explained in the text.

APPENDIX 1, Continued

LEACHING DATA Form #6 V/S = 2.77 cm

43	1.12E-03	9.00E-04	7.51E-03	6.90E-03	11.19
44	9.30E-04	8.50E-04	6.43E-03	6.75E-03	11.16
45	8.06E-04	8.50E-04	6.90E-03	6.65E-03	11.15
46	7.36E-04	8.50E-04	6.08E-03	6.55E-03	11.15
47		8.50E-04		6.40E-03	
48		8.00E-04		6.30E-03	
49		8.00E-04		6.20E-03	
50	1.56E-03	8.00E-04	2.24E-02	6.10E-03	11.55
51	6.55E-04	8.00E-04	6.46E-03	6.00E-03	11.14
52	6.56E-04	8.00E-04	5.31E-03	5.90E-03	11.14
53	6.27E-04	8.00E-04	5.49E-03	5.80E-03	11.08
54		7.50E-04		5.75E-03	
55		7.50E-04		5.65E-03	
56	1.52E-03	7.50E-04	1.56E-02	5.60E-03	11.45
57	7.52E-04	7.50E-04	5.56E-03	5.50E-03	11.11
58	6.12E-04	7.50E-04	5.30E-03	5.40E-03	11.09
59	6.98E-04	7.50E-04	5.20E-03	5.35E-03	11.11
60	6.21E-04	7.00E-04	5.66E-03	5.30E-03	11.07
61		7.00E-04		5.20E-03	
62		7.00E-04		5.10E-03	
63	1.61E-03	7.00E-04	1.42E-02	5.05E-03	11.45
64	6.41E-04	7.00E-04	4.58E-03	5.00E-03	11.04
65	5.66E-04	7.00E-04	4.75E-03	4.95E-03	11.07
66	6.60E-04	7.00E-04	4.88E-03	4.85E-03	11.03
67	6.76E-04	7.00E-04	4.91E-03	4.80E-03	10.90
68		6.50E-04		4.75E-03	
69		6.50E-04		4.70E-03	
70		6.50E-04		4.65E-03	
71		6.50E-04		4.60E-03	
72	1.69E-03	6.50E-04	2.24E-02	4.55E-03	11.53
73	9.12E-04	6.00E-04	5.01E-03	4.50E-03	11.19
74	5.60E-04	6.00E-04	3.98E-03	4.45E-03	11.02
75		6.00E-04		4.40E-03	
76		6.00E-04		4.35E-03	
77	1.27E-03	6.00E-04	1.19E-02	4.30E-03	11.32
78	7.35E-04	5.50E-04	4.70E-03	4.25E-03	10.96
79	3.21E-04	5.50E-04	4.29E-03	4.20E-03	10.83
80	3.88E-04	5.50E-04	4.03E-03	4.15E-03	10.70
81	4.26E-04	5.50E-04	4.49E-03	4.10E-03	10.82
82		5.50E-04		4.05E-03	
83		5.50E-04		4.00E-03	
84	7.43E-04	5.00E-04	1.10E-02	4.00E-03	10.97
85	5.79E-04	5.00E-04	3.84E-03	3.95E-03	10.83
86	7.17E-04	5.00E-04	4.11E-03	3.90E-03	10.90
87	5.96E-04	5.00E-04	3.60E-03	3.85E-03	10.79
88	2.51E-04	5.00E-04	2.98E-03	3.80E-03	10.69
89		5.00E-04		3.80E-03	
90		4.50E-04		3.75E-03	
91	1.50E-03	4.50E-04	1.07E-02	3.70E-03	10.97
92	4.95E-04	4.50E-04	3.36E-03	3.70E-03	10.45
93	5.14E-04	4.50E-04	3.28E-03	3.65E-03	10.55
94	4.37E-04	4.50E-04	3.18E-03	3.60E-03	10.53

APPENDIX 1, Continued

LEACHING DATA Form #6 V/S = 2.77 cm

95	3.96E-04	4.55E-04	3.91E-03	3.60E-03	10.61
96		4.50E-04		3.50E-03	
97		4.00E-04		3.50E-03	
98	1.00E-03	4.00E-04	9.99E-03	3.50E-03	11.17
99	4.52E-04	4.00E-04	2.98E-03	3.45E-03	10.79
100	6.11E-04	4.00E-04	3.16E-03	3.40E-03	10.83
101	4.16E-04	4.00E-04	3.55E-03	3.40E-03	10.79
102	4.80E-04	4.00E-04	3.42E-03	3.35E-03	10.80
103		4.00E-04		3.35E-03	
104		3.50E-04		3.30E-03	
105	9.88E-04	3.50E-04	9.08E-03	3.30E-03	10.84
106	4.43E-04	3.50E-04	3.16E-03	3.25E-03	10.79
107	3.97E-04	3.50E-04	2.79E-03	3.20E-03	10.61
108	2.63E-04	3.50E-04	2.66E-03	3.15E-03	10.65
109	3.34E-04	3.50E-04	3.19E-03	3.10E-03	10.75
110		3.00E-04		3.05E-03	
111		3.00E-04		2.95E-03	
112	9.21E-04	3.00E-04	7.00E-03	2.90E-03	10.67
113	3.61E-04	3.00E-04	3.08E-03	2.80E-03	10.59
114	2.47E-04	3.00E-04	2.17E-03	2.75E-03	10.26
115	2.62E-04	3.00E-04	1.97E-03	2.65E-03	9.92
116	1.85E-04	3.00E-04	1.73E-03	2.55E-03	9.81
117		2.50E-04		2.45E-03	
118		2.50E-04		2.30E-03	
119	5.14E-04	2.50E-04	7.99E-03	2.15E-03	10.82
120	2.71E-04	2.50E-04	2.20E-03	1.95E-03	9.77
121	1.49E-04	2.50E-04	1.88E-03	1.75E-03	9.91

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