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PROPERTIES OF RADIOACTIVE WASTES AND WASTE CONTAINERS

QUARTERLY PROGRESS REPORT
APRIL — JUNE 1981

Nabil Morcos and Allen J. Weiss

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ABSTRACT

An empirical relationship has been developed to estimate the cumulative fractional releases of ^{137}Cs from simulated waste forms as a function of leaching time and the geometric surface-to-volume ratios. Data from an on-going leaching study were used. The simulated waste forms consisted of organic cation exchange resins solidified in Portland I cement at a waste-to-cement ratio of 0.6 and water-to-cement ratio of 0.4. The nominal specimen dimensions were: 1-inch diameter x 1-inch high, 2-inch diameter x 2-inch high, 2-inch diameter x 4-inch high, 3-inch diameter x 3-inch high, 6-inch diameter x 6-inch high, 6-inch diameter x 12-inch high, and 12-inch diameter x 12-inch high. The waste forms were leached in deionized water using a modified IAEA leaching procedure.

A study designed to evaluate the leachability of ^{137}Cs, ^{85}Sr, and ^{60}Co from simulated boric acid waste solidified in Portland III cement and to measure the compressive strength of the ensuing waste forms before and after leaching was concluded. Leaching data extending over 229 days are presented. The simulated waste forms were leached in deionized water using a modified IAEA leaching procedure. The compressive strength of the specimens was measured initially and after their exposure to a leaching environment for 352 days.

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SUMMARY

I. Experiments were initiated earlier to determine if the leachability of ^{137}Cs from small-scale laboratory samples could be used in predicting the leaching behavior of larger waste forms. This progress report updates the experimental data obtained to date, presents an empirical method of correlating the leaching data from the small-scale samples to those from large samples, and offers a method of estimating the cumulative fraction release for a given waste form size for a given total leaching time.

Simulated waste forms consisted of organic cation exchange resins solidified in Portland I cement at a waste-to-cement (w/w) ratio of 0.6 and a water-to-cement (w/w) ratio of 0.4. Samples with nominal specimen dimensions evaluated to date were: 1-inch diameter x 1-inch high, 2-inch diameter x 2-inch high, 2-inch diameter x 4-inch high, 3-inch diameter x 3-inch high, 6-inch diameter x 6-inch high, 6-inch diameter x 12-inch high, and 12-inch diameter x 12-inch high. The waste forms were leached in deionized water using a modified IAEA leaching procedure. Incremental and cumulative fractional releases of ^{137}Cs were determined.

Observations and conclusions from the data collected to date are:

- The physical integrity of the 6-inch diameter x 12-inch high, and 12-inch diameter x 12-inch high waste forms began to deteriorate after approximately 100 days of leaching. (We are currently attempting to understand the reasons for this deterioration, and are preparing new forms with possibly a modified formulation that will withstand longer leaching periods.)

- An empirical relationship was developed from the leaching data obtained to date in this study. This empirical approach relates the cumulative fractional release to the geometric surface-to-volume ratio of the waste forms and the square root of the leaching time.

II. This progress report concludes a study initiated earlier, and designed to evaluate the leachability of ^{137}Cs, ^{85}Sr, and ^{60}Co from simulated boric acid waste solidified in Portland III cement. The compressive strength of the ensuing waste forms was measured before and after 352 days of leaching.

The waste forms were made with 3%, 6%, and 12% boric acid solutions whose pH's were adjusted to approximately 12. The waste-to-cement ratios studied were 0.5 and 0.7.

The following conclusions and observations were made:

- Increasing the waste-to-cement ratio from 0.5 to 0.7 caused an increase in the leachability of ^{137}Cs from the three boric

acid/cement composite formulations (i.e., made with 3%, 6%, and 12% boric/acid solutions as waste). This effect is not noticeable for the leachability of ^{85}Sr from these composites.

- For a waste-to-cement (w/w) ratio of 0.7, increasing the boric acid solution concentration (from 3% to 6% and 12%) effectively decreased the leachability of both ^{137}Cs and ^{85}Sr. This trend is less noticeable for a waste-to-cement ratio of 0.5 when comparing composites made with 3% and 6% boric acid solutions, but becomes prominent between composites made with 3% and 12%. The reasons for this decrease in ^{137}Cs and ^{85}Sr leachability with increasing boric acid content of the composites are not presently understood.

- The extent of ^{85}Sr release was approximately one-twentieth that of ^{137}Cs from these composites.

- Cobalt-60 was below the detection limit in the leachates from all the composites (3.0×10^{-2} μCi per 1.5 L·samples).

- Compressive strength data:

  For w/c ratio of 0.5 - Leaching for 352 days caused a substantial decrease (approx. 50%) in the specimens compressive strength.

  For w/c ratio of 0.7 - Although initially the compressive strength of these specimens was approximately 40 to 50% lower than those at w/c ratio of 0.5, it did not decrease further after 352 days of leaching.

  The compressive strength of the specimens at w/c ratios of both 0.5 and 0.7 was approximately 20 to 38 times higher than the lower acceptable limit (50 psi) set forth in the proposed Code of Federal Regulations, 10CFR Part 61.56.

- Leachate pH data:

  The leachate pH values from composites at both w/c ratio of 0.5 and 0.7 did not differ, however, those from the samples containing the 3% boric acid solutions were systematically lower than those containing the 6% and 12% boric acid solutions by approximately one to two pH units.

PROPERTIES OF RADIOACTIVE WASTES AND WASTE CONTAINERS
QUARTERLY PROGRESS REPORT, APRIL-JUNE 1981

1. CORRELATION OF ^{137}Cs LEACHABILITY FROM SMALL-SCALE (LABORATORY) SAMPLES TO LARGE-SCALE WASTE FORMS (W. Becker, A. Colavito, P. Hayde, L. Milian, and N. Morcos)

1.1 Introduction

Licensing of near surface low-level radioactive waste disposal sites and waste forms/containers requires the ability to predict the dispersibility of radionuclides from waste forms and waste containers disposed in burial sites. Basic concerns in licensing radioactive waste forms and containers are their dimensional stability and the potential for migration of the radionuclides enclosed therein in a near- and long-term predictable fashion. To assess these concerns, a data base is needed for evaluating the acceptability of solidified low-level radioactive waste packages for disposal. Furthermore, the need to develop test procedures and methodologies exists to enable the prediction and extrapolation of long-term performance of waste forms based on short-term laboratory tests.

Several theoretical and empirical methods based on mass transport and diffusion theory have been developed to predict the leachability of radioisotopes from waste composites.[1-8] A method has been recommended earlier (1970) by the International Atomic Energy Agency (IAEA) for leaching samples and for the analysis and interpretation of leaching data.[9] Recently, a standard method, which has much in common with the earlier IAEA method, was proposed by the American Nuclear Society Standards Committee Working Group (ANS-16.1). This method suggests the accumulation of data over a short-term period (five days) to determine the "Leachability Index," a material parameter. This parameter characterizes the leaching of a radionuclide from the waste form under evaluation, and may be used for performance predictions under actual environmental conditions, if the type of material being tested was characterized through generic studies. A working group (ISO/TC 85/SC 5/WG 5) of the International Standards Organization (ISO) is also currently directing efforts toward the adoption of a uniform standard leach test.

The IAEA method assumes a semi-infinite plane source model of diffusion for radioisotopes from waste composites, and relates the amount of substance diffused out of a waste composite to the leaching time, the amount of that substance initially present, and a diffusion rate. The solution for the rate equation describing this diffusion mode can be written as[1,10]:

$$f = \frac{S}{V} \times 2\left(\frac{D\,t}{\pi}\right)^{1/2} \qquad (1.1)$$

where f = fraction of substance diffused out of the composite during time t,

S/V = ratio of the geometric surface of the sample to its volume,

D = effective diffusion coefficient of the substance for the particular composite matrix.

The underlying assumptions dictated by Equation (1.1) are that the isotope under study is either stable or has a long half-life as compared to the duration of the experiment and that the initial isotope surface concentration of the waste form is zero. Furthermore, the relationship in Equation (1.1) implies that initially for t = 0, the fraction leached (f) is also zero. However, experimental leaching data deviates from this prediction for small values of t, and a more general relationship is suggested[1,11]:

$$f = \frac{S}{V} \cdot 2\left(\frac{D\ t}{\pi}\right)^{1/2} + \alpha \qquad (1.2)$$

where the added term (α) is attributed to non-diffusive contributions from the surface of the waste form.[4,12] Furthermore, a linear relationship of this added term (α) with the S/V ratio of the waste form was shown to exist.[12]

Experiments were initiated earlier[13] to determine if the leachability of ^{137}Cs from small-scale laboratory samples could be used in predicting the leaching behavior of larger waste forms. This report updates the experimental data obtained to date, presents a method of correlating the leaching data from the small-scale samples to those from large samples, and offers a method of estimating the cumulative fractional release for a given waste form size and a given leaching time.

1.2 Experimental

The waste forms being evaluated in this study are representative of those that are expected to be generated at nuclear power plants, e.g., organic ion exchange resins, boric acid, and sodium sulfate regenerative waste solidified in Portland cements and vinyl ester-styrene (Dow). Cylindrical waste composites with the following dimensions (inches) are considered in this study (diameter x height): 1 x 1, 2 x 2, 2 x 4, 3 x 3, 6 x 6, 6 x 12, 12 x 12, and 22 x 22. The largest size approaches the dimensions of waste solidified in a 55-gallon drum.

This report presents updated leaching data obtained from 1 x 1, 2 x 2, 2 x 4, 3 x 3, and 6 x 6 forms together with new data from 6 x 12 and 12 x 12 forms incorporating organic cation exchange resins loaded with ^{137}Cs and solidified in Portland I cement. An empirical method of predicting cumulative fractional releases from various size forms as a function of total leaching time is also presented. Larger size forms (22 x 22) are presently in the leaching phase.

The amounts of ^{137}Cs added to the different size waste forms were chosen by using the relationship $f_1(V/S)_1 = f_2(V/S)_2$ where f_1 and f_2 are the cumulative release fractions leached from two different waste forms during the same leaching time, and $(V/S)_1$ and $(V/S)_2$ are the geometric surface-to-volume ratios of these two forms. The measured leached fractions from 2 x 4 organic cation exchange resin/Portland II cement composites(14) were substituted for f_1, and f_2 was calculated for the various sizes using the appropriate $(V/S)_2$ value.

A modified IAEA leaching procedure(15) was followed. The first leaching period was 100 minutes, and thereafter the leachant was changed daily, during the first 42 days, except for weekends, where the leaching periods extended from Friday to Monday. (However, the leachant was changed during the first weekend). After 42 days, the leaching periods were extended to a week, and later to a month, based on the amount of activity observed in the leachates.

1.2.1 Organic Cation Exchange Resin Preparation

Organic cation exchange resins (Rohm and Haas IRN-77, H^+ form) were converted to the Na^+ form with 2 molar NaOH solution. The volume of NaOH solution was twice that of the resin and was decanted after the sorption period. The resins were then rinsed with deionized water until the pH of the rinse water was comparable to that of the initial deionized water. The resins were stored under deionized water.

1.2.2 Organic Cation Exchange Resin/Cement Composites

Organic cation exchange resin/cement composites were fabricated with a waste-to-cement (w/w) (Portland I) ratio of 0.6 and a water-to-cement (w/w) ratio of 0.4. The incorporated simulated waste composition consisted of 33 weight percent IRN-77 cation exchange resin, Na^+ form, loaded with ^{137}Cs, and 67 weight percent deionized water. This formulation was chosen because test samples maintained their physical integrity during a prolonged leaching period (4-5 weeks), and because it provided good workability of the mixture during the mixing stage. Earlier process parameter investigations(16) for the solidification of ion exchange resins in cement had defined boundaries for the components of the waste form (resin, water, and cement) where a free standing solid product was produced. However, the durability of the solidified product upon immersion in water had not been evaluated. Formulations corresponding to those shown in the area bounded by heavy lines in the table reproduced from Reference 16 were evaluated (see next page). Up to twelve two-inch-diameter by four-inch-high forms were made and immersed in deionized water to evaluate their physical integrity (no evidence of crumbling) under leaching conditions. Only two formulations, denoted by the triangle and circle in the table, passed the immersion and workability

Table (From Manaktala and Weiss - Ref. 16)

Formulation of Ion Exchange Resin Test Samples
(all weights given in grams)

Water/Cement ↓ \ Waste/Cement →	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8
0.3	15.7[a] 47.1 157.1	41.2 41.2 137.6	61.1 36.7 122.2	77.0 33.0 110.0	90.0 30.0 100.0	100.8 27.5 91.7	110.0 25.4 84.6	117.9 23.6 78.6
0.4	0.0 62.8 157.2	27.5 55.0 137.5	48.9 48.9 122.2	66.0 44.0 110.0	80.0 40.0 100.0	91.7 36.7 91.7	101.5 33.9 84.6	110.0 31.4 78.6
0.5		13.8 68.7 137.5	36.7 61.1 122.2	55.0 55.0 110.0	70.0 50.0 100.0	82.5 45.8 91.7	93.1 42.3 84.6	102.1 39.3 78.6
0.6		0.0 82.5 137.5	24.4 73.3 122.2	44.0 66.0 110.0	60.0 60.0 100.0	73.3 55.0 91.7	84.6 50.8 84.6	94.3 47.1 78.6
0.7			12.2 85.6 122.2	33.0 77.0 110.0	50.0 70.0 100.0	64.2 64.2 91.7	76.2 59.2 84.6	86.4 55.0 78.6
0.8			0.0 97.8 122.2	22.0 88.0 110.0	40.0 80.0 100.0	55.0 73.3 91.7	67.7 67.7 84.6	78.6 62.8 78.6
0.9				110.0 99.0 110.0	30.0 90.0 100.0	45.8 82.5 91.7	59.2 76.2 84.6	70.7 70.7 78.6
1.0				0.0 110.0 110.0	20.0 100.0 100.0	36.6 91.7 91.7	50.8 84.6 84.6	62.8 78.6 78.6

[a]Each entry is composed of three parts, viz., resin (15.7), water (47.1), and cement (157.1).

tests. However, some of the forms with the triangle formulation began to crumble after several days in water, whereas there were no failures of the formulation shown in the circle.

The objective of this work is not to develop a formulation for processing ion exchange resins for waste disposal, but specifically to obtain composites for these experiments, which will maintain physical integrity during an extended leaching period, perhaps as long as one year for the large waste forms.

The following procedure was used in preparing the 1 x 1, 2 x 2, 2 x 4, and 3 x 3 forms: The appropriate amounts of resins were added to each mold and covered with deionized water to which a measured amount of ^{137}Cs radiotracer was added while stirring. After a twenty-four-hour equilibration period, the water was sampled and assayed for ^{137}Cs content to assure uptake by the resin. The water was then removed by suction through a fritted filter and an amount of fresh water was added commensurate with the formulation for the composite. The larger samples (6 x 6, 6 x 12, and 12 x 12) were prepared in a slightly different manner. The amount of water added to the resins prior to the addition of ^{137}Cs was the amount needed for solidification, and therefore was not decanted after equilibration and ^{137}Cs assay. The amount of ^{137}Cs remaining in the aqueous phase (after sorption) for all samples was less than 0.1% of the initially added activity, indicating that greater than 99.9% of the ^{137}Cs was sorbed onto the resins.

The mixtures of cement, water, and resins in individual molds were hand stirred with polyethylene rods for five minutes and capped to prevent water evaporation during the 28-29-day curing period. Earlier work has shown that ion exchange resin/cement composites cured in air or left open to air after curing, disintegrated after immersion in water.

Table 1.1 summarizes the waste composite sizes made to date, together with their contents, volume-to-surface ratios, and leachant volumes. Each sample size was prepared in triplicate.

Table 1.1

Composite Dimensions, Components, and Leachant Volumes

Sample	Composite				Components (g)			^{137}Cs Added to Composite (μCi)	Volume of Leachant (mL)
	Diameter (in.)	Height (in.)	V/S (cm)	Weight (g)	Cement Portland I	Waste IRN-77[a]	Waste H_2O		
1 x 1	0.89	0.90	0.396	20	12.5	2.5	5.0	1	265
	0.89	0.90	0.396	b	12.5	2.5	5.0	1	265
	0.89	0.90	0.396	b	12.5	2.5	5.0	1	265
2 x 2	1.75	1.80	0.784	150	93.8	18.8	37.5	10	1,050
	1.75	1.80	0.784	150	93.8	18.8	37.5	10	1,050
	1.75	1.80	0.784	150	93.8	18.8	37.5	10	1,050
2 x 4	1.77	3.46	0.936	290	181.3	36.3	72.5	10	1,700
	1.77	3.46	0.936	290	181.3	36.3	72.5	10	1,700
	1.77	3.46	0.936	290	181.3	36.3	72.5	10	1,700
3 x 3	2.86	3.20	1.32	734	460	92.0	184	10	2,950
	2.86	3.20	1.32	735	460	92.0	184	10	2,950
	2.86	3.20	1.32	735	460	92.0	184	10	2,950
6 x 6	5.79	5.53	2.54	b	3,250	650	1,300	500	11,000
	5.79	5.47	2.54	b	3,250	650	1,300	500	11,000
	5.79	5.45	2.54	b	3,250	650	1,300	500	11,000
6 x 12	6.00	11.6	3.03	9,620	6,139	1,228	2,456	1,000	18,200
	6.00	12.5	3.07	9,250	6,139	1,228	2,456	1,000	18,200
	6.00	11.1	3.00	9,430	6,139	1,228	2,456	1,000	18,200
12 x 12	12.5	11.5	5.14	40,000	24,900	4,990	9,980	10,000	44,000
	12.3	11.5	5.09	40,100	24,900	4,990	9,980	10,000	44,000
	12.3	11.5	5.09	39,800	24,900	4,990	9,980	10,000	44,000

[a]Rohm and Haas Amberlite organic cation exchange resin.
[b]Not weighed.

1.2.3 Leaching

The composites were leached in deionized water using a modified IAEA leaching procedure[10] described earlier. The leaching volume was determined by the relationship: $V = 10\ cm \times S$, where V is the leachant volume and S is the geometric surface of the composite being leached.

Leaching was carried out using two sets of leach containers. The samples were placed in fresh leachant and the leachate from the previous period was acidified with HNO_3 (volume of conc. acid ≈1% volume of leachate). Ten-milliliter aliquots of this acidified leachate were withdrawn in a plastic test tube and assayed for ^{137}Cs content in a 3 in. x 3 in. NaI well crystal. The remaining liquid was removed, the container was washed, and fresh leachant was added to it for the next leaching period. The fresh leachant was allowed to equilibrate to room temperature overnight before transferring the waste form from the other container.

All samples were counted so as to achieve a minimum of 1,000 counts in the "window" set around the ^{137}Cs photopeak (661.6 keV). Data reduction was performed using a computer program developed at BNL by Barletta, et. al.[17] Fractional and cumulative fractional releases from the forms were calculated and cumulative fractional release data as a function of time were plotted by the program.

1.3 Results and Discussion

1.3.1 Leaching

The calculated incremental and cumulative fractions released from each waste form are given in Tables 1.2-1.8. The errors quoted represent only the statistical errors associated with the counting of each fraction. These data are also graphically shown in Figures 1.1-1.14. Each pair of figures shown on a page presents the leaching data of three replicate samples and the average cumulative fraction release of the three replicates except for the 12 x 12 samples. The average cumulative fraction release curves have been normalized for V/S variation in the waste forms.

Two of the 1 x 1, and one of the 6 x 6 composites partially disintegrated during the first three weeks of leaching. The cause of the deterioration of the 1 x 1 samples is not known. However, in the case of the 6 x 6 sample, the deterioration occurred mainly along a line on the sample that was inadvertently exposed to ambient air during the curing process. This line corresponds to a crack in the mold used in the fabrication of this sample.

The cumulative fraction releases from the composites that deteriorated were higher than those from the composites that remained intact. However, the actual geometric surfaces of the deteriorated composites were not measured, and their geometric surfaces prior to leaching were used to calculate the normalizing V/S ratio.

(Continued on Page 22)

Table 1.2

^{137}Cs Incremental and Cumulative Fractions Released From
1 x 1 Organic Cation Exchange Resin/Portland I Cement Composites

	Composite #1		Composite #2		Composite #3	
Time Days	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100
0.07	10.7 (1.1)	10.7 ± 0.1	4.00 (1.8)	4.0 ± 0.1	2.75 (2.1)	2.75 ± 0.06
1	27.8 (0.7)	38.5 ± 0.2	25.1 (0.7)	29.1 ± 0.2	11.9 (1.0)	14.7 ± 0.1
2	10.1 (1.1)	48.6 ± 0.2	11.9 (1.0)	41.0 ± 0.2	6.18 (1.4)	20.8 ± 0.2
3	6.19 (1.4)	54.8 ± 0.3	7.58 (1.3)	48.6 ± 0.2	4.43 (1.7)	25.3 ± 0.2
4	4.60 (1.7)	59.4 ± 0.3	5.71 (1.5)	54.3 ± 0.3	3.44 (1.9)	28.7 ± 0.2
5	3.53 (1.9)	63.0 ± 0.3	4.48 (1.7)	58.8 ± 0.3	2.69 (2.2)	31.4 ± 0.2
6	2.76 (2.1)	65.7 ± 0.3	3.69 (1.9)	62.5 ± 0.3	2.31 (2.3)	33.7 ± 0.2
7	2.30 (2.4)	68.0 ± 0.3	3.14 (2.0)	65.6 ± 0.3	1.87 (2.6)	35.6 ± 0.2
8	1.76 (2.7)	69.8 ± 0.3	2.58 (2.2)	68.2 ± 0.3	1.60 (2.9)	21.7 ± 0.2
9	1.66 (2.9)	71.4 ± 0.3	2.13 (2.5)	70.3 ± 0.3	1.53 (2.9)	38.7 ± 0.2
12	3.23 (2.0)	74.7 ± 0.3	4.60 (1.7)	74.9 ± 0.3	3.50 (1.9)	42.2 ± 0.2
13	0.957 (3.9)	75.6 ± 0.3	1.35 (3.2)	76.3 ± 0.3	1.10 (3.7)	43.3 ± 0.2
14	0.966 (3.9)	76.6 ± 0.3	1.28 (3.3)	77.6 ± 0.3	1.23 (3.4)	44.5 ± 0.2
15	0.780 (4.4)	77.4 ± 0.3	1.07 (3.6)	87.6 ± 0.3	1.05 (3.7)	45.6 ± 0.2
16	0.764 (4.5)	78.1 ± 0.3	1.04 (3.8)	79.7 ± 0.3	1.09 (3.6)	46.7 ± 0.2
19	1.76 (2.8)	79.7 ± 0.3	2.04 (2.6)	81.7 ± 0.3	2.32 (2.3)	49.0 ± 0.3
20	0.622 (3.6)	80.5 ± 0.3	0.697 (4.6)	82.4 ± 0.3	0.889 (3.9)	49.9 ± 0.3
21	0.596 (3.7)	81.1 ± 0.3	0.705 (4.7)	83.1 ± 0.3	0.836 (4.2)	50.7 ± 0.3
22	0.515 (4.1)	81.6 ± 0.3	0.587 (3.7)	83.7 ± 0.3	0.721 (4.6)	12.4 ± 0.3
23	0.474 (4.4)	82.1 ± 0.3	0.576 (3.8)	84.3 ± 0.3	0.781 (4.4)	52.2 ± 0.3
26	1.23 (3.4)	83.3 ± 0.3	1.44 (3.0)	85.7 ± 0.3	1.92 (2.6)	54.1 ± 0.3
27	0.457 (6.0)	83.8 ± 0.3	0.543 (3.9)	86.3 ± 0.3	0.733 (4.5)	54.9 ± 0.3
28	0.401 (5.0)	84.2 ± 0.3	0.485 (4.5)	86.7 ± 0.3	0.641 (3.5)	55.5 ± 0.3
29	0.437 (4.6)	84.6 ± 0.3	0.424 (4.7)	82.7 ± 0.3	0.661 (3.5)	56.2 ± 0.3
30	0.379 (4.9)	85.0 ± 0.3	0.360 (5.2)	87.5 ± 0.3	0.635 (3.5)	56.8 ± 0.3
33	1.05 (2.8)	86.0 ± 0.3	1.04 (1.6)	88.6 ± 0.3	1.66 (1.3)	58.5 ± 0.3
34	0.355 (5.9)	86.4 ± 0.3	0.337 (3.6)	88.9 ± 0.3	0.586 (2.5)	59.1 ± 0.3
35	0.335 (6.3)	86.7 ± 0.3	0.303 (3.6)	89.2 ± 0.3	0.530 (2.5)	59.6 ± 0.3
36	0.284 (3.9)	87.0 ± 0.3	0.286 (3.8)	89.5 ± 0.3	0.484 (2.8)	60.1 ± 0.3
37	0.229 (4.8)	87.2 ± 0.3	0.260 (4.2)	89.8 ± 0.3	0.467 (2.9)	60.5 ± 0.3
40	0.621 (2.4)	87.9 ± 0.3	0.644 (2.3)	90.4 ± 0.3	1.28 (1.1)	61.8 ± 0.3
41	0.278 (4.0)	88.1 ± 0.3	0.241 (4.6)	90.6 ± 0.3	0.521 (2.1)	62.4 ± 0.3
42	0.448 (2.4)	94.3 ± 0.3	0.438 (2.5)	96.8 ± 0.3	0.670 (2.0)	68.6 ± 0.3
49	1.30 (0.93)	95.6 ± 0.3	1.15 (1.0)	97.9 ± 0.3	2.53 (0.71)	71.1 ± 0.3
56	1.11 (1.5)	96.7 ± 0.3	0.889 (1.6)	98.8 ± 0.3	2.35 (1.0)	73.5 ± 0.3
63	1.02 (1.5)	97.7 ± 0.3	0.768 (1.7)	99.6 ± 0.3	2.36 (1.0)	75.8 ± 0.3
70	1.10 (1.5)	98.8 ± 0.3	0.883 (1.6)	100.4 ± 0.3	2.26 (1.0)	78.1 ± 0.3
77	0.876 (1.6)	99.7 ± 0.3	0.513 (2.1)	101.0 ± 0.3	1.83 (1.1)	79.9 ± 0.3
84	0.797 (1.8)	100.5 ± 0.3	0.759 (1.7)	101.7 ± 0.3	1.78 (1.2)	81.7 ± 0.3
112	1.62 (2.7)	102.1 ± 0.3	0.650 (4.3)	102.4 ± 0.3	4.74 (1.6)	86.4 ± 0.3

[a]Number in ( ) = 1σ percent counting uncertainty.

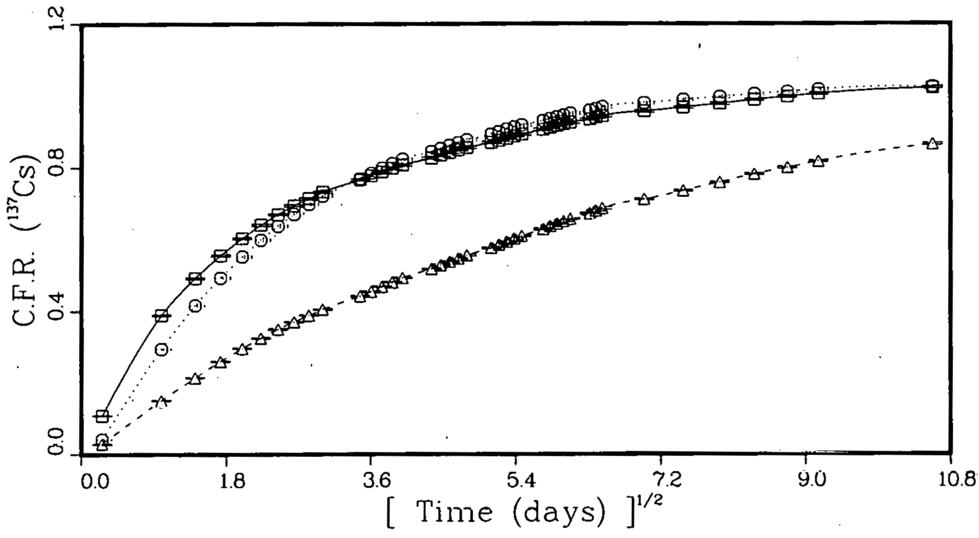

Figure 1.1 ^{137}Cs cumulative fractional release vs $(time)^{1/2}$ from 1-inch-diameter x 1-inch-high waste composites (w/c = 0.6; V/S = 0.396 cm). (The two forms denoted by □ and o partially disintegrated during the first three weeks of leaching.)

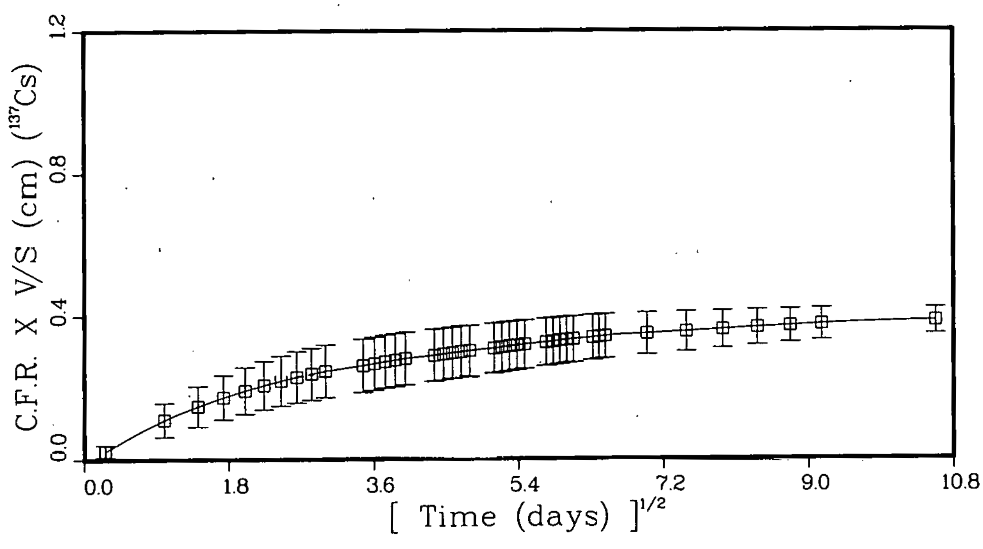

Figure 1.2 Average cumulative fractional release of ^{137}Cs vs $(time)^{1/2}$ from 1-inch-diameter x 1-inch-high waste composites (w/c = 0.6; V/S = 0.396 cm).

Table 1.3

^{137}Cs Incremental and Cumulative Fractions Released From
2 x 2 Organic Cation Exchange Resin/Portland I Cement Composites

	Composite #1		Composite #2		Composite #3	
Time Days	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100
0.07	2.32 (1.4)	2.32 ± 0.03	1.54 (1.7)	1.54 ± 0.03	1.16 (2.0)	1.16 ± 0.02
1	7.71 (0.8)	10.0 ± 0.1	5.70 (0.9)	7.24 ± 0.06	5.24 (0.9)	6.4 ± 0.05
2	3.31 (1.2)	13.4 ± 0.1	2.73 (0.4)	9.97 ± 0.06	3.13 (1.2)	9.5 ± 0.07
3	2.26 (1.4)	15.6 ± 0.1	2.04 (1.5)	12.0 ± 0.1	2.21 (1.4)	11.7 ± 0.1
4	7.76 (1.6)	17.4 ± 0.1	1.67 (1.7)	13.7 ± 0.1	1.83 (1.6)	13.6 ± 0.1
5	1.45 (1.8)	18.8 ± 0.1	1.40 (1.8)	15.1 ± 0.1	1.51 (1.7)	15.1 ± 0.1
6	1.23 (2.0)	20.1 ± 0.1	1.20 (2.0)	16.3 ± 0.1	1.30 (1.9)	16.4 ± 0.1
7	1.90 (2.1)	21.1 ± 0.1	1.09 (2.1)	17.4 ± 0.1	1.15 (2.0)	17.5 ± 0.1
8	0.917 (2.3)	22.1 ± 0.1	0.896 (2.3)	18.3 ± 0.1	1.05 (2.3)	1.95 ± 0.1
9	0.858 (2.3)	22.9 ± 0.1	0.872 (2.3)	19.1 ± 0.1	8.85 (1.5)	21.6 ± 0.1
12	1.89 (1.6)	24.8 ± 0.1	1.94 (1.5)	21.0 ± 0.1	2.11 (1.5)	21.6 ± 0.1
13	0.729 (2.5)	25.5 ± 0.1	0.656 (2.7)	21.7 ± 0.1	0.718 (2.6)	22.3 ± 0.1
14	0.709 (2.5)	26.2 ± 0.1	0.665 (2.6)	22.4 ± 0.1	0.760 (2.5)	23.1 ± 0.1
15	0.597 (2.8)	26.8 ± 0.1	0.3 1 (2.7)	23.0 ± 0.1	0.659 (2.6)	23.7 ± 0.1
16	0.572 (2.8)	27.4 ± 0.1	0.572 (2.8)	23.6 ± 0.1	0.662 (2.6)	24.4 ± 0.1
19	0.135 (1.8)	28.8 ± 0.1	1.35 (1.8)	25.0 ± 0.1	1.50 (1.8)	25.9 ± 0.1
20	0.549 (2.9)	29.3 ± 0.1	0.526 (3.0)	25.5 ± 0.1	0.562 (2.9)	26.4 ± 0.1
21	0.513 (3.0)	29.8 ± 0.1	0.501 (2.9)	26.0 ± 0.1	0.559 (2.9)	27.0 ± 0.1
22	0.471 (3.1)	30.3 ± 0.1	0.486 (3.1)	26.4 ± 0.1	0.527 (3.0)	27.5 ± 0.1
23	0.501 (3.0)	30.8 ± 0.1	0.494 (3.1)	27.0 ± 0.1	0.497 (3.1)	28.0 ± 0.1
26	1.20 (2.0)	32.0 ± 0.1	1.20 (1.9)	28.2 ± 0.1	1.39 (1.8)	29.4 ± 0.1
27	0.480 (3.1)	32.5 ± 0.1	0.443 (3.2)	28.6 ± 0.1	0.529 (3.0)	29.9 ± 0.1
28	0.416 (3.3)	32.9 ± 0.1	0.432 (3.3)	29.0 ± 0.1	0.519 (3.0)	30.5 ± 0.1
29	0.425 (3.2)	33.3 ± 0.1	0.444 (3.2)	29.5 ± 0.1	0.514 (3.0)	31.0 ± 0.1
30	0.418 (3.3)	33.7 ± 0.1	0.402 (3.4)	29.9 ± 0.1	0.475 (3.1)	31.4 ± 0.1
33	1.12 (0.9)	34.8 ± 0.1	1.16 (0.9)	31.0 ± 0.1	1.34 (0.8)	32.8 ± 0.1
34	0.484 (1.4)	35.3 ± 0.1	0.485 (1.4)	31.5 ± 0.1	0.503 (1.4)	33.3 ± 0.1
35	0.428 (1.5)	35.8 ± 0.1	0.429 (1.5)	32.0 ± 0.1	0.325 (2.0)	33.6 ± 0.1
36	0.381 (1.5)	36.1 ± 0.1	0.411 (1.5)	32.4 ± 0.1	0.317 (2.0)	33.9 ± 0.1
37	0.390 (1.5)	36.5 ± 0.1	0.391 (1.5)	32.8 ± 0.1	0.460 (1.4)	34.4 ± 0.1
40	0.943 (1.0)	37.5 ± 0.1	0.919 (1.0)	33.7 ± 0.1	1.09 (0.9)	36.0 ± 0.1
41	0.436 (1.5)	37.9 ± 0.1	0.440 (1.5)	34.1 ± 0.1	0.479 (1.3)	36.0 ± 0.1
42	0.374 (1.6)	38.3 ± 0.1	0.489 (1.4)	34.6 ± 0.1	0.446 (1.4)	36.4 ± 0.1
49	0.336 (1.6)	38.6 ± 0.1	0.343 (1.6)	34.9 ± 0.1	0.410 (1.5)	36.8 ± 0.1
56	1.65 (0.75)	40.3 ± 0.1	1.61 (0.80)	36.7 ± 0.1	1.89 (0.71)	38.7 ± 0.1
63	1.31 (0.85)	41.5 ± 0.1	1.58 (0.76)	38.1 ± 0.1	1.79 (0.72)	40.5 ± 0.1
70	1.71 (0.73)	43.3 ± 0.1	1.56 (0.77)	39.7 ± 0.1	1.81 (0.71)	42.3 ± 0.1
77	1.31 (0.85)	44.6 ± 0.1	1.37 (0.80)	41.1 ± 0.1	1.49 (0.77)	43.8 ± 0.1
84	1.32 (0.84)	45.9 ± 0.1	1.37 (0.80)	42.5 ± 0.1	1.55 (0.77)	45.3 ± 0.1
112	3.58 (1.1)	49.5 ± 0.1	3.86 (1.1)	46.3 ± 0.1	4.33 (1.0)	49.7 ± 0.1

[a]Number in ( ) = 1σ percent counting uncertainty.

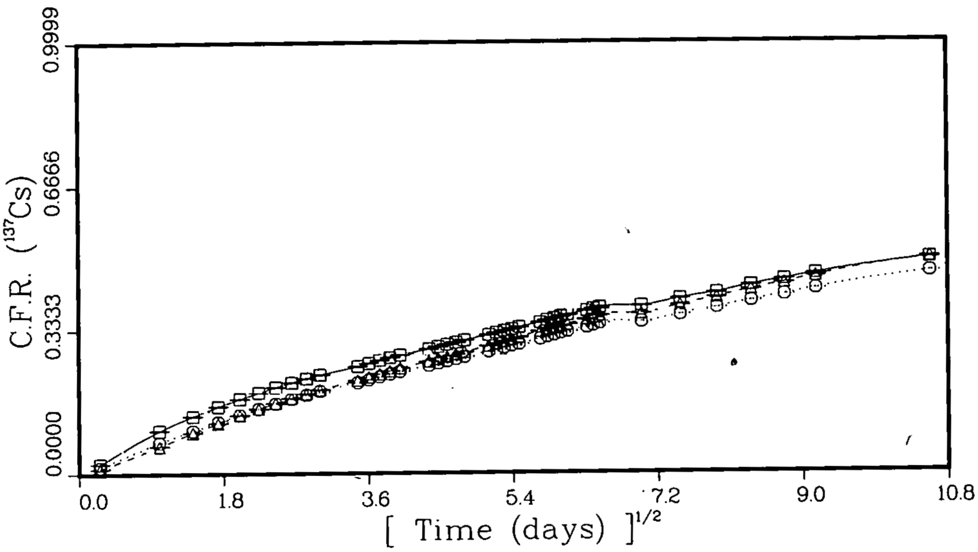

Figure 1.3 ^{137}Cs cumulative fractional release vs $(time)^{1/2}$ from 2-inch-diameter x 2-inch-high waste composites (w/c = 0.6; V/S = 0.784 cm).

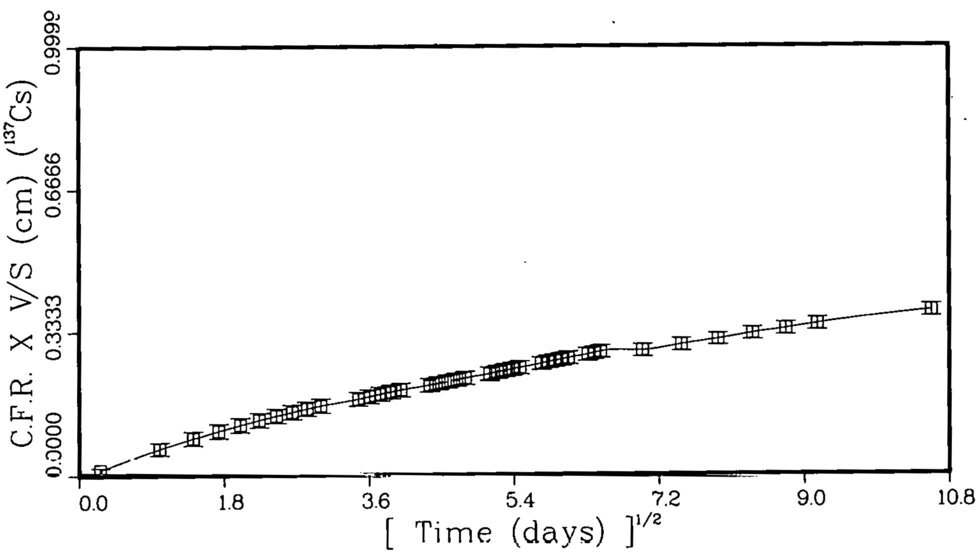

Figure 1.4 Average cumulative fractional release of ^{137}Cs vs $(time)^{1/2}$ from 2-inch-diameter x 2-inch-high waste composites (w/c = 0.6; V/S = 0.784 cm).

Table 1.4

^{137}Cs Incremental and Cumulative Fractions Released From 2 x 4 Organic Cation Exchange Resin/Portland I Cement Composites

	Composite #1		Composite #2		Composite #3	
Time Days	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100
0.07	1.14 (2.5)[a]	1.14 ± 0.03	1.06 (2.7)	1.06 ± 0.03	0.999 (2.7)	1.00 ± 0.03
1	3.81 (1.4)	4.95 ± 0.06	4.15 (1.3)	5.21 ± 0.06	4.13 (1.3)	5.13 ± 0.06
2	2.40 (1.8)	7.35 ± 0.07	2.55 (1.7)	7.76 ± 0.08	2.46 (1.7)	7.59 ± 0.08
3	0.950 (4.0)	8.30 ± 0.08	2.02 (1.9)	9.78 ± 0.09	2.01 (1.9)	9.60 ± 0.08
4	1.60 (2.1)	9.90 ± 0.09	1.62 (2.1)	11.4 ± 0.1	1.59 (2.1)	11.2 ± 0.1
5	1.32 (2.4)	11.2 ± 0.1	1.43 (2.3)	12.8 ± 0.1	1.37 (2.3)	12.6 ± 0.1
6	1.16 (1.3)	12.4 ± 0.1	1.20 (2.5)	14.0 ± 0.1	1.21 (2.5)	13.8 ± 0.1
7	1.08 (2.6)	13.5 ± 0.1	1.06 (2.7)	15.1 ± 0.1	1.09 (2.6)	14.9 ± 0.1
8	0.988 (2.8)	14.4 ± 0.1	0.934 (2.9)	16.0 ± 0.1	0.901 (2.9)	15.8 ± 0.1
9	0.982 (2.7)	15.4 ± 0.1	0.905 (2.9)	16.9 ± 0.1	0.854 (3.0)	16.6 ± 0.1
12	2.00 (1.9)	17.4 ± 0.1	2.00 (1.9)	18.9 ± 0.1	1.99 (1.9)	18.6 ± 0.1
13	0.725 (3.2)	18.1 ± 0.1	0.765 (3.1)	19.7 ± 0.1	0.760 (3.1)	19.4 ± 0.1
14	0.771 (3.1)	18.9 ± 0.1	0.762 (3.1)	20.5 ± 0.1	0.749 (3.2)	20.1 ± 0.1
15	0.706 (3.3)	19.6 ± 0.1	0.690 (3.3)	21.2 ± 0.1	0.710 (3.2)	20.8 ± 0.1
16	0.695 (3.3)	20.3 ± 0.1	0.607 (3.4)	21.8 ± 0.1	0.656 (3.4)	21.5 ± 0.1
19	1.59 (2.1)	21.9 ± 0.1	1.58 (2.2)	23.3 ± 0.1	1.57 (2.2)	23.0 ± 0.1
20	0.626 (3.4)	22.5 ± 0.1	0.610 (3.5)	24.0 ± 0.1	0.570 (3.6)	23.6 ± 0.1
21	0.591 (3.5)	23.1 ± 0.1	0.594 (3.5)	24.5 ± 0.1	0.598 (3.5)	24.2 ± 0.1
22	0.581 (3.6)	23.7 ± 0.1	0.580 (3.6)	25.1 ± 0.1	0.566 (3.7)	24.8 ± 0.1
23	0.061 (3.6)	24.3 ± 0.1	0.538 (3.7)	25.7 ± 0.1	0.567 (3.7)	25.4 ± 0.1
26	1.45 (2.2)	25.8 ± 0.1	1.32 (2.4)	27.0 ± 0.1	1.23 (2.5)	26.6 ± 0.1
27	0.585 (3.5)	26.3 ± 0.1	0.553 (3.6)	27.5 ± 0.1	0.531 (3.8)	27.1 ± 0.1
28	0.568 (3.6)	26.9 ± 0.1	0.517 (3.9)	28.1 ± 0.1	0.510 (2.8)	27.8 ± 0.1
29	0.533 (3.8)	27.5 ± 0.1	0.562 (2.6)	28.6 ± 0.1	0.536 (3.7)	28.2 ± 0.1
30	0.516 (3.7)	28.0 ± 0.1	0.533 (2.6)	29.1 ± 0.1	0.474 (3.0)	28.6 ± 0.1
33	1.40 (1.0)	29.4 ± 0.1	1.35 (1.0)	30.5 ± 0.1	1.33 (1.1)	30.0 ± 0.1
34	0.561 (1.6)	29.9 ± 0.1	0.555 (1.6)	31.1 ± 0.1	0.559 (1.6)	30.5 ± 0.1
35	0.535 (1.7)	30.5 ± 0.1	0.518 (1.7)	31.6 ± 0.1	0.531 (1.7)	31.0 ± 0.1
36	0.530 (1.7)	31.0 ± 0.1	0.512 (1.7)	32.1 ± 0.1	0.513 (1.7)	31.6 ± 0.1
37	0.527 (1.7)	31.5 ± 0.1	0.457 (1.8)	32.5 ± 0.1	0.473 (1.7)	32.0 ± 0.1
40	1.22 (1.1)	32.7 ± 0.1	1.07 (1.2)	33.6 ± 0.1	1.10 (1.1)	33.1 ± 0.1
41	0.556 (1.6)	33.3 ± 0.1	0.525 (1.7)	34.1 ± 0.1	0.519 (1.7)	33.7 ± 0.1
42	0.518 (1.7)	33.8 ± 0.2	0.479 (1.7)	34.6 ± 0.2	0.470 (1.7)	34.1 ± 0.2
49	2.10 (1.9)	35.9 ± 0.2	2.00 (1.9)	36.6 ± 0.2	0.396 (1.9)	34.5 ± 0.2
56	1.99 (0.86)	37.9 ± 0.2	1.87 (0.87)	38.5 ± 0.2	1.90 (0.90)	36.4 ± 0.2
63	1.85 (8.8)	39.7 ± 0.2	1.75 (0.93)	40.2 ± 0.2	1.78 (0.91)	38.2 ± 0.2
70	1.86 (8.8)	41.6 ± 0.2	1.78 (0.91)	42.0 ± 0.2	1.83 (0.89)	40.1 ± 0.2
77	1.60 (0.97)	43.2 ± 0.2	1.52 (0.98)	43.5 ± 0.2	1.57 (0.99)	41.6 ± 0.2
84	1.59 (9.7)	44.8 ± 0.2	1.49 (0.99)	45.0 ± 0.2	1.57 (0.99)	43.2 ± 0.2
112	4.32 (1.3)	49.1 ± 0.2	4.04 (1.4)	49.1 ± 0.2	4.31 (1.3)	47.5 ± 0.2

[a]Number in ( ) = 1σ percent counting uncertainty.

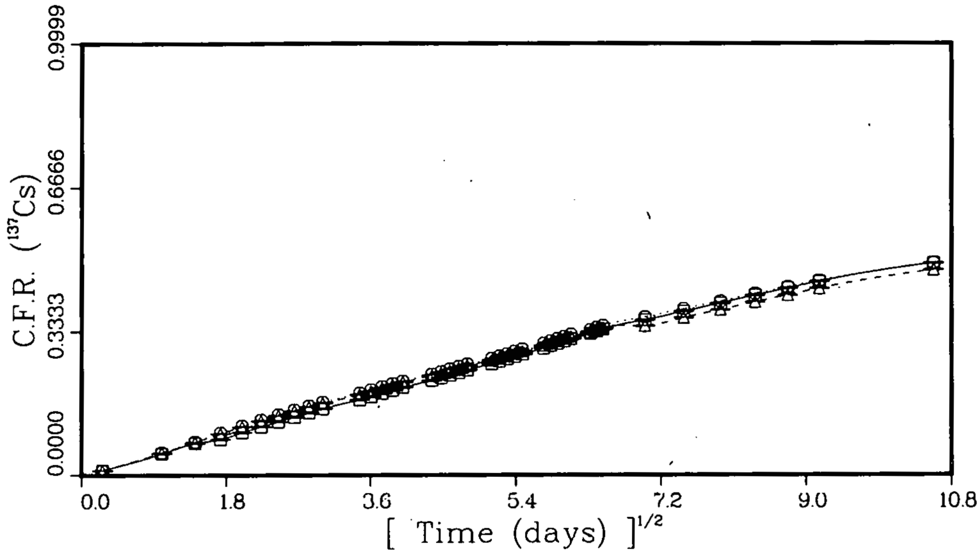

Figure 1.5 ^{137}Cs cumulative fractional release vs $(time)^{1/2}$ from 2-inch-diameter x 4-inch-high waste composites (w/c = 0.6; V/S = 0.936 cm).

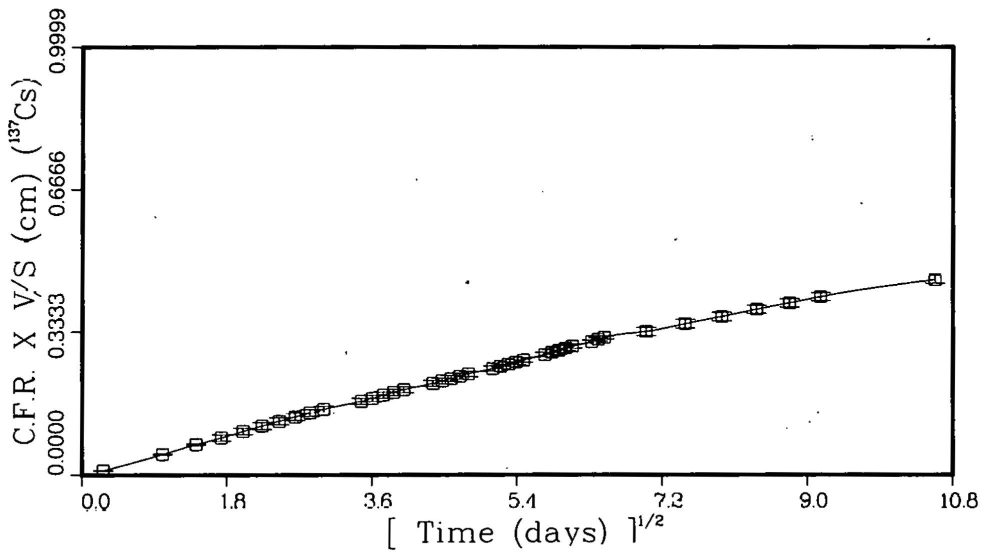

Figure 1.6 Average cumulative fractional release of ^{137}Cs vs $(time)^{1/2}$ from 2-inch-diameter x 4-inch-high waste composites (w/c = 0.6; V/S = 0.936 cm).

Table 1.5

^{137}Cs Incremental and Cumulative Fractions Released From 3 x 3 Organic Cation Exchange Resin/Portland I Cement Composites

	Composite #1		Composite #2		Composite #3	
Time Days	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100
0.07	1.30 (3.1)[a]	1.30 ± 0.04	0.914 (3.7)	0.91 ± 0.03	0.623 (4.5)	0.62 ± 0.03
1	2.77 (2.1)	4.07 ± 0.07	2.40 (2.3)	3.31 ± 0.07	2.65 (2.2)	3.27 ± 0.06
2	1.30 (3.1)	5.37 ± 0.08	1.23 (3.2)	4.54 ± 0.08	1.35 (3.1)	4.62 ± 0.08
3	0.997 (3.5)	6.37 ± 0.09	0.901 (3.8)	5.45 ± 0.08	1.01 (3.5)	5.63 ± 0.08
4	0.878 (2.7)	7.25 ± 0.09	0.780 (2.9)	6.23 ± 0.09	0.905 (5.3)	6.54 ± 0.10
5	0.812 (2.8)	8.06 ± 0.10	0.685 (3.1)	6.91 ± 0.09	0.800 (5.8)	7.34 ± 0.11
6	0.717 (3.0)	8.78 ± 0.10	0.665 (3.0)	7.57 ± 0.09	0.761 (5.8)	8.10 ± 0.12
7	0.658 (3.0)	9.44 ± 0.10	0.584 (3.2)	8.16 ± 0.09	0.709 (6.1)	8.81 ± 0.12
8	0.669 (3.0)	10.1 ± 0.1	0.582 (3.2)	8.74 ± 0.10	0.623 (6.5)	9.43 ± 0.13
9	0.629 (3.2)	10.7 ± 0.1	0.531 (3.6)	9.27 ± 0.10	0.670 (6.2)	10.1 ± 0.1
12	1.17 (3.2)	11.9 ± 0.1	1.10 (3.4)	10.4 ± 0.1	1.27 (3.2)	11.4 ± 0.1
13	0.543 (3.5)	12.4 ± 0.1	0.482 (5.7)	10.9 ± 0.1	0.563 (6.7)	11.9 ± 0.1
14	0.523 (3.4)	13.0 ± 0.1	0.452 (3.6)	11.3 ± 0.1	0.589 (6.6)	12.5 ± 0.2
15	0.493 (3.6)	13.5 ± 0.1	0.451 (3.6)	11.8 ± 0.1	0.526 (7.0)	13.0 ± 0.2
16	0.467 (3.8)	13.9 ± 0.1	0.444 (3.7)	12.3 ± 0.1	0.478 (7.4)	13.5 ± 0.2
19	0.896 (2.7)	14.8 ± 0.1	0.812 (2.8)	13.0 ± 0.1	1.17 (4.6)	14.7 ± 0.2
20	0.456 (2.5)	15.3 ± 0.1	0.423 (2.4)	13.4 ± 0.1	0.443 (12.0)	15.1 ± 0.2
21	0.470 (2.4)	15.7 ± 0.1	0.413 (2.4)	13.8 ± 0.1	0.443 (12.0)	15.6 ± 0.2
22	0.427 (2.4)	16.2 ± 0.1	0.406 (2.5)	14.3 ± 0.1	0.439 (12.1)	16.0 ± 0.2
23	0.425 (2.4)	16.6 ± 0.1	0.419 (2.4)	14.7 ± 0.1	0.457 (11.9)	16.5 ± 0.2
26	0.848 (1.8)	17.4 ± 0.1	0.769 (1.7)	15.4 ± 0.1	0.967 (8.1)	17.4 ± 0.2
27	0.422 (2.4)	17.9 ± 0.1	0.390 (2.6)	15.8 ± 0.1	0.428 (12.1)	17.9 ± 0.2
28	0.387 (2.6)	18.3 ± 0.1	0.390 (2.6)	16.2 ± 0.1	0.401 (12.6)	18.3 ± 0.2
29	0.424 (2.4)	18.7 ± 0.1	0.395 (2.6)	16.6 ± 0.1	0.434 (12.2)	18.7 ± 0.2
30	0.405 (2.5)	19.0 ± 0.1	0.375 (2.7)	17.0 ± 0.1	0.423 (12.2)	19.1 ± 0.2
33	0.639 (2.2)	19.7 ± 0.1	0.704 (2.0)	17.7 ± 0.1	0.791 (1.8)	19.9 ± 0.2
34	0.404 (2.2)	20.1 ± 0.1	0.413 (2.4)	18.1 ± 0.1	0.424 (2.4)	20.3 ± 0.2
35	0.409 (2.5)	20.5 ± 0.1	0.380 (2.7)	18.5 ± 0.1	0.395 (2.6)	20.7 ± 0.2
36	0.382 (2.6)	20.9 ± 0.1	0.379 (2.7)	18.9 ± 0.1	0.414 (2.4)	21.1 ± 0.2
37	0.396 (2.6)	21.3 ± 0.1	0.381 (2.7)	19.2 ± 0.1	0.377 (2.7)	21.5 ± 0.2
40	0.645 (2.2)	21.0 ± 0.1	0.722 (1.9)	20.0 ± 0.1	0.756 (1.8)	22.3 ± 0.2
41	0.410 (2.5)	22.4 ± 0.1	0.452 (2.2)	20.4 ± 0.1	0.451 (2.2)	22.7 ± 0.2
42	0.399 (2.5)	22.8 ± 0.1	0.374 (2.7)	20.8 ± 0.1	0.401 (2.5)	23.1 ± 0.2
49	0.232 (3.3)	23.0 ± 0.1	0.192 (3.9)	21.0 ± 0.1	0.236 (3.2)	23.4 ± 0.2
56	1.14 (1.4)	24.1 ± 0.1	1.08 (1.5)	22.1 ± 0.1	1.14 (1.4)	24.5 ± 0.2
63	1.09 (1.5)	25.2 ± 0.1	1.06 (1.6)	23.1 ± 0.1	1.12 (1.5)	25.6 ± 0.2
70	1.14 (1.4)	26.4 ± 0.1	1.12 (1.5)	24.2 ± 0.1	1.18 (1.5)	26.8 ± 0.2
77	1.01 (1.6)	27.4 ± 0.1	0.928 (1.6)	25.2 ± 0.1	0.976 (1.6)	27.8 ± 0.2
84	0.977 (1.6)	28.3 ± 0.1	0.948 (1.6)	26.1 ± 0.1	0.972 (1.6)	28.8 ± 0.2
112	2.69 (2.2)	31.0 ± 0.1	2.40 (2.3)	28.5 ± 0.1	2.64 (2.2)	31.4 ± 0.3

[a]Number in ( ) = 1σ percent counting uncertainty.

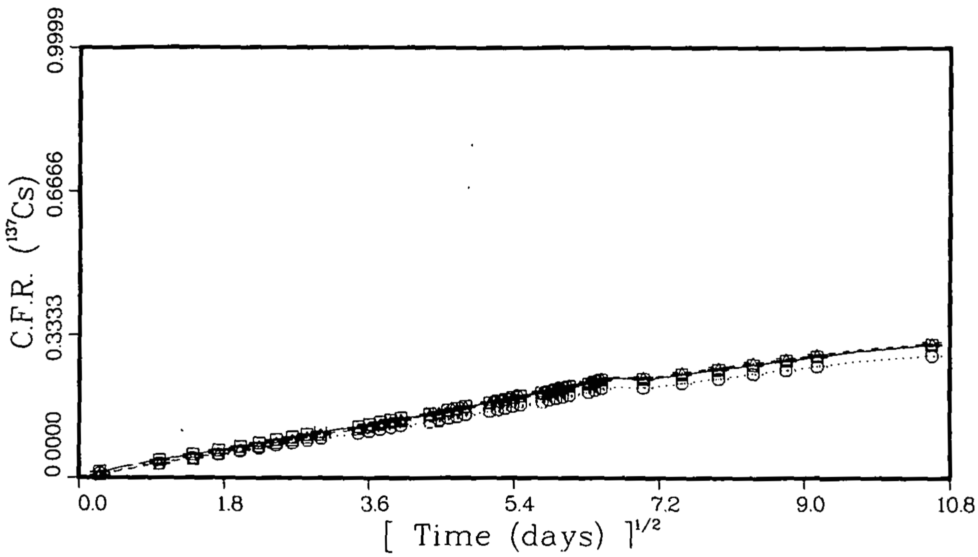

Figure 1.7 ^{137}Cs cumulative fractional release vs (time)$^{1/2}$ from 3-inch-diameter x 3-inch-high waste composites (w/c = 0.6; V/S = 1.32 cm).

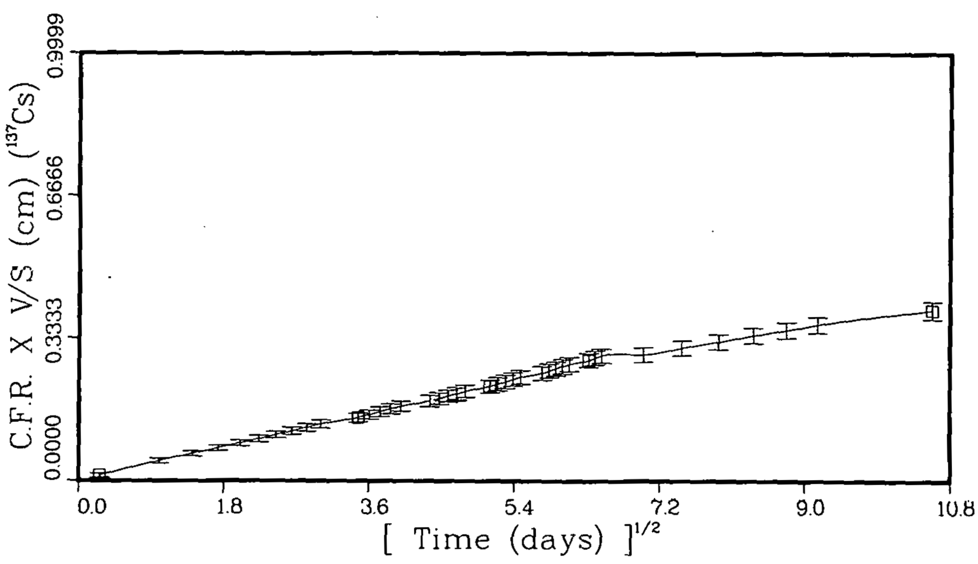

Figure 1.8 Average cumulative fractional release of ^{137}Cs vs (time)$^{1/2}$ from 3-inch-diameter x 3-inch-high waste composites (w.c. = 0.6; V/S = 1.32 cm).

Table 1.6

^{137}Cs Incremental and Cumulative Fractions Released From
6 x 6 Organic Cation Exchange Resin/Portland I Cement Composites

	Composite #1		Composite #2		Composite #3	
Time Days	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100
0.07	0.580 (0.9)[a]	0.58 ± 0.01	0.489 (1.0)	0.49 ± 0.01	0.469 (1.0)	0.47 ± 0.01
1	2.71 (0.4)	3.29 ± 0.01	1.95 (0.5)	2.44 ± 0.01	1.55 (0.6)	2.02 ± 0.01
2	1.72 (5.2)	5.01 ± 0.02	1.19 (0.6)	3.63 ± 0.01	0.877 (0.7)	2.90 ± 0.01
3	1.35 (0.6)	6.36 ± 0.02	0.944 (0.7)	4.57 ± 0.01	0.708 (0.8)	3.60 ± 0.01
4	2.92 (0.4)	9.28 ± 0.02	1.94 (0.5)	6.51 ± 0.02	1.50 (0.6)	5.10 ± 0.02
7	0.818 (1.1)	10.1 ± 0.1	0.533 (1.3)	7.05 ± 0.02	0.431 (1.5)	5.54 ± 0.02
8	0.665 (1.2)	10.8 ± 0.1	0.452 (1.4)	7.50 ± 0.02	0.360 (1.6)	5.90 ± 0.02
9	0.729 (1.1)	11.5 ± 0.1	0.470 (1.4)	7.97 ± 0.02	0.407 (1.5)	6.30 ± 0.02
10	0.634 (1.2)	12.1 ± 0.1	0.410 (1.5)	8.38 ± 0.02	0.335 (1.7)	6.64 ± 0.02
13	1.63 (0.3)	13.8 ± 0.1	1.09 (0.4)	9.47 ± 0.02	0.945 (0.5)	7.58 ± 0.02
14	0.561 (0.6)	14.3 ± 0.1	0.369 (0.7)	9.84 ± 0.02	0.316 (0.8)	7.90 ± 0.02
15	0.514 (0.6)	14.8 ± 0.1	0.333 (0.7)	10.2 ± 0.1	0.286 (0.8)	8.18 ± 0.02
16	0.482 (0.6)	15.3 ± 0.1	0.322 (0.8)	10.5 ± 0.1	0.262 (0.8)	8.45 ± 0.02
17	0.432 (0.7)	15.8 ± 0.1	0.286 (0.8)	10.8 ± 0.1	0.251 (0.9)	8.70 ± 0.02
20	1.07 (0.4)	16.8 ± 0.1	0.741 (0.5)	11.5 ± 0.1	0.647 (0.5)	9.34 ± 0.02
21	0.381 (0.7)	17.2 ± 0.1	0.277 (0.8)	11.8 ± 0.1	0.243 (0.9)	9.58 ± 0.02
22	0.359 (0.74)	17.6 ± 0.1	0.263 (0.87)	12.1 ± 0.1	0.232 (0.90)	9.82 ± 0.1
29	1.85 (0.72)	19.4 ± 0.1	1.31 (0.85)	13.4 ± 0.1	1.20 (0.89)	11.0 ± 0.1
36	1.65 (0.34)	21.1 ± 0.1	1.19 (0.40)	14.6 ± 0.1	1.05 (0.43)	12.1 ± 0.1
43	1.47 (0.36)	22.5 ± 0.1	1.09 (0.42)	15.7 ± 0.1	0.963 (0.44)	13.0 ± 0.1
50	1.49 (0.36)	24.0 ± 0.1	1.11 (0.41)	16.8 ± 0.1	0.930 (0.45)	14.0 ± 0.1
57	1.31 (0.38)	25.3 ± 0.1	0.963 (0.44)	17.7 ± 0.1	0.792 (0.49)	14.8 ± 0.1
64	1.28 (0.39)	26.6 ± 0.1	0.952 (0.45)	18.7 ± 0.1	0.800 (0.49)	15.6 ± 0.1
92	3.40 (0.53)	30.0 ± 0.1	2.64 (0.60)	21.3 ± 0.1	2.32 (0.64)	17.9 ± 0.1

[a]Number in ( ) = 1σ percent counting uncertainty.

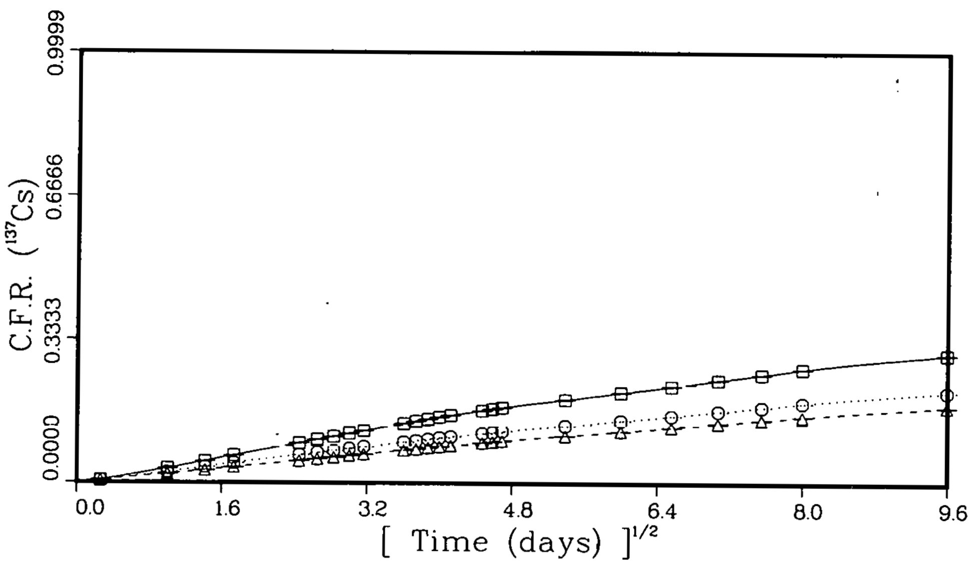

Figure 1.9 ^{137}Cs cumulative fractional release vs (time)$^{1/2}$ from 6-inch-diameter x 6-inch-high waste composites (w/c = 0.6; V/S = 2.52 cm). (The form denoted by □ partially disintegrated during the first four weeks of leaching.)

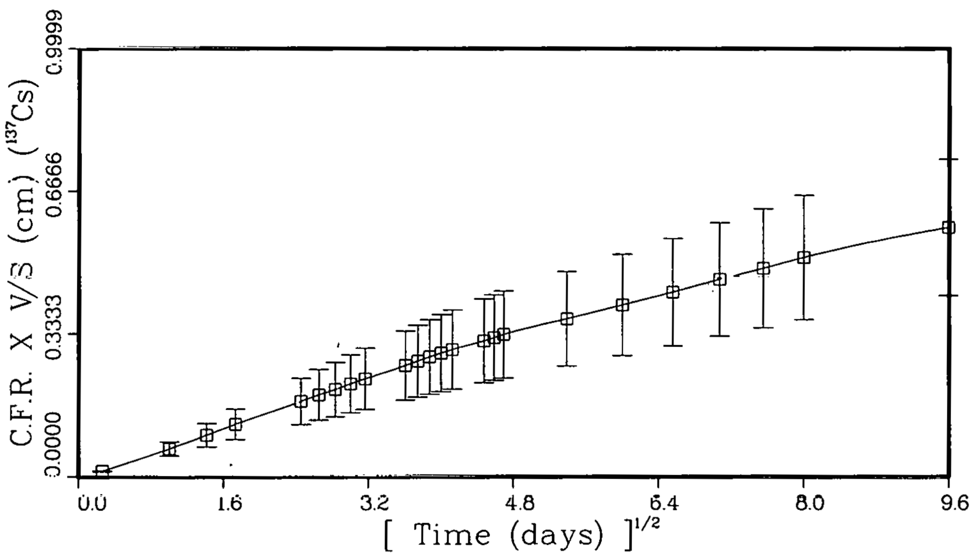

Figure 1.10 Average cumulative fractional release of ^{137}Cs vs (time)$^{1/2}$ from 6-inch-diameter x 6-inch-high waste composites (w/c = 0.6; V/S = 2.52 cm).

Table 1.7

^{137}Cs Incremental and Cumulative Fractions Released From
6 x 12 Organic Cation Exchange Resin/Portland I Cement Composites

	Composite #1		Composite #2		Composite #3	
Time Days	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100
0.07	0.305 (1.7)[a]	0.305 ± 0.005	0.286 (1.8)	0.286 ± 0.005	0.279 (1.77)	0.279 ± 0.005
1	1.76 (0.71)	2.07 ± 0.01	1.96 (0.67)	2.25 ± 0.01	1.69 (0.72)	1.96 ± 0.01
2	1.18 (0.86)	3.24 ± 0.02	1.33 (0.82)	3.58 ± 0.02	1.07 (0.90)	3.04 ± 0.02
3	0.950 (0.97)	4.19 ± 0.02	1.05 (0.92)	4.63 ± 0.02	0.862 (1.0)	3.90 ± 0.02
4	0.779 (1.1)	4.97 ± 0.02	0.861 (1.0)	5.49 ± 0.02	0.704 (1.1)	4.60 ± 0.02
8	2.31 (0.62)	7.28 ± 0.03	2.43 (0.60)	7.92 ± 0.03	1.92 (0.68)	6.52 ± 0.02
9	0.517 (1.3)	7.79 ± 0.03	0.511 (1.3)	8.43 ± 0.03	0.387 (1.5)	6.91 ± 0.02
10	0.478 (1.4)	8.27 ± 0.03	0.464 (1.4)	8.90 ± 0.03	0.370 (1.5)	7.28 ± 0.03
11	0.362 (1.6)	8.63 ± 0.03	0.356 (1.6)	9.25 ± 0.03	0.290 (1.7)	7.57 ± 0.03
14	0.895 (1.0)	9.53 ± 0.03	0.917 (0.98)	10.2 ± 0.1	0.758 (1.1)	8.32 ± 0.03
15	0.285 (1.8)	9.81 ± 0.03	0.296 (1.7)	10.5 ± 0.1	0.252 (1.9)	8.58 ± 0.03
16	0.268 (1.8)	10.1 ± 0.1	0.273 (1.8)	10.7 ± 0.1	0.235 (2.0)	8.81 ± 0.03
17	0.281 (1.8)	10.4 ± 0.1	0.292 (1.7)	11.0 ± 0.1	0.239 (1.9)	9.05 ± 0.03
18	0.267 (1.8)	10.6 ± 0.1	0.286 (1.8)	11.3 ± 0.1	0.241 (1.9)	9.29 ± 0.03
21	0.759 (1.1)	11.4 ± 0.1	0.800 (1.0)	12.1 ± 0.1	0.670 (1.1)	10.0 ± 0.1
22	0.247 (1.9)	11.6 ± 0.1	0.265 (1.8)	12.4 ± 0.1	0.241 (1.9)	10.2 ± 0.1
23	0.245 (1.9)	11.9 ± 0.1	0.259 (1.8)	12.6 ± 0.1	0.238 (1.9)	10.4 ± 0.1
24	0.220 (2.0)	12.1 ± 0.1	0.248 (1.9)	12.9 ± 0.1	0.226 (2.0)	10.7 ± 0.1
25	0.202 (2.1)	12.3 ± 0.1	0.235 (1.9)	13.1 ± 0.1	0.215 (2.0)	10.9 ± 0.1
28	0.461 (1.4)	12.8 ± 0.1	0.585 (1.2)	13.7 ± 0.1	0.559 (1.2)	11.4 ± 0.1
29	0.145 (2.4)	12.9 ± 0.1	0.195 (2.1)	13.9 ± 0.1	0.192 (2.1)	11.6 ± 0.1
30	0.158 (2.3)	13.1 ± 0.1	0.218 (2.0)	14.1 ± 0.1	0.223 (2.0)	11.9 ± 0.1
31	0.159 (2.4)	13.2 ± 0.1	0.215 (2.0)	14.3 ± 0.1	0.217 (2.0)	12.1 ± 0.1
32	0.138 (2.6)	13.4 ± 0.1	0.201 (2.1)	14.5 ± 0.1	0.208 (2.0)	12.3 ± 0.1
35	0.363 (1.6)	13.7 ± 0.1	0.539 (1.3)	15.1 ± 0.1	0.573 (1.2)	12.9 ± 0.1
36	0.142 (2.5)	13.9 ± 0.1	0.201 (2.1)	15.3 ± 0.1	0.227 (1.9)	13.1 ± 0.1
37	0.121 (2.7)	14.0 ± 0.1	0.182 (2.2)	15.5 ± 0.1	0.188 (2.2)	13.3 ± 0.1
38	0.126 (2.7)	14.1 ± 0.1	0.170 (2.3)	15.6 ± 0.1	0.193 (2.1)	13.5 ± 0.1
39	0.132 (2.5)	14.2 ± 0.1	0.173 (2.2)	15.8 ± 0.1	0.196 (2.1)	13.7 ± 0.1
42	0.317 (1.7)	14.6 ± 0.1	0.450 (1.4)	16.3 ± 0.1	0.508 (1.3)	14.2 ± 0.1
43	0.122 (2.7)	14.7 ± 0.1	0.170 (2.3)	16.4 ± 0.1	0.204 (2.1)	14.4 ± 0.1
44	0.115 (2.8)	14.8 ± 0.1	0.165 (2.3)	16.6 ± 0.1	0.192 (2.2)	14.6 ± 0.1
49	0.484 (1.3)	15.3 ± 0.1	0.691 (1.1)	17.3 ± 0.1	0.794 (1.1)	15.4 ± 0.1
50	0.116 (2.7)	15.4 ± 0.1	0.173 (2.2)	17.5 ± 0.1	0.214 (2.0)	15.6 ± 0.1
51	0.119 (2.7)	15.5 ± 0.1	0.162 (2.3)	17.6 ± 0.1	0.195 (2.1)	15.8 ± 0.1
52	0.135 (2.6)	15.7 ± 0.1	0.176 (2.3)	17.8 ± 0.1	0.222 (2.0)	16.0 ± 0.1
53	0.116 (2.8)	15.8 ± 0.1	0.151 (2.4)	17.9 ± 0.1	0.189 (2.2)	16.2 ± 0.1
56	0.281 (1.8)	16.0 ± 0.1	0.387 (1.5)	18.3 ± 0.1	0.495 (1.3)	16.7 ± 0.1

[a]Number in ( ) = 1σ percent counting uncertainty.

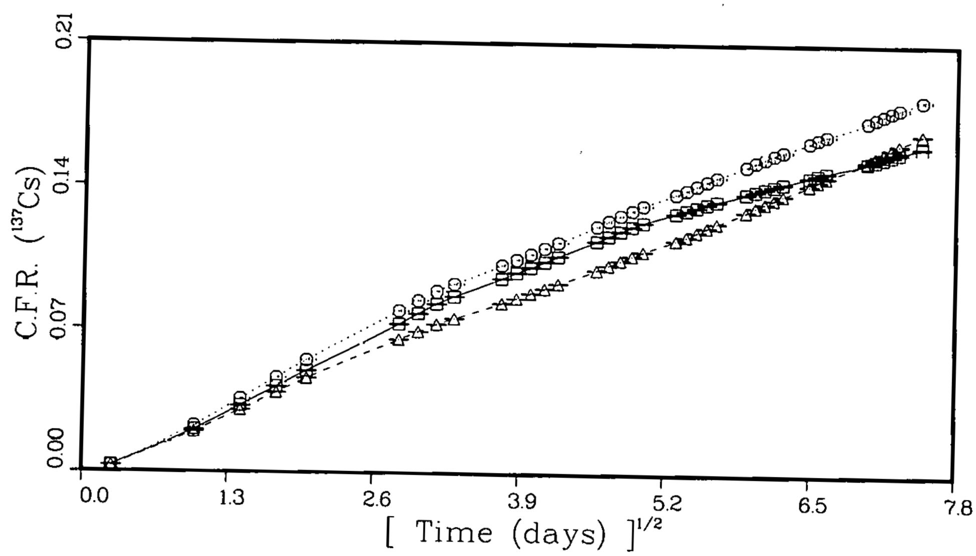

Figure 1.11 ^{137}Cs cumulative fractional release vs $(time)^{1/2}$ from 6-inch-diameter x 12-inch high waste composites (w/c = 0.6; V/S = 3.30).

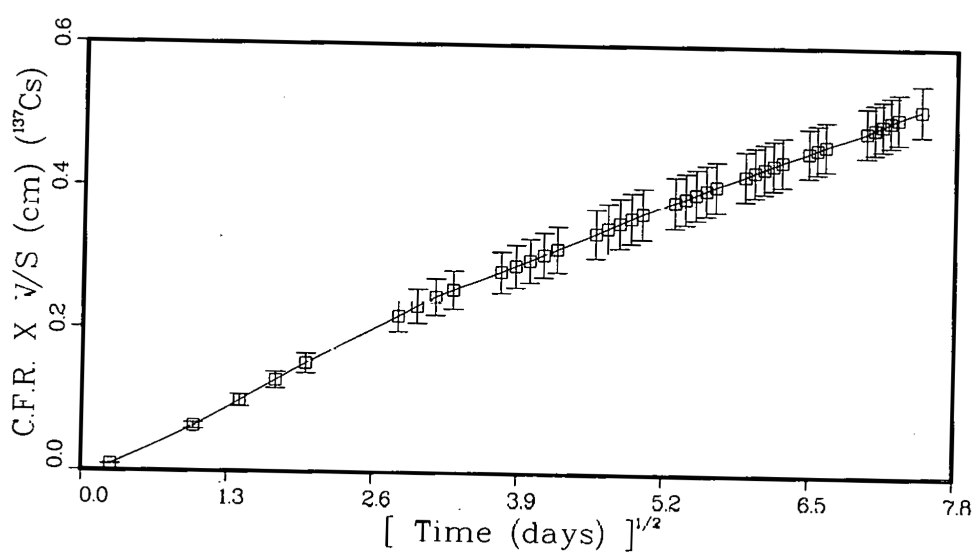

Figure 1.12 Average cumulative fractional release of ^{137}Cs vs $(time)^{1/2}$ from 6-inch-diameter x 12-inch-high waste composites (w/c = 0.6; V/S = 3.30).

Table 1.8

^{137}Cs Incremental and Cumulative Fractions Released From 12 x 12 Organic Cation Exchange Resin/Portland I Cement Composite #1[a]

Time Days	Incremental Fraction Released x 100	Cumulative Fraction Released x 100
0.07	0.117 (1.3)[b]	0.117 ± 0.002
1	0.825 (0.48)	0.943 ± 0.004
2	0.582 (0.58)	1.53 ± 0.005
5	1.89 (0.32)	3.42 ± 0.008
6	0.951 (0.45)	4.37 ± 0.009
7	0.346 (0.75)	4.71 ± 0.01
8	0.285 (0.82)	5.00 ± 0.01
9	0.254 (0.87)	5.25 ± 0.01
12	0.640 (0.55)	5.89 ± 0.01
13	0.226 (0.92)	6.12 ± 0.01
14	0.188 (1.0)	6.31 ± 0.01
15	0.173 (1.1)	6.48 ± 0.01
16	0.300 (0.80)	6.78 ± 0.01
19	0.361 (0.73)	7.14 ± 0.01
20	0.120 (1.3)	7.26 ± 0.01
21	0.124 (1.2)	7.38 ± 0.01
22	0.122 (1.3)	7.51 ± 0.01
23	0.123 (1.3)	7.63 ± 0.01
27	0.421 (0.68)	8.05 ± 0.01
28	0.115 (1.3)	8.16 ± 0.01
29	0.107 (1.3)	8.27 ± 0.01
30	0.109 (1.3)	8.38 ± 0.01
33	0.242 (0.90)	8.62 ± 0.01
34	0.088 (1.5)	8.71 ± 0.01
35	0.088 (1.5)	8.80 ± 0.01
36	0.090 (1.5)	8.89 ± 0.01
37	0.091 (1.5)	8.98 ± 0.01
40	0.220 (0.93)	9.20 ± 0.01
41	0.089 (1.5)	9.29 ± 0.01
42	0.076 (1.6)	9.37 ± 0.01
43	0.081 (1.6)	9.45 ± 0.01
44	0.087 (1.5)	9.53 ± 0.01
47	0.200 (0.98)	9.73 ± 0.01

[a]Composites #2 and 3 were made at a later date and will be reported in a future report.
[b]Number in ( ) = 1σ percent counting uncertainty.

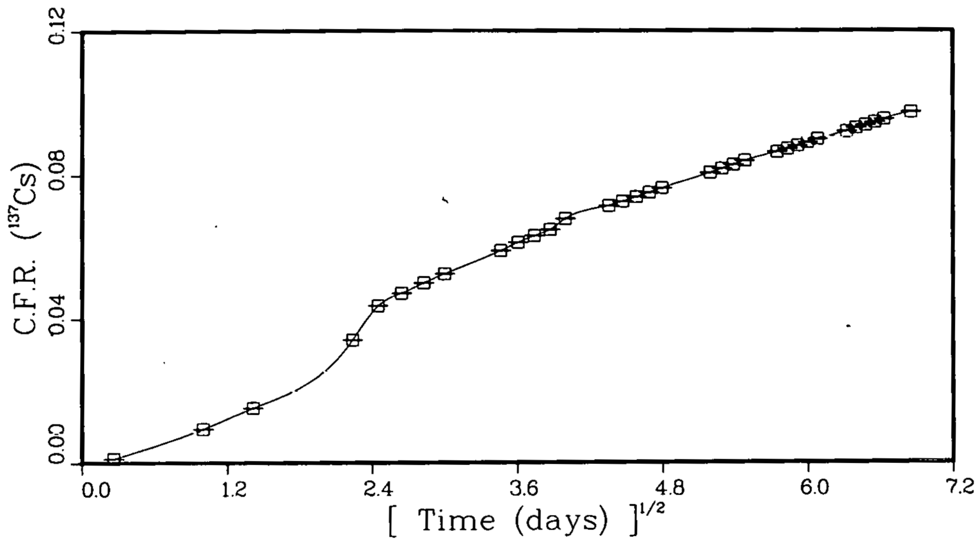

Figure 1.13 ^{137}Cs cumulative fractional release vs (time)$^{1/2}$ from 12-inch-diameter x 12-inch-high waste composites (w/c = 0.6; V/S = 5.11).

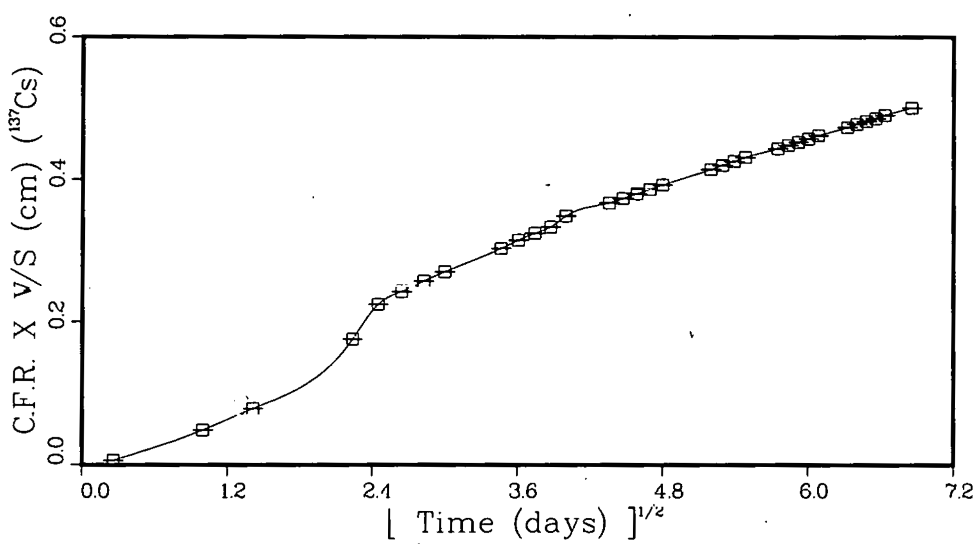

Figure 1.14 Cumulative fractional release of ^{137}Cs x V/S vs (time)$^{1/2}$ from 12-inch-diameter x 12-inch-high waste composite (w/c = 0.6; V/S = 5.11).

Table 1.9 summarizes the cumulative fraction released from all the samples studied to date at 11 different leaching periods (0.07, 1, 2, 3, 4, 5, 9, 15, 21, 30, and 42 days). Leaching periods beyond 42 days will be considered in a later report when data from the larger waste forms become available.

Table 1.9

Cumulative Fractional Release at Fixed Intervals[a]

Size	S/V	Cumulative Fractional Release Within Days 0.07d	1d	2d	3d	4d	5d	9d	15d	21d	30d	42d
1 x 1	2.53	2.8	14.7	20.8	25.3	28.7	31.4	38.7	45.6	50.7	56.8	68.6
2 x 2	1.28	1.70	7.80	11.0	13.1	14.9	16.3	21.2	24.5	27.6	31.7	36.3
2 x 4	1.07	1.10	5.10	7.47	9.23	10.8	12.2	16.3	20.5	23.9	28.6	34.2
3 x 3	0.76	0.94	3.60	4.84	5.82	6.67	7.40	10.0	12.8	15.0	18.4	22.2
6 x 6	0.40	0.51	2.20	2.23	3.27	4.09	5.80	7.20	9.20	10.7	12.2	14.4
6 x 12	0.33	0.29	2.10	3.29	4.24	5.02	5.00	7.70	9.60	11.2	13.0	15.0
12 x 12	0.19	0.10	0.94	1.53	3.42	4.37	3.40	5.30	6.50	7.38	8.40	9.37

[a]For sample sizes studied to date.

1.3.2 Analysis of Leaching Data

An empirical approach is presented in analyzing the leaching data. Equation (1.2) ($f = S/V \cdot 2(Dt/\pi)^{1/2} + \alpha$) indicates that a plot of the cumulative fractional release vs (S/V) would yield a line with slope equal to $(Dt/\pi)^{1/2}$ and intersect the "cumulative fraction release" axis at α.

The cumulative fractional releases (CFR) were plotted as a function of S/V ratio at each of the leaching times mentioned above, and are shown in Figure 1.15. A linear dependence of CFR on the S/V ratio is observed. It should also be noted that these lines do not meet at the origin, indicating that $(\alpha)_{t_0} \neq 0$.

A least squares linear regression was performed on these lines to determine the best fit slopes and intercepts. The results of these calculations are summarized in Table 1.10 together with the coefficients of determination as defined by:

$$R_t^2 = \left(\frac{\alpha\Sigma(CFR)_i + b\Sigma(S/V)_i \times (CFR)_i - 1/n(\Sigma(CFR)_i)^2}{\Sigma(CFR)_i^2 - 1/n(\Sigma CFR)_i^2} \right)_t$$

where the coefficients α and b are the derived coefficients from the fitting: $(CFR)_t=[\alpha + b\ (S/V)]_t$ for each leaching period considered.

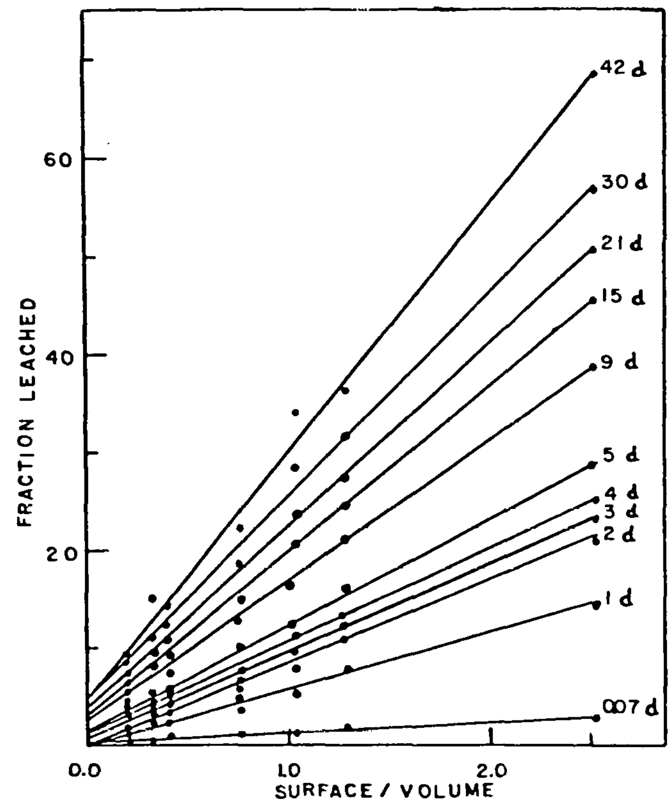

Figure 1.15 Experimental cumulative fractional release data vs S/V and their least squares linear regression fits.

Furthermore, since the slopes of these lines are equal to $(Dt/\pi)^{1/2}$, together with the assumption that the effective diffusion coefficient should remain constant for the same matrix,[13] then the rate of change of the slopes (rewritten as slope = $2(D/\pi)^{1/2} \times t^{1/2}$ should be linear with respect to the square root of the leaching time, i.e., for $Z = t^{1/2}$, then $dS/dZ = (D/\pi)^{1/2}$ = (a constant value).

A plot of these slopes (Table 1.10) at the different leaching periods (0.07, 1, 2, 3, 4, 5, 9, 15, 21, 30, and 42 days), vs the square root of time ($\sqrt{\text{days}}$) is shown in Figure 1.16, and indicates a linear relationship after the five-day period. These data indicate that $(D/\pi)^{1/2}$ is not a constant value for leaching periods shorter than 5 days, but gradually approaches a constant value. This is not surprising considering that during the initial leaching period the mass transport is not predominantly diffusion-controlled.[4]

A least squares linear regression on the slopes for leaching periods from 9 days to 42 days, yields an expression of the form: Slope = $\alpha + bx$ with:

R^2 = 0.99 (coefficient of determination)
α = 5.41
b = 2.94
$x = \sqrt{t}$.

Table 1.10

Summary of Slopes and Intercepts of CFR vs S/V

Time (Days)	$\left(\frac{\text{Time}}{\text{Days}}\right)^{1/2}$	Slope[a] (b)	Intercept[a] (α)	Coefficient[b] of Determination
0.07	0.26	1.15	-0.01	0.98
1	1.0	5.86	-0.29	0.99
2	1.41	8.34	-0.51	0.98
3	1.73	9.72	0.09	0.98
4	2.0	10.86	0.47	0.98
5	2.24	12.05	0.35	0.99
9	3.0	14.49	1.62	0.99
15	3.87	16.81	2.64	0.99
21	4.58	18.54	3.55	0.99
30	5.48	20.71	4.75	0.99
42	6.48	25.13	5.03	0.99

[a]Slopes intercepts are obtained for the general relationship: CFR = α + b (S/V).

[b]The coefficient of determination is defined as:

$$R_t^2 = \left(\frac{\alpha\Sigma(\text{CFR})_i + b\Sigma(\text{S/V})_i \times (\text{CFR})_i - 1/n(\Sigma(\text{CFR})_i)^2}{\Sigma(\text{CFR})_i^2 - 1/n(\Sigma\text{CFR})_i^2} \right)_t$$

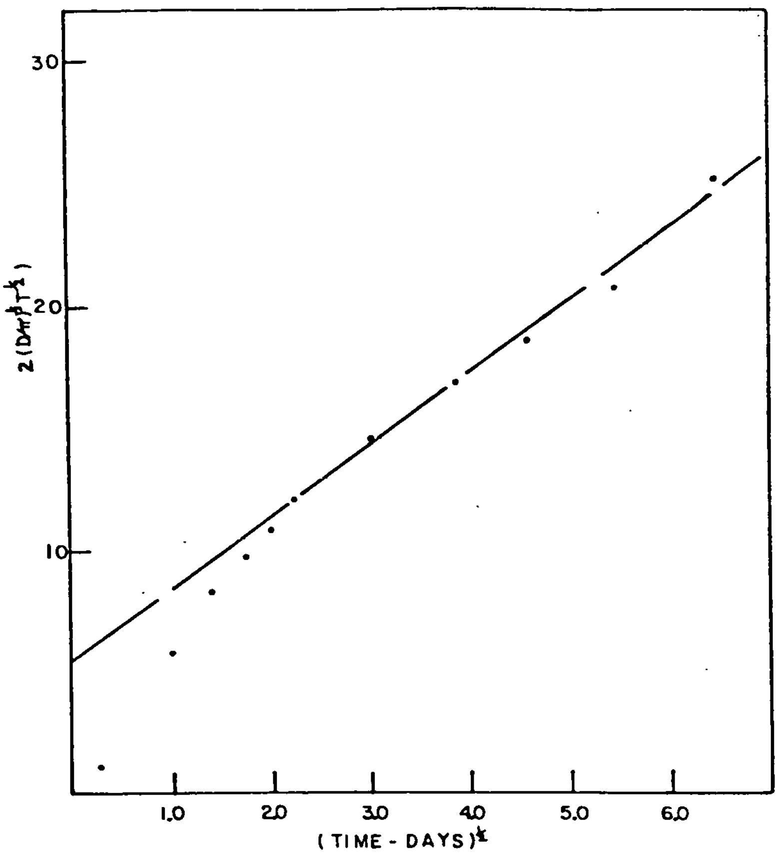

Figure 1.16 Plot of the slopes $[(D/\pi)^{1/2} \times t^{1/2}]$ of the lines shown in Figure 1.15 vs $(t)^{1/2}$. Note: The straight line is a least squares linear regression on the points for 9 days to 42 days.

Thus, the slope $2(Dt/\pi)^{1/2}$ [or the effective diffusion coefficient $2(D/\pi)^{1/2} \times t^{1/2}$] could be calculated for any leaching period from nine days and greater within the range of this experiment using the relationship:

$$(\text{Slope})_t = 5.41 + 2.94 \times \sqrt{t} \qquad (1.3)$$

A similar fit was performed on the intercepts (α) of the lines shown in Figure 1.15 and the square root of time ($\sqrt{}$ day) resulting in Equation (1.4), with a coefficient of determination $R^2 = 0.98$

$$\alpha_t = 1.78 + 1.12 \sqrt{t} \qquad (1.4)$$

A plot of these α_t vs their corresponding square root of time is shown in Figure 1.17.

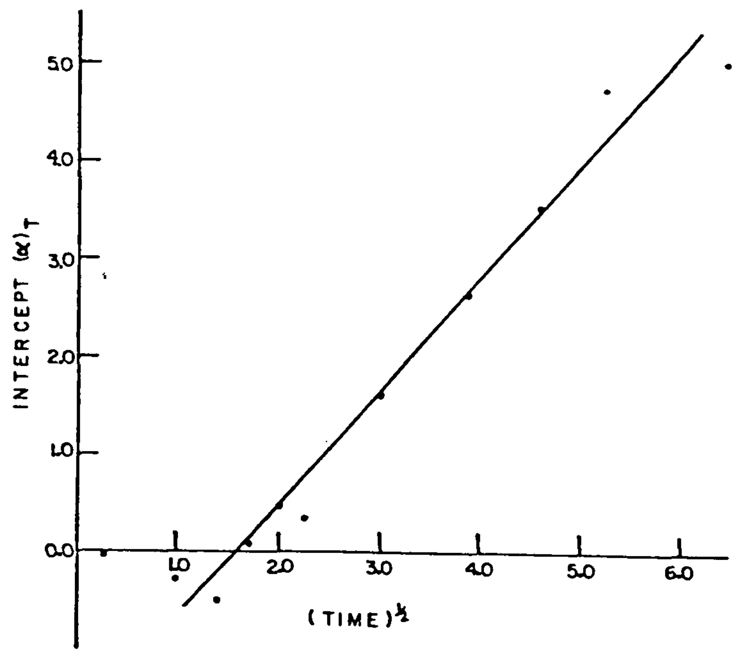

Figure 1.17 Plot of the intercepts $[(\alpha)_t]$ of the lines shown in Figure 1.15 vs $(t)^{1/2}$. Note: The straight line is a least squares linear regression on the points for 9 days to 42 days.

The observed linear relationship (Fig. 1.17) does not imply the dependence of α_t on diffusion. The mechanism(s) contributing to this term are not presently understood.

Combining Equations (1.3) and (1.4) into Equation (1.2), we get:

$$(CFR)_t = \frac{S}{V} (2.94 \sqrt{t} + 5.41) + (1.12 \sqrt{t} - 1.78) \tag{1.5}$$

Thus, the cumulative fractional release at a given time t from a sample with a geometric surface-to-volume ratio of S/V, can be calculated using Equation (1.5). The cumulative fractional release calculated for several S/V values at different time intervals are summarized in Table 1.11 together with the experimental data obtained at these values. These calculated cumulative fractional releases are plotted in Figure 1.18 together with the lines derived from fitting the experimental data. A good agreement is observed between the calculated values and the least square linear regression fits through the experimental data.

Table 1.11

Cumulative Fractional Release Experimental and Calculated Data

Dimension	S/V	Mode	Cumulative Fractional Release Within Time (Days)													
			0.07	1	2	3	4	5	9	15	21	30	42	47	56	112
1 x 1	2.53	Expmt.	2.8	14.7	2.08	25.3	28.7	31.4	38.7	45.6	50.7	56.8	68.6		73.5	86.4
		Calc.	14.2	20.5	24.0	26.7	29.0	31.0	37.6	45.0	51.1	58.8	67.4		75.9	102.4
2 x 2	1.28	Expmt.	1.70	7.80	11.0	13.1	14.9	16.3	21.2	24.5	27.6	31.7	36.3		38.6	48.5
		Calc.	6.44	10.0	12.1	13.6	14.9	16.1	19.8	24.1	27.5	31.9	36.8		41.7	56.8
2 x 4	1.07	Exmpt.	1.10	5.10	7.47	9.23	10.8	12.2	16.3	20.5	23.9	28.6	34.2		37.6	48.6
		Calc.	5.14	8.27	10.0	11.4	12.5	13.5	16.8	20.5	23.6	27.4	31.7		35.9	49.2
3 x 3	0.76	Exmpt.	0.94	3.60	4.84	5.82	6.67	7.40	10.0	12.8	15.0	18.4	22.2		23.6	30.3
		Calc.	3.22	5.69	7.08	8.14	9.04	9.83	12.4	15.3	17.7	20.7	24.1		27.4	37.8
6 x 6	0.40	Exmpt.	0.51	2.20	2.23	3.27	4.09	5.80	7.20	9.20	10.7	12.2	14.4		16.3	19.6
		Calc.	0.99	2.68	3.63	4.36	4.98	5.52	7.27	9.28	10.9	12.9	15.3		17.7	22.4
6 x 12	0.33	Exmpt.	0.29	2.10	3.29	4.24	5.02	5.0	7.70	9.60	11.2	13.0	15.0		17.0	
		Calc.	0.56	2.10	2.96	3.63	4.19	4.68	6.28	8.10	9.58	11.5	13.6		15.6	
12 x 12	0.19	Exmpt.	0.10	0.94	1.53	3.42	4.37	3.40	5.30	6.50	7.38	8.40	9.37	9.73		
		Calc.	-0.3	0.93	1.62	2.16	2.61	3.00	4.28	5.75	6.94	8.44	10.1	10.7		

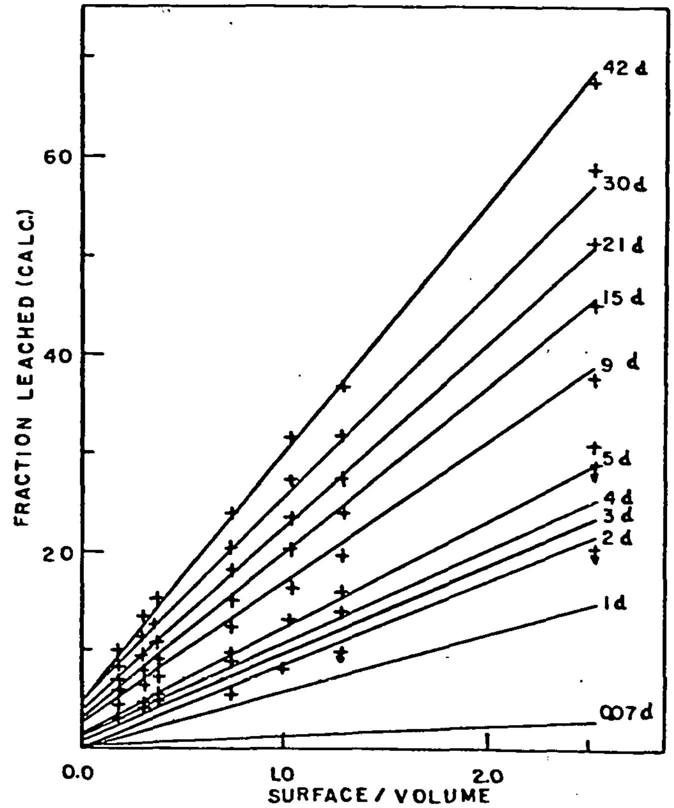

Figure 1.18 Calculated cumulative fraction releases (+) vs S/V. Note: The lines are the least squares linear regression fits through the experimental data.

1.4 Conclusions

An empirical relationship has been developed from the leaching data obtained to date in this study, and can be used to estimate the cumulative fraction releases from forms varying in size from 1 x 1 to 12 x 12 for a given leaching time. This method will be applied to the leaching data presently being developed for the largest waste form (22 x 22) under study.

2. LEACHABILITY AND COMPRESSIVE STRENGTH OF BORIC ACID WASTE IN PORTLAND III CEMENT (P. Hayde and N. Morcos)

2.1 Introduction

A study of the leachability and compressive strength properties of boric acid waste solidified in Portland III cement has been concluded. This report presents additional data and the conclusions of the study.

Boric acid waste and its sodium salts are a major constituent (up to 12% by weight) of radioactive waste derived from pressurized water reactors. This waste interacts with the cement matrix during the solidification process, sometimes preventing solidification and resulting in waste forms with poor physical integrity. Work was performed earlier in our laboratory on optimized process parameters and the treatment of boric acid waste prior to solidification in Portland III cement.[16,18] This earlier work indicates that adjustment of the boric acid waste pH to a value of 10 to 12 assures proper solidification for waste to binder ratios of 0.5 and 0.7.

2.2 Experimental

Samples incorporating simulated boric acid waste in Portland III Cement matrix were made at two different waste-to-cement ratios (w/c) of 0.5 and 0.7. Boric acid solutions of 3%, 6% and 12% (by weight) were solidified in Portland III cement at each of these w/c formulations. Control samples for compressive strength testing consisted of Portland III cement only. The leached samples were also evaluated for their compressive strength after a 352-day period of leaching. All samples were prepared in five replicates.

2.2.1 Specimen Preparation

Stock solutions containing approximately 3, 6, and 12 weight percent boric acid were prepared. The pH of these solutions was adjusted to approximately 12, by the addition of sodium hydroxide, and their compositions are shown in Table 2.1.

Table 2.1

Boric Acid Stock Solutions Composition[a]

Waste Components	3% Solution	6% Solution	12% Solution
Deionized H_2O	95.2%	90.5%	81.7%
H_3BO_3	2.9%	5.8%	11.1%
NaOH	1.9%	3.7%	7.2%

[a]Composition expressed as weight %.

These solutions, hereafter referred to as "simulated waste," were heated to 170°F prior to solidification in Portland III cement so as to simulate actual solidification conditions at power reactor sites. The ratios of waste-to-cement were 0.5 and 0.7, and the dimensions of the solidified samples were 4.6 cm (diameter) by 9.1 to 9.5 cm (height). The leaching samples contained one microcurie each of ^{137}Cs, ^{85}Sr, and ^{60}Co. Control samples for compressive strength testing were made with Portland III cement and water. The compositions of simulated boric acid waste forms are summarized in Table 2.2. All samples were made in quintuplets and cured for a period of 35 days in sealed polyethylene containers.

Table 2.2

Sample Compositions
(Weight in Grams)

Waste/Cement Ratio	Matrix Component \ H_3BO_3 Stock Solution	Set A 3% H_3BO_3 Solution	Set B 6% H_3BO_3 Solution	Set C 12% H_3BO_3 Solution
0.5	H_2O	93.6	89.0	83.1
	H_3BO_3	2.9	5.7	11.3
	NaOH	1.9	3.6	7.3
	Portland III	196.7	196.7	203.3
0.7	H_2O	111.2	107.0	98.7
	H_3BO_3	3.4	6.9	13.4
	NaOH	2.2	4.4	8.7
	Portland III	166.7	168.8	172.7

The ratios by weight of the components (H_3BO_3 and NaOH) to cement (Portland III) used to make the waste forms are summarized in Table 2.3 together with their respective ratios of NaOH to H_3BO_3.

Table 2.3

Ratios of NaOH, H_3BO_3, and Cement in the Waste Composites

% H_3BO_3 Solution Used	Waste/Cement	H_3BO_3/Cement x 100	NaOH/Cement x 100	NaOH/H_3BO_3
3%	0.5	1.5	1.0	0.7
	0.7	2.0	1.3	0.7
6%	0.5	2.9	1.8	0.6
	0.7	4.1	2.6	0.6
12%	0.5	5.6	3.6	0.7
	0.7	7.8	5.0	0.7

2.2.2 Specimen Leaching

The specimens were leached using a modified IAEA leaching procedure[15] consisting of 24-hour leaching periods for the first ten days of leaching. Thereafter, the leaching period was extended to a week, and later on to a month, based on the amount of activity observed in the leachates.

2.2.3 Analysis of Leach Specimens

The waste forms and their leachates were counted under identical geometries using a Ge(Li) detector system. The activities in the waste forms and their respective leachants were quantitatively determined, and the leachate activities expressed as incremental fractional release.

2.2.4 Compressive Strength Testing

Compressive strength measurements were performed on specimens after the cure period and on the leached specimens at the end of the leaching experiment. These latter samples were exposed to a leaching environment for a period of 352 days.

The compressive strength of the specimens was measured using a Soil-Test concrete tester in accordance with ASTM C 39-72. Prior to testing, the samples were capped on each end with a sulfur-based capping compound approved for use with concrete specimens.

2.3 Results and Discussion

2.3.1 Leaching Data

The waste forms evaluated were divided into three sets (A, B and C). Each set corresponded to one of the three boric acid solution concentrations (3%, 6% and 12% by weight) that were solidified. In addition, in each set, two different waste-to-cement ratios (w/c) were used. These w/c ratios were 0.5 and 0.7. Five replicates of each formulation were prepared.

The cumulative fractional release data from these specimens are summarized in Tables 2.4 through 2.9 for ^{137}Cs and Tables 2.10 through 2.15 for ^{85}Sr. The errors quoted represent only the statistical errors asociated with the counting of each fraction. This data is also shown graphically in Figures 2.1 through 2.12 for ^{137}Cs and Figures 2.13 through 2.24 for ^{85}Sr. Each pair of figures shown on a page presents the leaching data of five replicate samples for a given formulation and the average cumulative fractional release of the five replicates. These average cumulative fractional releases were normalized for the volume to geometric surface area (V/S) of the waste forms. Cobalt-60 in the leachates from all samples was below the detection limit (3.0×10^{-2} μCi per 1.5 L sample or an incremental fractional release of less than 3.0×10^{-2}) of the experiment.

The curves shown in Figures 2.1-2.24 were computer-generated, using a cubic spline interpolation between data points. In the absence of additional data between known points, any reasonable method may be employed to connect adjacent points. These curves do not imply any expected or known leaching behavior.

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Table 2.4

^{137}Cs Incremental and Cumulative Fractions Released From
Boric Acid/Portland III Cement Composites (3% Boric Acid Solution and w/c Ratio of 0.5)

	Composite #1		Composite #2		Composite #3	
Time Days	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100
1	13.34 (7.0)[a]	13.3 ± 0.9	9.01 (9.8)[a]	9.01 ± 0.88	11.2 (8.8)[a]	11.3 ± 0.96
2	7.00 (9.5)	20.4 ± 1.1	3.32 (16.0)	12.3 ± 1.0	6.64 (11.1)	17.9 ± 1.2
3	5.68 (10.6)	26.1 ± 1.3	2.47 (18.6)	14.8 ± 1.1	3.65 (14.9)	21.6 ± 1.3
4	4.02 (12.6)	30.1 ± 1.4	2.30 (19.3)	17.1 ± 1.2	1.38 (24.3)	22.9 ± 1.4
5	2.49 (16.0)	32.6 ± 1.5	2.38 (18.9)	19.5 ± 1.3	2.11 (19.6)	25.0 ± 1.4
6	2.30 (12.9)	34.9 ± 1.5	1.96 (20.9)	21.4 ± 1.4	2.10 (19.3)	27.2 ± 1.5
7	2.94 (14.8)	37.9 ± 1.6	1.28 (25.9)	22.7 ± 1.4	2.03 (20.0)	29.3 ± 1.5
8	2.11 (17.4)	40.0 ± 1.6	0.986 (29.3)	23.7 ± 1.4	1.54 (23.0)	30.8 ± 1.6
9	1.51 (20.5)	41.6 ± 1.6	1.11 (27.7)	24.8 ± 1.5	1.38 (24.3)	32.2 ± 1.6
10	1.38 (5.61)	42.8 ± 1.6	1.84 (5.6)	26.6 ± 1.5	1.57 (5.9)	33.7 ± 1.6
15	5.83 (2.80)	48.7 ± 1.6	3.86 (4.2)	30.5 ± 1.5	5.54 (3.2)	39.3 ± 1.6
20	3.87 (3.44)	52.5 ± 1.6	3.38 (4.5)	33.9 ± 1.5	4.23 (3.7)	43.5 ± 1.6
29	5.86 (2.81)	58.4 ± 1.7	5.08 (3.7)	39.0 ± 1.5	6.79 (2.9)	50.3 ± 1.7
43	7.20 (2.55)	65.6 ± 1.7	5.56 (3.5)	44.5 ± 1.5	7.29 (2.8)	57.6 ± 1.7
71	9.04 (2.31)	74.6 ± 1.7	7.65 (3.1)	52.2 ± 1.5	8.75 (2.6)	66.3 ± 1.7
100	6.87 (2.60)	81.5 ± 1.7	6.74 (3.3)	58.9 ± 1.5	6.57 (3.0)	72.9 ± 1.7
158	6.88 (2.60)	88.4 ± 1.7	7.84 (3.0)	66.7 ± 1.5	7.95 (2.8)	80.9 ± 1.7
229	5.66 (2.23)	94.1 ± 1.7	6.65 (2.4)	73.4 ± 1.6	5.56 (2.5)	86.4 ± 1.7

	Composite #4		Composite #5	
Time Days	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100
1	7.28 (10.9)[a]	7.28 ± 0.80	15.4 (7.4)[a]	15.4 ± 1.0
2	3.30 (16.2)	10.6 ± 0.96	4.66 (13.4)	20.1 ± 1.3
3	3.45 (15.8)	14.1 ± 1.1	4.24 (14.0)	24.3 ± 1.4
4	1.65 (23.0)	15.7 ± 1.2	3.66 (15.1)	28.0 ± 1.5
5	1.56 (23.6)	17.3 ± 1.2	3.74 (14.9)	31.7 ± 1.6
6	1.27 (26.0)	18.5 ± 1.3	2.41 (18.6)	34.1 ± 1.7
7	0.867 (31.6)	19.4 ± 1.3	1.83 (21.4)	35.9 ± 1.7
8	1.04 (28.9)	20.4 ± 1.3	1.91 (20.9)	37.9 ± 1.8
9	0.884 (31.4)	21.3 ± 1.4	1.15 (27.0)	39.0 ± 1.8
10	0.954 (7.9)	22.3 ± 1.4	1.26 (6.6)	40.3 ± 1.8
15	3.71 (4.3)	26.0 ± 1.4	5.27 (3.4)	45.5 ± 1.8
20	2.93 (4.9)	28.9 ± 1.4	4.28 (3.7)	49.8 ± 1.8
29	4.77 (3.9)	33.7 ± 1.4	5.74 (3.2)	55.6 ± 1.8
43	5.65 (3.6)	39.3 ± 1.4	7.44 (2.9)	63.0 ± 1.8
71	7.96 (3.0)	47.3 ± 1.4	8.75 (2.7)	71.7 ± 1.9
100	7.00 (3.2)	54.3 ± 1.4	7.45 (2.9)	79.2 ± 1.9
158	7.65 (3.1)	61.9 ± 1.5	8.08 (2.8)	87.3 ± 1.9
229	6.75 (2.4)	68.7 ± 1.5	6.81 (2.3)	94.1 ± 1.9

[a]Number in ( ) = 1σ percent counting uncertainty.

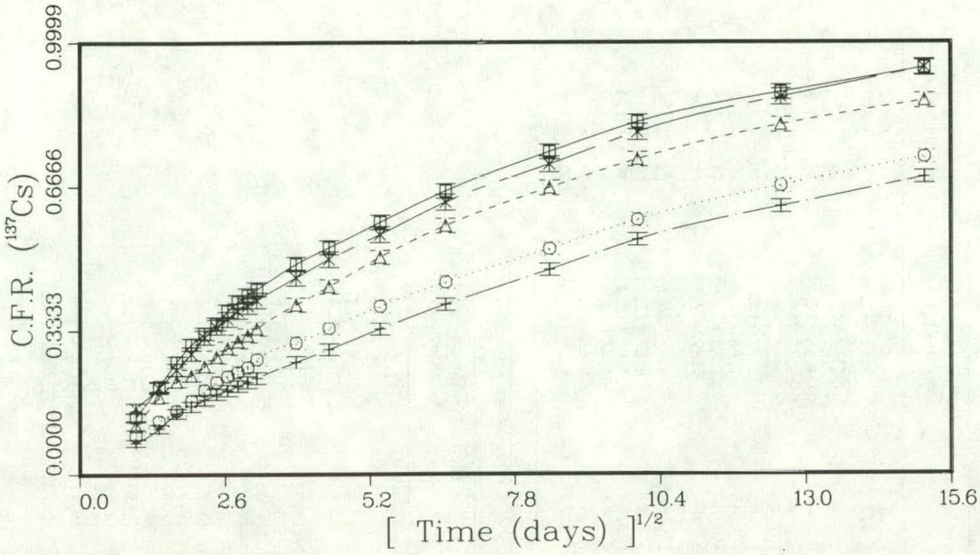

Figure 2.1 ^{137}Cs cumulative fractional release vs $(time)^{1/2}$ from 3% H_3BO_3 waste composites (w/c = 0.5; V/S = 0.94 cm).

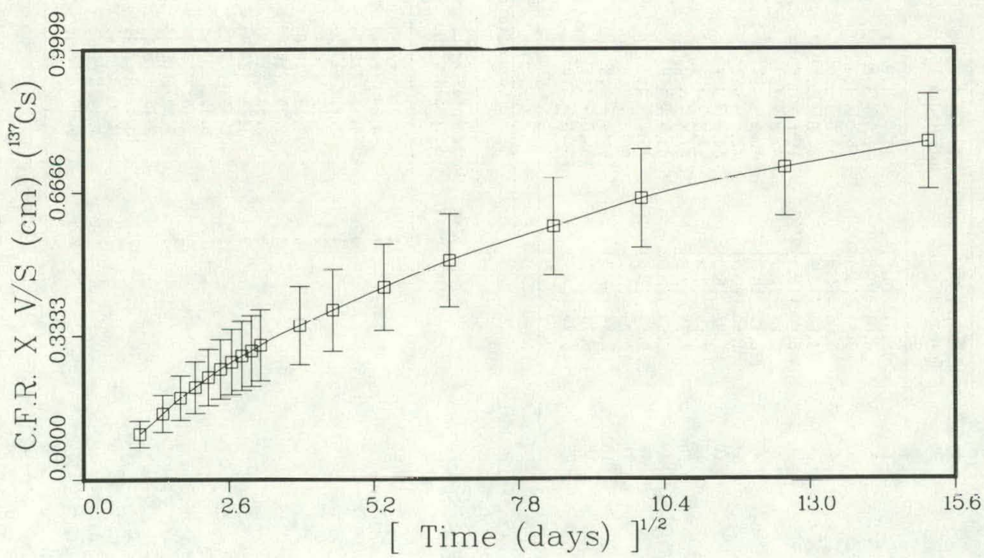

Figure 2.2 Average cumulative fractional release of ^{137}Cs vs $(time)^{1/2}$ from 3% H_3BO_3 waste composites (w/c = 0.5; V/S = 0.94 cm).

Table 2.5

^{137}Cs Incremental and Cumulative Fractions Released From Boric Acid/Portland III Cement Composites (3% Boric Acid Solution and w/c Ratio of 0.7)

Time Days	Composite #1 Incremental Fraction Released x 100	Composite #1 Cumulative Fraction Released x 100	Composite #2 Incremental Fraction Released x 100	Composite #2 Cumulative Fraction Released x 100	Composite #3 Incremental Fraction Released x 100	Composite #3 Cumulative Fraction Released x 100
1	15.0 (6.9)[a]	15.0 ± 1.0	16.4 (7.0)[a]	16.4 ± 1.1	14.7 (7.2)[a]	14.7 ± 1.1
2	6.04 (10.8)	21.0 ± 1.2	6.14 (11.3)	22.7 ± 1.3	5.41 (11.8)	20.1 ± 1.2
3	3.94 (13.4)	25.0 ± 1.3	4.50 (13.3)	27.2 ± 1.5	5.26 (12.0)	25.3 ± 1.4
4	5.06 (11.8)	30.0 ± 1.5	3.55 (14.9)	30.7 ± 1.6	3.46 (14.8)	28.8 ± 1.5
5	3.94 (13.4)	34.0 ± 1.6	2.05 (19.6)	32.8 ± 1.6	3.68 (14.3)	32.5 ± 1.6
6	2.60 (16.5)	36.6 ± 1.6	2.45 (18.0)	35.2 ± 1.7	3.16 (15.5)	35.6 ± 1.6
7	2.25 (17.7)	38.8 ± 1.7	3.16 (15.8)	38.4 ± 1.7	2.10 (18.9)	37.7 ± 1.7
8	2.11 (18.3)	40.9 ± 1.7	2.45 (18.0)	40.8 ± 1.8	2.93 (16.0)	40.6 ± 1.8
9	1.60 (20.9)	42.5 ± 1.7	1.44 (23.4)	42.3 ± 1.8	1.88 (20.0)	42.5 ± 1.8
10	1.97 (5.3)	44.5 ± 1.7	1.93 (5.3)	44.2 ± 1.8	1.80 (2.9)	44.3 ± 1.8
15	7.59 (2.8)	52.1 ± 1.8	6.92 (2.9)	51.1 ± 1.8	7.39 (2.9)	51.7 ± 1.8
20	5.33 (3.3)	57.4 ± 1.8	5.49 (3.2)	56.6 ± 1.9	4.84 (3.6)	56.6 ± 1.8
29	8.53 (2.6)	65.9 ± 1.8	8.68 (2.6)	65.3 ± 1.9	7.98 (2.8)	64.5 ± 1.8
43	9.64 (2.5)	75.6 ± 1.8	10.4 (2.4)	75.6 ± 1.9	8.67 (2.7)	73.2 ± 1.8
71	11.2 (2.7)	86.7 ± 1.8	12.4 (2.2)	88.0 ± 1.9	11.6 (2.4)	84.8 ± 1.9
100	7.64 (2.8)	94.4 ± 1.8	9.30 (2.5)	97.3 ± 1.9	9.66 (2.6)	94.4 ± 1.9
158	6.13 (3.1)	101.0 ± 1.8	8.75 (2.6)	106.0 ± 1.9	8.57 (2.7)	103.0 ± 1.9
229	2.99 (3.1)	104.0 ± 1.8	5.26 (2.6)	111.0 ± 1.9	5.17 (2.5)	108.0 ± 1.9

Time Days	Composite #4 Incremental Fraction Released x 100	Composite #4 Cumulative Fraction Released x 100	Composite #5 Incremental Fraction Released x 100	Composite #5 Cumulative Fraction Released x 100
1	13.7 (7.5)[a]	13.7 ± 1.0	11.8 (8.2)[a]	11.8 ± 1.0
2	4.89 (12.4)	18.6 ± 1.2	4.35 (13.5)	16.1 ± 1.1
3	4.51 (12.9)	23.1 ± 1.3	4.19 (13.8)	20.3 ± 1.2
4	3.91 (13.9)	27.0 ± 1.4	4.43 (13.4)	24.8 ± 1.4
5	3.61 (14.4)	30.6 ± 1.5	2.85 (16.7)	27.6 ± 1.5
6	2.33 (18.0)	33.0 ± 1.6	2.37 (18.3)	30.0 ± 1.5
7	1.96 (19.6)	34.9 ± 1.6	1.42 (23.6)	31.4 ± 1.6
8	2.63 (16.9)	37.5 ± 1.7	1.98 (20.0)	33.4 ± 1.6
9	1.75 (20.8)	39.3 ± 1.7	1.36 (24.1)	34.8 ± 1.7
10	1.41 (6.0)	40.7 ± 1.7	1.66 (6.2)	36.4 ± 1.7
15	6.61 (2.9)	47.3 ± 1.7	7.22 (3.0)	43.6 ± 1.7
20	5.18 (3.2)	52.5 ± 1.7	5.30 (3.5)	48.9 ± 1.7
29	7.99 (2.6)	60.5 ± 1.8	8.89 (2.8)	57.8 ± 1.7
43	9.13 (2.4)	69.6 ± 1.8	9.21 (2.7)	67.0 ± 1.7
71	10.0 (2.4)	79.6 ± 1.8	11.2 (2.5)	78.2 ± 1.7
100	8.25 (2.6)	87.9 ± 1.8	9.99 (2.6)	88.2 ± 1.8
158	7.59 (2.7)	95.5 ± 1.8	8.10 (2.9)	96.3 ± 1.8
229	6.09 (2.4)	102.0 ± 1.8	7.03 (2.3)	103.0 ± 1.0

[a]Number in ( ) = 1σ percent counting uncertainty.

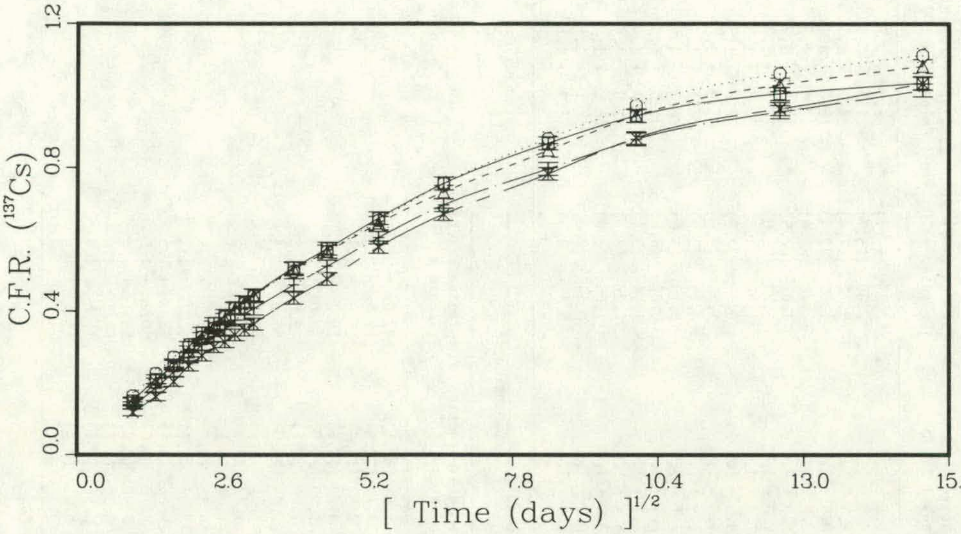

Figure 2.3 ^{137}Cs cumulative fraction release of vs $(time)^{1/2}$ from 3% H_3BO_3 waste composites (w/c = 0.7 ; V/S = 0.94 cm).

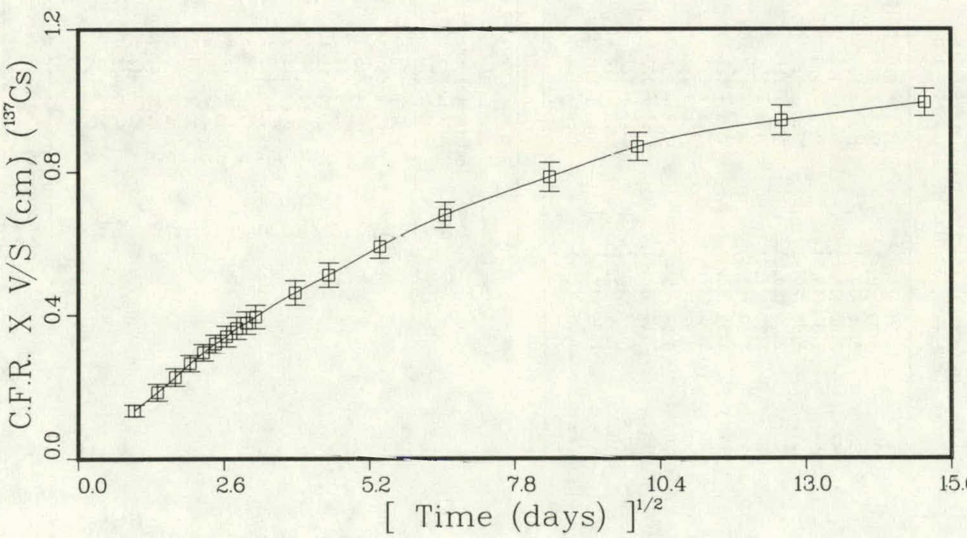

Figure 2.4 Average cumulative fraction release of ^{137}Cs vs $(time)^{1/2}$ from 3% H_3BO_3 waste composites (w/c = 0.7 ; V/S = 0.94 cm).

Table 2.6

^{137}Cs Incremental and Cumulative Fractions Released From Boric Acid/Portland III Cement Composites (6% Boric Acid Solution and w/c Ratio of 0.5)

Time Days	Composite #1		Composite #2		Composite #3	
	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100
1	11.05 (10.0)[a]	11.1 ± 1.0	10.58 (8.9)[a]	10.6 ± 1.0	8.59 (9.7)[a]	8.59 ± 0.83
2	5.28 (8.7)	16.3 ± 1.2	4.10 (14.2)	14.7 ± 1.1	2.89 (16.7)	11.5 ± 0.96
3	3.46 (12.5)	19.8 ± 1.3	3.77 (14.8)	18.5 ± 1.2	2.72 (17.2)	14.2 ± 1.1
4	2.80 (15.5)	22.6 ± 1.4	2.05 (20.0)	20.5 ± 1.3	1.60 (22.4)	15.8 ± 1.1
5	2.80 (15.5)	25.4 ± 1.5	2.38 (18.6)	22.9 ± 1.4	1.77 (21.4)	17.6 ± 1.2
6	1.98 (20.4)	27.4 ± 1.5	1.97 (20.4)	24.9 ± 1.4	1.61 (22.4)	19.2 ± 1.2
7	2.39 (18.5)	29.8 ± 1.6	1.15 (26.7)	26.0 ± 1.5	1.28 (25.0)	20.5 ± 1.3
8	1.81 (21.4)	31.6 ± 1.6	1.39 (24.3)	27.4 ± 1.5	1.36 (24.3)	21.8 ± 1.3
9	1.63 (22.4)	33.2 ± 1.7	1.10 (27.3)	28.5 ± 1.5	0.738 (32.8)	22.6 ± 1.3
10	1.88 (5.5)	35.1 ± 1.7	1.26 (6.7)	29.8 ± 1.5	1.25 (6.6)	23.8 ± 1.4
15	5.44 (3.5)	40.5 ± 1.7	4.13 (3.8)	33.9 ± 1.5	4.30 (3.9)	28.1 ± 1.4
20	3.93 (4.1)	44.5 ± 1.7	3.23 (4.2)	37.1 ± 1.5	3.19 (4.5)	31.3 ± 1.4
29	6.05 (3.4)	50.5 ± 1.7	5.32 (3.3)	42.4 ± 1.6	5.27 (3.6)	36.6 ± 1.4
43	7.14 (3.1)	57.7 ± 1.7	6.43 (3.0)	48.9 ± 1.6	7.14 (3.1)	43.7 ± 1.4
71	7.80 (3.0)	65.5 ± 1.7	7.56 (2.8)	56.4 ± 1.6	7.22 (3.1)	51.0 ± 1.4
100	7.05 (3.1)	72.5 ± 1.7	6.20 (3.1)	62.6 ± 1.6	7.66 (3.0)	58.6 ± 1.4
158	7.75 (3.0)	80.3 ± 1.8	7.83 (2.8)	70.5 ± 1.6	8.54 (2.8)	67.1 ± 1.5
229	6.08 (2.5)	86.4 ± 1.8	5.94 (2.5)	76.4 ± 1.6	6.72 (2.3)	73.9 ± 1.5

Time Days	Composite #4		Composite #5	
	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100
1	9.80 (8.9)[a]	9.80 ± 0.88	7.67 (10.1)[a]	7.67 ± 0.78
2	6.14 (11.3)	15.9 ± 1.1	4.77 (12.8)	12.4 ± 0.99
3	3.34 (15.3)	19.3 ± 1.2	3.52 (14.9)	16.0 ± 1.1
4	2.33 (18.3)	21.6 ± 1.3	3.29 (15.5)	19.2 ± 1.2
5	3.19 (15.6)	24.8 ± 1.4	1.80 (20.9)	21.0 ± 1.3
6	2.18 (18.9)	27.0 ± 1.5	1.46 (23.1)	22.5 ± 1.3
7	2.57 (17.4)	29.5 ± 1.5	1.49 (23.0)	24.0 ± 1.4
8	1.87 (20.4)	31.4 ± 1.6	2.11 (19.3)	26.1 ± 1.4
9	1.26 (24.8)	32.7 ± 1.6	1.77 (21.1)	27.9 ± 1.5
10	1.48 (6.0)	34.1 ± 1.6	1.42 (6.1)	29.3 ± 1.5
15	5.52 (3.2)	39.7 ± 1.6	4.82 (3.6)	34.1 ± 1.5
20	4.01 (3.7)	43.7 ± 1.6	3.47 (4.3)	3.67 ± 1.5
29	5.88 (3.1)	49.6 ± 1.6	5.48 (3.4)	43.1 ± 1.5
43	6.97 (2.9)	56.5 ± 1.6	7.12 (3.0)	50.2 ± 1.5
71	8.57 (2.6)	65.1 ± 1.7	7.96 (2.9)	58.1 ± 1.5
100	6.69 (2.9)	71.8 ± 1.7	6.36 (3.2)	64.5 ± 1.6
158	7.78 (2.7)	79.5 ± 1.7	6.96 (3.1)	71.5 ± 1.6
229	5.93 (2.4)	35.5 ± 1.7	5.67 (2.5)	77.1 ± 1.6

[a]Number in ( ) = 1σ percent counting uncertainty.

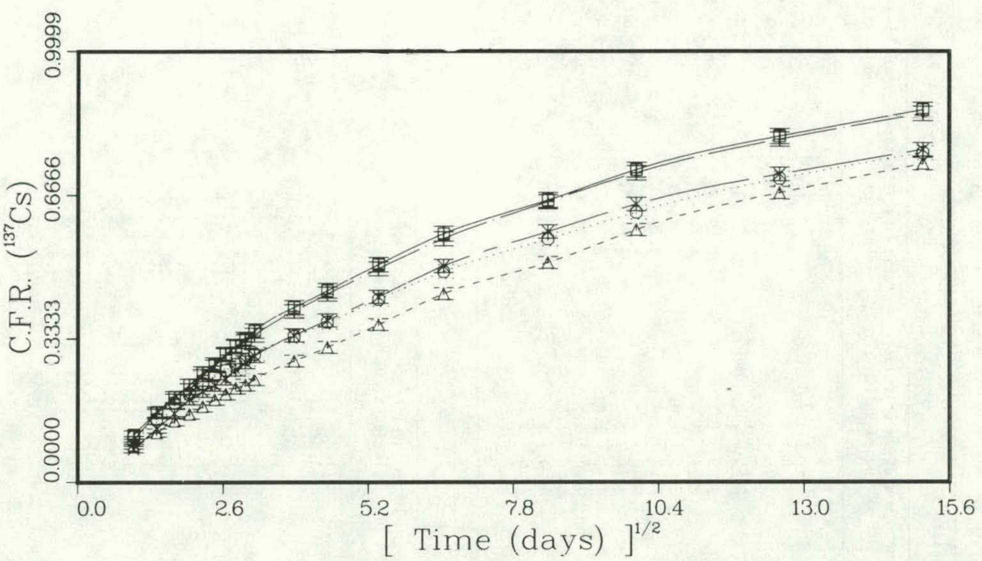

Figure 2.5 ^{137}Cs cumulative fractional release vs $(time)^{1/2}$ from 6% H_3BO_3 waste composites (w/c = 0.5; V/S = 0.94 cm).

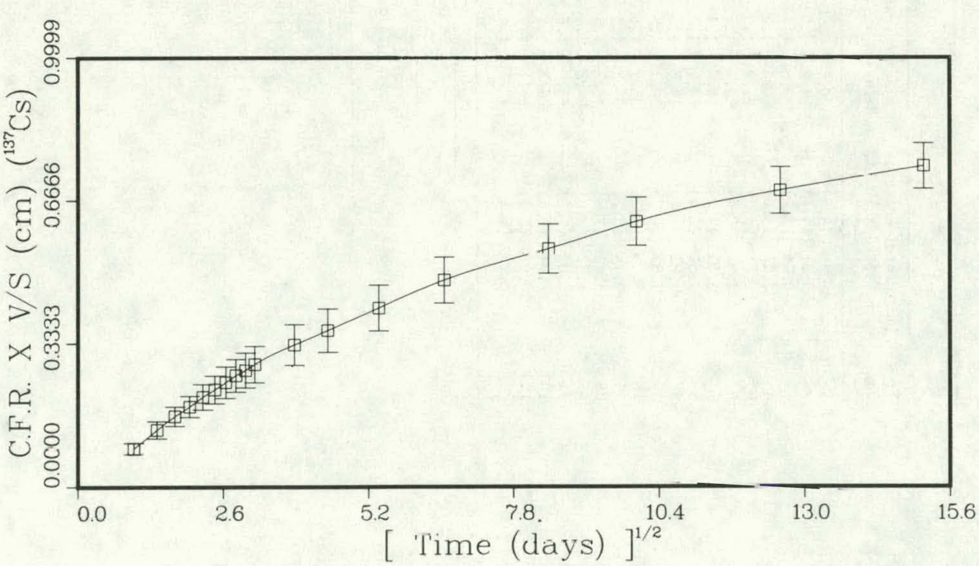

Figure 2.6 Average cumulative fractional release of ^{137}Cs vs $(time)^{1/2}$ from 6% H_3BO_3 waste composites (w/c = 0.5; V/S = 0.94 cm).

Table 2.7

^{137}Cs Incremental and Cumulative Fractions Released From
Boric Acid/Portland III Cement Composites (6% Boric Acid Solution and w/c Ratio of 0.7)

	Composite #1		Composite #2		Composite #3	
Time Days	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100
1	10.5 (8.5)[a]	10.5 ± 0.90	10.9 (8.3)[a]	10.9 ± 0.91	10.8 (8.4)[a]	10.8 ± 0.91
2	3.61 (14.4)	14.2 ± 1.0	3.16 (15.5)	14.1 ± 1.0	3.86 (14.0)	14.7 ± 1.1
3	3.76 (14.2)	17.9 ± 1.2	2.49 (17.4)	16.6 ± 1.1	3.18 (15.5)	17.9 ± 1.2
4	2.11 (19.0)	20.0 ± 1.2	2.03 (19.3)	18.6 ± 1.2	2.35 (18.0)	20.2 ± 1.2
5	2.71 (16.7)	22.7 ± 1.3	2.11 (19.0)	20.7 ± 1.2	3.26 (15.3)	23.5 ± 1.3
6	1.81 (20.4)	24.5 ± 1.4	2.26 (18.3)	23.0 ± 1.3	1.82 (20.4)	25.3 ± 1.4
7	2.03 (19.3)	26.6 ± 1.4	0.828 (30.2)	23.8 ± 1.3	1.59 (21.8)	26.9 ± 1.4
8	1.51 (22.4)	28.1 ± 1.5	1.28 (24.3)	25.1 ± 1.4	1.74 (20.9)	28.6 ± 1.5
9	1.25 (24.6)	29.3 ± 1.5	0.858 (29.7)	25.9 ± 1.4	1.24 (24.6)	29.9 ± 1.5
10	1.33 (6.2)	30.7 ± 1.5	1.37 (6.1)	27.3 ± 1.4	1.29 (6.3)	31.2 ± 1.5
15	5.25 (3.2)	35.9 ± 1.5	3.90 (4.0)	31.2 ± 1.4	5.13 (3.2)	36.3 ± 1.5
20	3.90 (3.7)	39.8 ± 1.5	3.43 (4.2)	34.6 ± 1.4	4.15 (3.6)	40.4 ± 1.5
29	6.41 (2.9)	46.2 ± 1.5	6.43 (3.1)	41.1 ± 1.4	6.76 (2.9)	47.2 ± 1.5
43	8.33 (2.6)	54.6 ± 1.5	7.38 (2.9)	48.4 ± 1.5	8.01 (2.7)	55.2 ± 1.6
71	10.8 (2.3)	65.4 ± 1.6	10.1 (2.5)	58.6 ± 1.5	10.9 (2.3)	66.1 ± 1.6
100	8.94 (2.5)	74.3 ± 1.6	8.79 (1.2)	67.4 ± 1.5	9.12 (2.5)	75.2 ± 1.6
158	10.8 (2.3)	85.1 ± 1.6	10.2 (2.5)	77.5 ± 1.5	10.1 (2.4)	85.3 ± 1.6
229	8.13 (2.1)	93.3 ± 1.6	8.17 (2.1)	85.7 ± 1.5	7.78 (2.1)	93.1 ± 1.6

	Composite #4		Composite #5	
Time Days	Incremental Fraction Released x 100	Cumulative Fraction Released x 100	Incremental Fraction Released x 100	Cumulative Fraction Released x 100
1	11.3 (8.2)[a]	11.3 ± 0.93	11.9 (7.9)[a]	11.9 ± 0.93
2	3.02 (15.8)	14.3 ± 1.0	4.52 (12.7)	16.4 ± 1.1
3	2.27 (18.3)	16.5 ± 1.1	3.64 (14.2)	20.0 ± 1.2
4	2.12 (18.9)	18.7 ± 1.2	1.97 (19.3)	22.0 ± 1.3
5	1.96 (19.6)	20.6 ± 1.3	1.89 (19.6)	23.9 ± 1.3
6	1.59 (21.8)	22.2 ± 1.3	1.24 (24.2)	25.1 ± 1.4
7	1.03 (27.1)	23.2 ± 1.3	1.38 (23.0)	26.5 ± 1.4
8	0.982 (27.7)	24.2 ± 1.4	2.11 (18.6)	28.6 ± 1.4
9	1.21 (25.0)	25.4 ± 1.4	1.28 (23.9)	29.9 ± 1.5
10	1.27 (6.4)	26.7 ± 1.4	1.18 (6.5)	31.1 ± 1.5
15	4.40 (3.7)	31.1 ± 1.4	4.90 (3.3)	36.0 ± 1.5
20	3.57 (4.2)	34.7 ± 1.4	4.23 (3.5)	40.2 ± 1.5
29	6.09 (3.2)	40.7 ± 1.4	6.65 (2.8)	46.9 ± 1.5
43	7.49 (2.9)	48.2 ± 1.4	8.16 (2.6)	55.0 ± 1.5
71	10.1 (2.5)	58.4 ± 1.5	10.1 (2.3)	65.1 ± 1.5
100	8.69 (2.7)	67.1 ± 1.5	8.64 (2.5)	73.8 ± 1.6
158	10.4 (2.5)	77.5 ± 1.5	10.1 (2.3)	83.9 ± 1.6
229	8.28 (2.1)	85.8 ± 1.5	7.10 (2.2)	91.0 ± 1.6

[a]Number in ( ) = 1σ percent counting uncertainty.

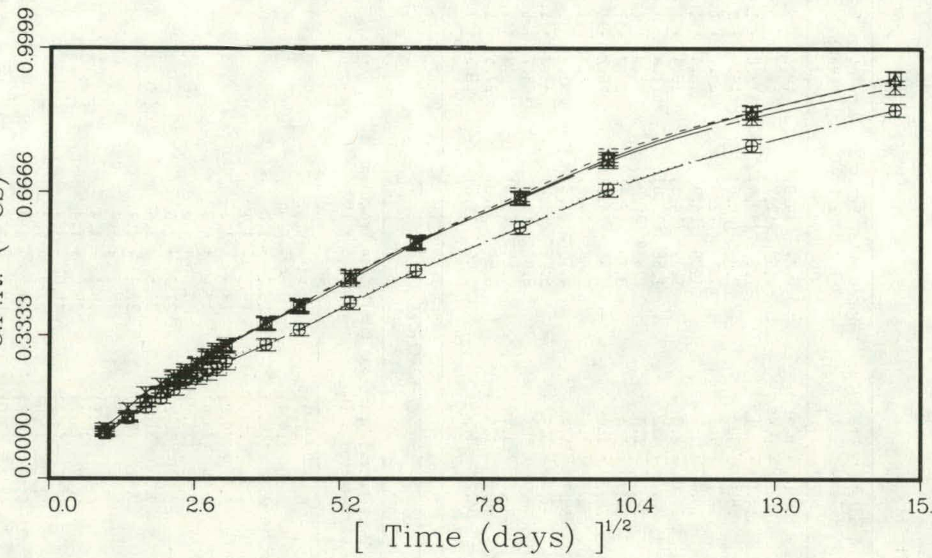

Figure 2.7 ^{137}Cs cumulative fractionalelease vs (time)$^{1/2}$ from 6% H_3BO_3 waste composites (w/c = 0.7; V/S = 0.94 cm).

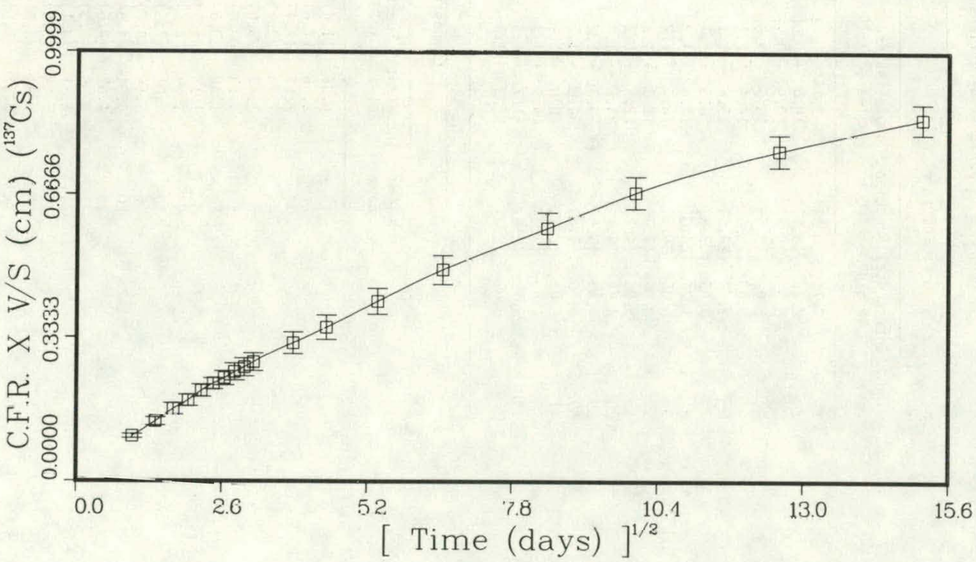

Figure 2.8 Average cumulative fractional release of ^{137}Cs vs (time)$^{1/2}$ from 6% H_3BO_3 waste composites (w/c = 0.7; V/S = 0.94 cm).

Table 2.8

^{137}Cs Incremental and Cumulative Fractions Released From
Boric Acid/Portland III Cement Composites (12% Boric Acid Solution and w/c Ratio of 0.5)

Time Days	Composite #1 Incremental Fraction Released x 100	Composite #1 Cumulative Fraction Released x 100	Composite #2 Incremental Fraction Released x 100	Composite #2 Cumulative Fraction Released x 100	Composite #3 Incremental Fraction Released x 100	Composite #3 Cumulative Fraction Released x 100
1	7.75 (10.0)[a]	7.75 ± .78	8.05 (10.0)[a]	8.05 ± 0.81	8.37 (9.9)[a]	8.37 ± 0.83
2	2.25 (18.6)	10.0 ± 0.88	2.90 (16.7)	11.0 ± 0.94	2.62 (17.7)	11.0 ± 0.95
3	0.931 (28.8)	10.9 ± 0.92	3.06 (16.2)	14.0 ± 1.1	1.97 (20.4)	13.0 ± 1.0
4	2.02 (19.6)	13.0 ± 1.0	2.42 (18.3)	16.4 ± 1.2	2.05 (20.0)	15.0 ± 1.1
5	1.40 (23.6)	14.4 ± 1.1	0.805 (31.6)	17.2 ± 1.2	1.64 (22.4)	16.7 ± 1.2
6	1.29 (24.5)	15.6 ± 1.1	2.17 (19.3)	19.4 ± 1.3	1.39 (24.3)	18.0 ± 1.2
7	0.698 (33.3)	16.3 ± 1.1	1.61 (22.4)	21.0 ± 1.3	1.39 (24.3)	19.4 ± 1.3
8	1.24 (25.0)	17.6 ± 1.2	1.37 (24.2)	22.4 ± 1.3	1.56 (23.0)	21.0 ± 1.3
9	0.807 (30.8)	18.4 ± 1.2	1.16 (26.4)	23.5 ± 1.4	0.869 (30.8)	21.9 ± 1.3
10	0.869 (7.7)	19.3 ± 1.2	1.13 (6.9)	24.7 ± 1.4	0.968 (7.5)	22.8 ± 1.3
15	3.06 (4.2)	22.3 ± 1.2	3.53 (4.3)	28.2 ± 1.4	3.41 (4.1)	26.2 ± 1.4
20	2.44 (4.7)	24.7 ± 1.2	2.80 (4.8)	31.0 ± 1.4	2.46 (4.8)	28.7 ± 1.4
29	4.53 (3.5)	29.3 ± 1.2	4.67 (3.8)	35.7 ± 1.4	4.71 (3.5)	33.4 ± 1.4
43	4.76 (3.4)	34.0 ± 1.2	5.96 (3.4)	41.6 ± 1.4	5.74 (3.2)	39.2 ± 1.4
71	6.02 (3.1)	40.0 ± 1.2	6.72 (3.2)	48.3 ± 1.4	6.50 (3.0)	45.7 ± 1.4
100	4.89 (3.4)	44.9 ± 1.3	5.46 (3.5)	53.8 ± 1.5	5.25 (3.3)	50.9 ± 1.4
158	6.71 (2.9)	51.7 ± 1.3	6.70 (3.2)	60.5 ± 1.5	6.56 (3.0)	57.5 ± 1.4
229	6.67 (2.3)	58.3 ± 1.3	5.70 (2.5)	66.2 ± 1.5	6.06 (2.5)	63.5 ± 1.4

Time Days	Composite #4 Incremental Fraction Released x 100	Composite #4 Cumulative Fraction Released x 100	Composite #5 Incremental Fraction Released x 100	Composite #5 Cumulative Fraction Released x 100
1	6.05 (11.4)[a]	6.04 ± 0.69	5.94 (11.7)[a]	5.94 ± 0.67
2	2.56 (17.4)	8.61 ± 0.82	3.90 (14.4)	9.84 ± 0.90
3	2.56 (17.4)	11.2 ± 0.93	3.17 (16.0)	13.0 ± 1.0
4	1.78 (20.9)	13.0 ± 1.0	3.17 (16.0)	16.1 ± 1.1
5	1.47 (23.0)	14.4 ± 1.1	1.87 (20.9)	18.1 ± 1.2
6	1.55 (22.4)	16.0 ± 1.1	1.55 (23.0)	19.6 ± 1.3
7	1.40 (23.6)	17.4 ± 1.2	1.22 (25.9)	20.8 ± 1.3
8	1.13 (26.1)	18.5 ± 1.2	0.895 (30.2)	21.7 ± 1.3
9	1.29 (24.6)	19.8 ± 1.2	0.830 (31.4)	22.5 ± 1.4
10	1.01 (7.3)	20.8 ± 1.2	0.813 (8.2)	23.4 ± 1.4
15	3.54 (4.2)	24.3 ± 1.3	3.87 (3.8)	27.2 ± 1.4
20	3.04 (4.5)	27.4 ± 1.3	2.83 (4.5)	30.1 ± 1.4
29	4.82 (3.6)	32.2 ± 1.3	5.29 (3.3)	35.3 ± 1.4
43	5.85 (3.3)	38.1 ± 1.3	5.61 (3.2)	41.0 ± 1.4
71	6.81 (3.1)	44.9 ± 1.3	6.73 (3.0)	47.7 ± 1.4
100	5.09 (3.6)	50.0 ± 1.3	5.54 (3.3)	53.2 ± 1.4
158	6.41 (3.2)	56.4 ± 1.3	6.34 (3.0)	59.6 ± 1.4
229	5.31 (2.5)	61.7 ± 1.3	5.80 (2.5)	65.4 ± 1.4

[a]Number in ( ) = 1σ percent counting uncertainty.

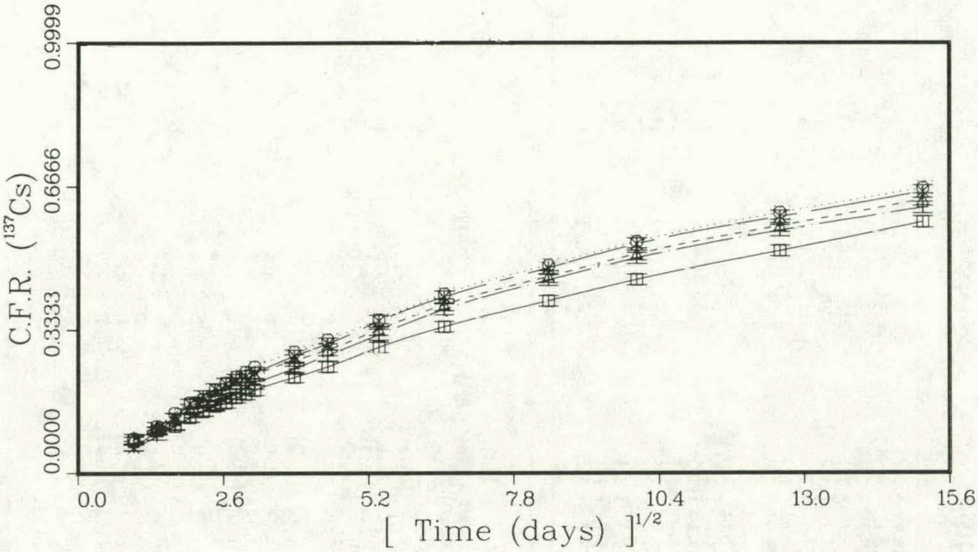

Figure 2.9 ^{137}Cs cumulative fractional release vs (time)$^{1/2}$ from 12% H_3BO_3 waste composites (w/c = 0.5; V/S = 0.94 cm).

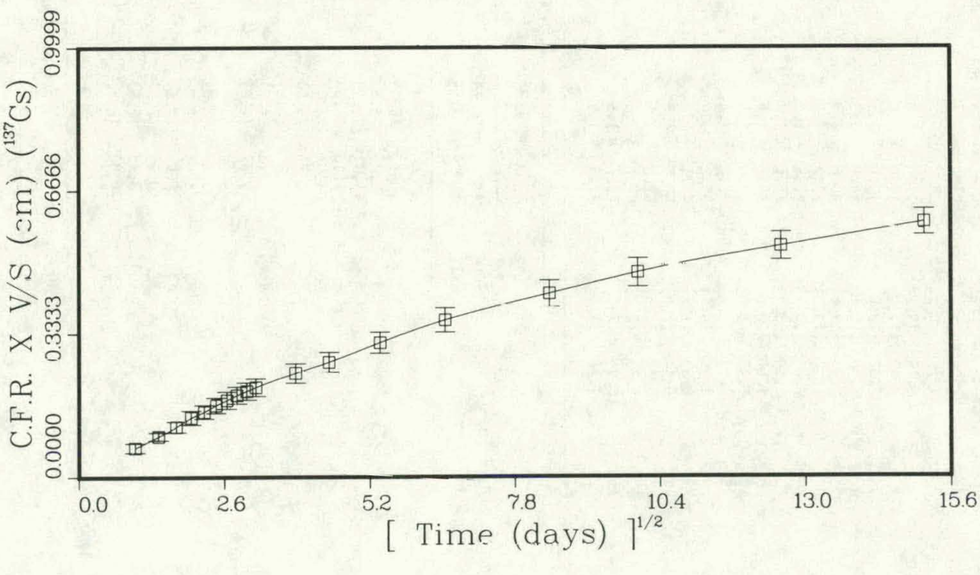

Figure 2.10 Average cumulative fractional release of ^{137}Cs vs (time)$^{1/2}$ from 12% H_3BO_3 waste composites (w/c = 0.5; V/S = 0.94 cm).

Table 2.9

^{137}Cs Incremental and Cumulative Fractions Released From Boric Acid/Portland III Cement Composites (12% Boric Acid Solution and w/c Ratio of 0.7)

Time Days	Composite #1 Incremental Fraction Released x 100	Composite #1 Cumulative Fraction Released x 100	Composite #2 Incremental Fraction Released x 100	Composite #2 Cumulative Fraction Released x 100	Composite #3 Incremental Fraction Released x 100	Composite #3 Cumulative Fraction Released x 100
1	9.14 (9.2)[a]	9.14 ± 0.84	9.85 (8.6)[a]	9.85 ± 0.85	11.3 (8.2)[a]	11.3 ± 0.92
2	3.46 (14.9)	12.6 ± 1.0	2.55 (16.9)	12.4 ± 0.96	4.56 (12.8)	15.9 ± 1.1
3	2.38 (18.0)	15.0 ± 1.1	2.77 (16.2)	15.2 ± 1.1	2.47 (17.4)	18.3 ± 1.2
4	3.38 (15.1)	18.4 ± 1.2	1.02 (26.7)	16.2 ± 1.1	2.25 (18.3)	20.6 ± 1.2
5	2.23 (18.6)	20.6 ± 1.3	2.48 (17.2)	18.7 ± 1.2	2.02 (19.3)	22.6 ± 1.3
6	2.07 (19.3)	22.7 ± 1.3	1.97 (19.3)	20.6 ± 1.2	1.57 (21.8)	24.2 ± 1.3
7	0.845 (30.2)	23.5 ± 1.3	1.68 (20.9)	22.3 ± 1.3	1.87 (20.0)	26.0 ± 1.4
8	1.54 (22.4)	25.1 ± 1.4	1.24 (24.3)	23.6 ± 1.3	1.95 (19.6)	28.0 ± 1.5
9	1.14 (26.0)	26.2 ± 1.4	0.890 (28.7)	24.5 ± 1.3	1.32 (23.9)	29.3 ± 1.5
10	1.46 (6.0)	27.6 ± 1.4	0.992 (7.1)	25.4 ± 1.3	1.26 (6.4)	30.6 ± 1.5
15	4.53 (3.7)	32.2 ± 1.4	4.16 (3.5)	29.6 ± 1.3	4.82 (3.6)	35.4 ± 1.5
20	3.60 (4.1)	35.8 ± 1.4	3.46 (3.8)	33.1 ± 1.4	3.80 (4.0)	39.2 ± 1.5
29	6.33 (3.2)	42.1 ± 1.4	6.00 (3.0)	39.1 ± 1.4	7.11 (3.0)	46.3 ± 1.5
43	8.44 (2.8)	50.6 ± 1.5	7.78 (2.6)	46.8 ± 1.4	7.87 (2.8)	54.2 ± 1.5
71	10.4 (2.5)	61.0 ± 1.5	10.9 (2.3)	57.8 ± 1.4	11.3 (2.4)	65.5 ± 1.6
100	8.73 (2.7)	69.7 ± 1.5	8.90 (2.5)	66.7 ± 1.4	9.12 (2.7)	74.6 ± 1.6
158	10.0 (2.6)	79.7 ± 1.5	10.30 (2.3)	76.9 ± 1.4	9.97 (2.6)	84.5 ± 1.6
229	7.77 (1.8)	87.6 ± 1.5	7.30 (2.1)	84.2 ± 1.5	7.26 (2.2)	91.8 ± 1.6

Time Days	Composite #4 Incremental Fraction Released x 100	Composite #4 Cumulative Fraction Released x 100	Composite #5 Incremental Fraction Released x 100	Composite #5 Cumulative Fraction Released x 100
1	10.9 (8.3)[a]	10.9 ± 0.90	9.98 (8.8)[a]	9.98 ± 0.88
2	3.13 (15.5)	14.0 ± 1.0	2.71 (16.9)	12.7 ± 1.0
3	2.76 (16.5)	16.8 ± 1.1	2.86 (16.5)	15.6 ± 1.1
4	1.71 (20.9)	18.5 ± 1.2	1.78 (20.9)	17.3 ± 1.2
5	2.16 (18.6)	20.6 ± 1.2	2.24 (18.6)	19.6 ± 1.2
6	1.04 (26.7)	21.7 ± 1.3	1.47 (23.0)	21.0 ± 1.3
7	1.34 (23.6)	23.0 ± 1.3	1.86 (20.4)	22.9 ± 1.3
8	1.86 (20.0)	24.9 ± 1.4	1.24 (25.0)	24.1 ± 1.4
9	1.22 (24.7)	26.1 ± 1.4	1.15 (26.0)	25.3 ± 1.4
10	1.37 (6.0)	27.5 ± 1.4	1.18 (6.6)	26.5 ± 1.4
15	4.65 (3.4)	32.1 ± 1.4	4.01 (4.0)	30.5 ± 1.4
20	3.61 (3.8)	35.7 ± 1.4	3.28 (4.4)	33.8 ± 1.4
29	6.87 (2.8)	42.6 ± 1.4	6.25 (3.2)	40.0 ± 1.4
43	8.09 (2.6)	50.7 ± 1.4	7.46 (3.0)	47.5 ± 1.5
71	10.8 (2.3)	61.4 ± 1.5	9.75 (2.6)	57.2 ± 1.5
100	8.65 (2.5)	70.1 ± 1.5	8.24 (2.8)	65.4 ± 1.5
158	9.02 (2.5)	79.1 ± 1.5	8.67 (2.8)	74.1 ± 1.5
229	6.86 (2.2)	86.0 ± 1.5	6.92 (2.3)	81.0 ± 1.5

[a]Number in ( ) = 1σ percent counting uncertainty.

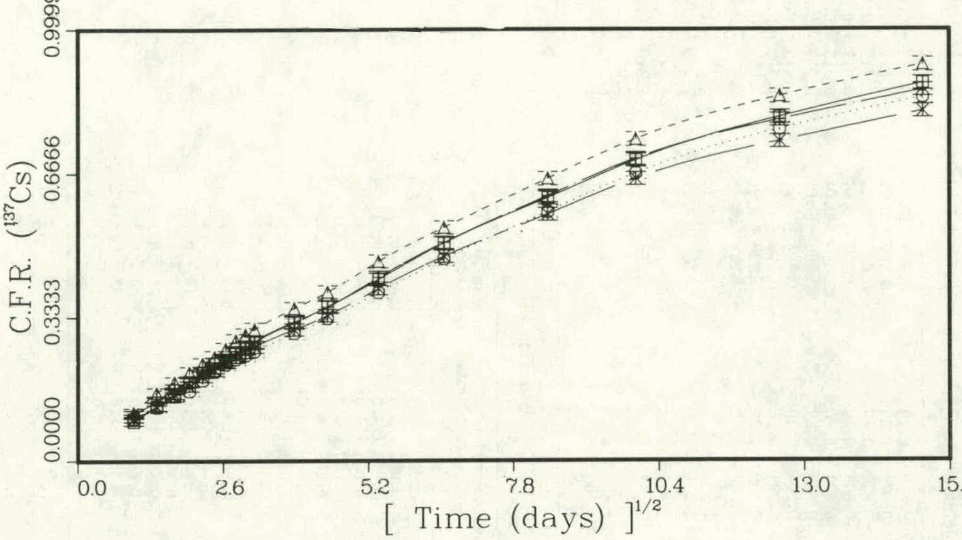

Figure 2.11 ^{137}Cs cumulative fractional release vs $(time)^{1/2}$ from 12% H_3BO_3 waste composites (w/c = 0.7; V/S = 0.94 cm).

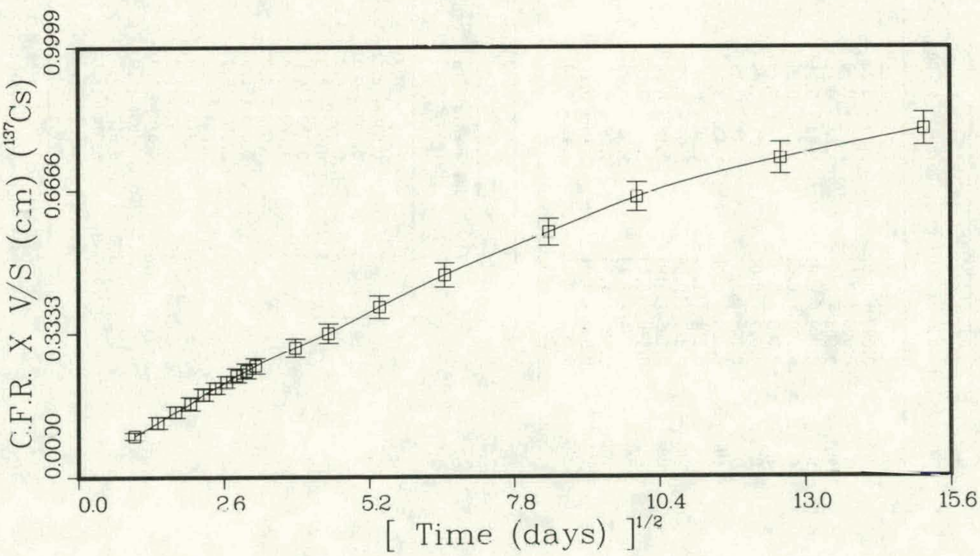

Figure 2.12 Average cumulative fractional release of ^{137}Cs vs $(time)^{1/2}$ from H_3BO_3 waste composites (w/c = 0.7; V/S = 0.94 cm).

Table 2.10

^{85}Sr Incremental and Cumulative Fractions Released From
Boric Acid/Portland III Cement Composites (3% Boric Acid Solution and w/c Ratio of 0.5)

Time Days	Composite #1: Incremental Fraction Released x 100[a,b]	Composite #1: Cumulative Fraction Released x 100	Composite #2: Incremental Fraction Released x 100[a,b]	Composite #2: Cumulative Fraction Released x 100	Composite #3: Incremental Fraction Released x 100[a,b]	Composite #3: Cumulative Fraction Released x 100
1	1.23 (20.7)	1.23 ± 0.25	0.809 (25.0)	0.809 ± 0.20	0.919 (23.4)	0.919 ± 0.22
2	0.000 ± 0.01	1.23 ± 0.25	0.000 ± 0.01	0.809 ± 0.20	0.000 ± 0.01	0.919 ± 0.22
3	0.000 ± 0.01	1.23 ± 0.25	0.000 ± 0.01	0.809 ± 0.20	0.000 ± 0.01	0.919 ± 0.22
4	0.000 ± 0.01	1.23 ± 0.25	0.000 ± 0.01	0.809 ± 0.20	0.000 ± 0.01	0.919 ± 0.22
5	0.000 ± 0.01	1.23 ± 0.25	0.000 ± 0.01	0.809 ± 0.20	0.000 ± 0.01	0.919 ± 0.22
6	0.000 ± 0.01	1.23 ± 0.25	0.000 ± 0.01	0.809 ± 0.20	0.000 ± 0.01	0.919 ± 0.22
7	0.000 ± 0.01	1.23 ± 0.25	0.000 ± 0.01	0.809 ± 0.20	0.687 (27.1)	1.61 ± 0.29
8	0.000 ± 0.01	1.23 ± 0.26	0.000 ± 0.01	0.809 ± 0.20	0.000 ± 0.01	1.61 ± 0.29
9	0.179 (54.1)	1.41 ± 0.28	0.000 ± 0.01	0.809 ± 0.21	0.000 ± 0.01	1.61 ± 0.29
10	0.000 ± 0.01	1.41 ± 0.28	0.000 ± 0.01	0.809 ± 0.21	0.121 (16.7)	1.73 ± 0.29
15	0.274 (11.2)	1.69 ± 0.28	0.344 (10.0)	1.15 ± 0.21	0.353 (9.7)	2.08 ± 0.29
20	0.326 (10.3)	2.01 ± 0.28	0.364 (9.7)	1.52 ± 0.21	0.374 (9.5)	2.45 ± 0.29
29	0.105 (18.0)	2.12 ± 0.28	0.546 (8.0)	2.06 ± 0.21	0.464 (8.5)	2.92 ± 0.29
43	0.548 (8.1)	2.66 ± 0.28	0.536 (6.1)	2.60 ± 0.22	0.475 (8.5)	3.39 ± 0.30
71	0.284 (11.1)	2.95 ± 0.29	0.546 (8.0)	3.14 ± 0.22	0.878 (6.2)	4.27 ± 0.30
100	0.502 (14.7)	3.45 ± 0.29	0.488 (14.9)	3.63 ± 0.23	0.733 (12.0)	5.00 ± 0.31
158	0.000 ± 0.01	3.45 ± 0.29	0.763 (16.3)	4.40 ± 0.27	1.07 (13.6)	6.08 ± 0.35
229	0.000 ± 0.01	3.45 ± 0.30	0.000 ± 0.01	4.40 ± 0.27	0.000 ± 0.01	6.08 ± 0.35

Time Days	Composite #4: Incremental Fraction Released x 100[a,b]	Composite #4: Cumulative Fraction Released x 100	Composite #5: Incremental Fraction Released x 100[a,b]	Composite #5: Cumulative Fraction Released x 100
1	1.25 (20.7)	1.25 ± 0.26	1.02 (22.3)	1.02 ± 0.23
2	0.000 ± 0.01	1.25 ± 0.26	0.000 ± 0.01	1.02 ± 0.23
3	0.000 ± 0.01	1.25 ± 0.26	0.879 (24.0)	1.90 ± 0.31
4	0.000 ± 0.01	1.25 ± 0.26	0.000 ± 0.01	1.90 ± 0.31
5	0.000 ± 0.01	1.25 ± 0.26	0.000 ± 0.01	1.90 ± 0.31
6	0.782 (26.2)	2.04 ± 0.33	0.000 ± 0.01	1.90 ± 0.31
7	0.000 ± 0.01	2.04 ± 0.33	0.000 ± 0.01	1.90 ± 0.31
8	0.000 ± 0.01	2.04 ± 0.33	0.000 ± 0.01	1.90 ± 0.31
9	0.064 (91.7)	2.10 ± 0.34	0.000 ± 0.01	1.90 ± 0.31
10	0.150 (15.7)	2.25 ± 0.34	0.152 (14.7)	2.05 ± 0.31
15	0.204 (13.2)	2.45 ± 0.34	0.344 (10.0)	2.40 ± 0.32
20	0.214 (13.0)	2.67 ± 0.34	0.354 (9.7)	2.75 ± 0.32
29	0.482 (8.7)	3.15 ± 0.34	0.435 (8.9)	3.18 ± 0.32
43	0.578 (8.0)	3.73 ± 0.35	0.900 (6.1)	4.08 ± 0.32
71	0.782 (6.9)	4.51 ± 0.30	0.758 (6.7)	4.84 ± 0.33
100	0.612 (13.7)	5.12 ± 0.36	0.637 (12.9)	5.48 ± 0.34
158	0.944 (15.0)	6.06 ± 0.39	0.638 (17.6)	6.12 ± 0.36
229	0.000 ± 0.01	6.06 ± 0.39	0.000 ± 0.01	6.12 ± 0.36

[a]Number in ( ) = 1σ percent counting uncertainty.
[b]For incremental fraction releases equal to zero, the error is based on the minimum detectable limit.

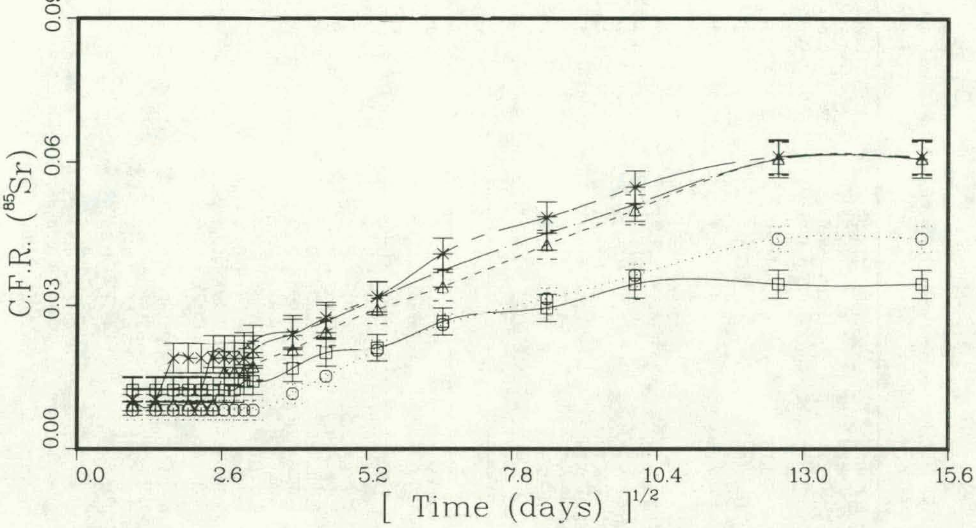

Figure 2.13 ^{85}Sr cumulative fractional release vs $(time)^{1/2}$ from 3% H_3BO_3 waste composites (w/c = 0.5; V/S = 0.94 cm).

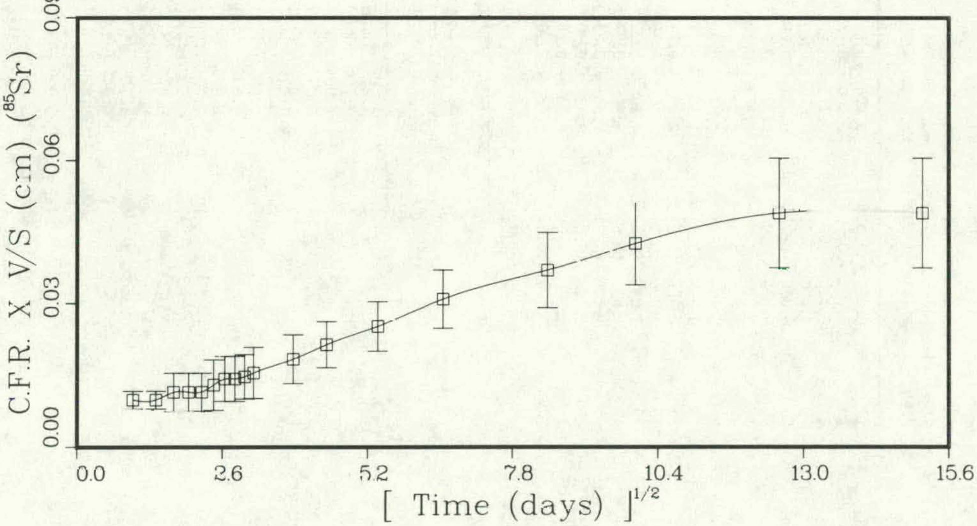

Figure 2.14 Average cumulative fractional release of ^{85}Sr vs $(time)^{1/2}$ from 3% H_3BO_3 waste composites (w/c = 0.5; V/S = 0.94 cm).

Table 2.11

^{85}Sr Incremental and Cumulative Fractions Released From
Boric Acid/Portland III Cement Composites (3% Boric Acid Solution and w/c Ratio of 0.7)

	Composite #1		Composite #2		Composite #3	
Time Days	Incremental Fraction Released x 100[a,b]	Cumulative Fraction Released x 100	Incremental Fraction Released x 100[a,b]	Cumulative Fraction Released x 100	Incremental Fraction Released x 100[a,b]	Cumulative Fraction Released x 100
1	0.000 ± 0.01	0.000 ± 0.01	0.298 (43.0)	0.298 ± 0.13	1.63 (18.0)	1.63 ± 0.29
2	0.000 ± 0.01	0.000 ± 0.02	1.25 (14.9)	1.54 ± 0.23	1.14 (15.2)	2.77 ± 0.34
3	0.773 ± (25.7)	0.773 ± 0.20	0.000 ± 0.01	1.54 ± 0.23	0.000 ± 0.01	2.77 ± 0.34
4	0.000 ± 0.01	0.773 ± 0.20	0.000 ± 0.01	1.54 ± 0.23	0.000 ± 0.01	2.77 ± 0.34
5	0.000 ± 0.01	0.773 ± 0.20	0.000 ± 0.01	1.54 ± 0.23	0.000 ± 0.01	2.77 ± 0.34
6	0.000 ± 0.01	0.773 ± 0.20	0.000 ± 0.01	1.54 ± 0.23	0.000 ± 0.01	2.77 ± 0.34
7	0.000 ± 0.01	0.773 ± 0.20	0.000 ± 0.01	1.54 ± 0.23	0.000 ± 0.01	2.77 ± 0.34
8	0.000 ± 0.01	0.773 ± 0.20	0.000 ± 0.01	1.54 ± 0.23	0.000 ± 0.01	2.77 ± 0.34
9	0.295 (41.4)	1.07 ± 0.24	0.132 (64.2)	1.68 ± 0.24	0.548 (30.1)	3.32 ± 0.38
10	0.285 (11.1)	1.35 ± 0.24	0.287 (11.2)	1.96 ± 0.25	0.422 (9.3)	3.74 ± 0.38
15	0.906 (6.2)	2.26 ± 0.24	0.628 (7.8)	2.59 ± 0.25	0.969 (6.1)	4.71 ± 0.39
20	0.895 (6.3)	3.15 ± 0.25	0.661 (7.5)	3.25 ± 0.26	0.696 (7.2)	5.41 ± 0.39
29	1.04 (5.8)	4.19 ± 0.26	0.849 (6.7)	4.10 ± 0.26	0.969 (6.1)	6.38 ± 0.40
43	1.67 (4.6)	5.86 ± 0.27	1.30 (5.4)	5.40 ± 0.27	1.28 (5.3)	7.65 ± 0.40
71	1.50 (4.9)	7.36 ± 0.28	1.63 (4.8)	7.03 ± 0.28	1.26 (5.4)	8.92 ± 0.41
100	1.07 (10.0)	8.43 ± 0.30	0.574 (14.2)	7.61 ± 0.29	0.991 (10.7)	9.91 ± 0.42
158	0.000 ± 0.01	8.43 ± 0.30	0.000 ± 0.01	7.61 ± 0.29	1.27 (12.9)	11.17 ± 0.45
229	0.000 ± 0.01	8.43 ± 0.30	0.000 ± 0.01	7.61 ± 0.30	0.000 ± 0.01	11.17 ± 0.45

	Composite #4		Composite #5	
Time Days	Incremental Fraction Released x 100[a,b]	Cumulative Fraction Released x 100	Incremental Fraction Released x 100[a,b]	Cumulative Fraction Released x 100
1	2.25 (15.5)	2.25 ± 0.34	0.000 ± 0.01	0.000 ± 0.01
2	0.704 (27.7)	2.96 ± 0.40	0.000 ± 0.01	0.000 ± 0.02
3	0.000 ± 0.01	2.96 ± 0.40	0.000 ± 0.01	0.000 ± 0.02
4	0.000 ± 0.01	2.96 ± 0.40	0.000 ± 0.01	0.000 ± 0.03
5	0.000 ± 0.01	2.96 ± 0.40	0.000 ± 0.01	0.000 ± 0.03
6	0.000 ± 0.01	2.96 ± 0.40	0.000 ± 0.01	0.000 ± 0.03
7	0.000 ± 0.01	2.96 ± 0.40	0.000 ± 0.01	0.000 ± 0.04
8	0.000 ± 0.01	2.96 ± 0.40	0.000 ± 0.01	0.000 ± 0.04
9	0.455 (34.5)	3.41 ± 0.43	0.309 (43.0)	0.309 ± 0.14
10	0.228 (12.4)	3.64 ± 0.43	0.286 (11.6)	0.595 ± 0.14
15	0.542 (8.2)	4.18 ± 0.43	0.732 (7.38)	1.33 ± 0.15
20	0.672 (7.3)	4.85 ± 0.44	0.526 (8.72)	1.85 ± 0.16
29	0.574 (8.0)	5.43 ± 0.44	0.618 (8.00)	2.47 ± 0.17
43	1.34 (5.2)	6.77 ± 0.45	1.60 (4.98)	4.07 ± 0.18
71	0.347 (10.3)	7.12 ± 0.45	0.457 (8.28)	4.53 ± 0.19
100	0.000 ± 0.01	7.12 ± 0.45	0.000 ± 0.01	4.53 ± 0.19
158	1.03 (14.3)	8.15 ± 0.47	0.000 ± 0.01	4.53 ± 0.19
229	0.000 ± 0.01	8.15 ± 0.47	0.000 ± 0.01	4.53 ± 0.20

[a]Number in ( ) = 1σ percent counting uncertainty.
[b]For incremental fraction releases equal to zero, the error is based on the minimum detectable limit.

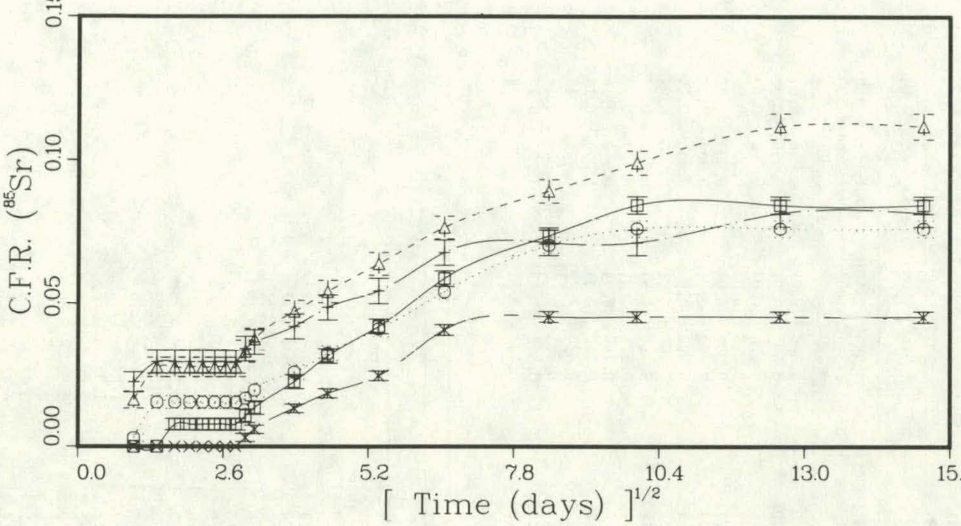

Figure 2.15 ^{85}Sr cumulative fractional release vs $(time)^{1/2}$ from 3% H_3BO_3 waste composites (w/c = 0.7; V/S = 0.94 cm).

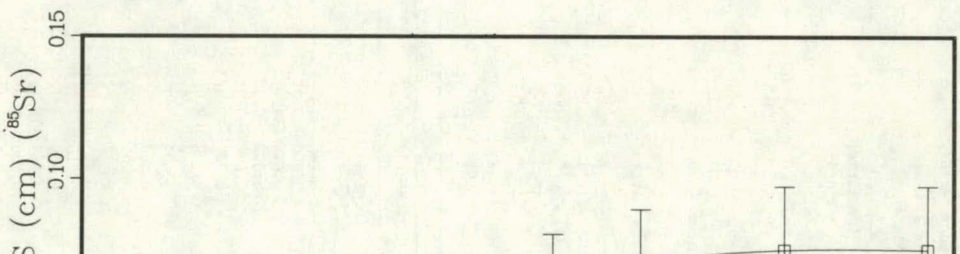

Figure 2.16 Average cumulative fractional release of ^{85}Sr vs $(time)^{1/2}$ from H_3BO_3 waste composites (w/c = 0.7; V/S = 0.94 cm).

Table 2.12

^{85}Sr Incremental and Cumulative Fractions Released From Boric Acid/Portland III Cement Composites (6% Boric Acid Solution and w/c Ratio of 0.5)

	Composite #1		Composite #2		Composite #3	
Time Days	Incremental Fraction Released x 100[a,b]	Cumulative Fraction Released x 100	Incremental Fraction Released x 100[a,b]	Cumulative Fraction Released x 100	Incremental Fraction Released x 100[a,b]	Cumulative Fraction Released x 100
1	0.000 ± 0.01	0.00 ± 0.01	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01
2	0.000 ± 0.01	0.00 ± 0.02	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.02
3	0.000 ± 0.01	0.00 ± 0.02	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.03	0.000 ± 0.03
4	0.000 ± 0.01	0.00 ± 0.03	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.03
5	0.000 ± 0.01	0.00 ± 0.03	0.572 (29.8)	0.572 ± 0.17	0.000 ± 0.01	0.000 ± 0.03
6	0.000 ± 0.01	0.00 ± 0.03	0.000 ± 0.01	0.572 ± 0.17	0.000 ± 0.01	0.000 ± 0.04
7	0.000 ± 0.01	0.00 ± 0.04	0.000 ± 0.01	0.572 ± 0.17	0.000 ± 0.01	0.000 ± 0.04
8	0.000 ± 0.01	0.00 ± 0.04	0.000 ± 0.01	0.572 ± 0.17	0.000 ± 0.01	0.000 ± 0.04
9	0.175 (54.1)	0.175 ± 0.10	0.174 (54.1)	0.746 ± 0.20	0.256 (46.5)	0.256 ± 0.13
10	0.227 (12.3)	0.402 ± 0.11	0.153 (14.7)	0.899 ± 0.20	0.223 (13.0)	0.479 ± 0.13
15	0.443 (8.86)	0.845 ± 0.11	0.603 (7.66)	1.50 ± 0.20	0.468 (8.84)	0.947 ± 0.14
20	0.319 (10.3)	1.16 ± 0.12	0.460 (8.69)	1.96 ± 0.21	0.346 (10.3)	1.29 ± 0.14
29	0.598 (7.62)	1.76 ± 0.13	0.510 (8.23)	2.47 ± 0.21	0.624 (7.71)	1.92 ± 0.15
43	0.783 (6.61)	2.56 ± 0.14	0.674 (7.15)	3.15 ± 0.22	0.713 (7.22)	2.63 ± 0.16
71	0.680 (7.15)	3.23 ± 0.14	0.797 (6.70)	3.94 ± 0.22	0.557 (8.23)	3.19 ± 0.16
100	0.758 (11.8)	3.98 ± 0.17	0.542 (14.1)	4.49 ± 0.24	0.497 (15.3)	3.69 ± 0.18
158	0.000 ± 0.01	3.98 ± 0.17	0.836 (15.7)	5.32 ± 0.27		
229	0.000 ± 0.01	3.98 ± 0.18	0.000 ± 0.04	5.32 ± 0.27		

	Composite #4		Composite #5	
Time Days	Incremental Fraction Released x 100[a,b]	Cumulative Fraction Released x 100	Incremental Fraction Released x 100[a,b]	Cumulative Fraction Released x 100
1	0.000 ± 0.01	0.000 ± 0.01	0.596 (29.2)	0.596 ± 0.17
2	0.543 (32.1)	0.543 ± 0.17	0.000 ± 0.01	0.596 ± 0.17
3	0.000 ± 0.02	0.543 ± 0.18	0.000 ± 0.01	0.596 ± 0.17
4	0.000 ± 0.01	0.543 ± 0.18	0.000 ± 0.01	0.596 ± 0.18
5	0.000 ± 0.01	0.543 ± 0.18	0.000 ± 0.01	0.596 ± 0.18
6	0.000 ± 0.01	0.543 ± 0.18	0.000 ± 0.01	0.596 ± 0.18
7	0.288 (43.8)	0.832 ± 0.22	0.000 ± 0.01	0.596 ± 0.18
8	0.000 ± 0.01	0.832 ± 0.22	0.000 ± 0.01	0.596 ± 0.18
9	0.000 ± 0.02	0.832 ± 0.22	0.000 ± 0.01	0.596 ± 0.18
10	0.155 (15.7)	0.987 ± 0.22	0.121 (16.7)	0.717 ± 0.18
15	0.510 (8.72)	1.50 ± 0.22	0.353 (9.74)	1.07 ± 0.18
20	0.455 (9.05)	1.95 ± 0.23	0.283 (11.1)	1.35 ± 0.18
29	0.710 (7.38)	2.66 ± 0.23	0.727 (6.84)	2.08 ± 0.19
43	0.876 (6.62)	3.54 ± 0.24	0.424 (8.84)	2.50 ± 0.20
71	0.865 (6.71)	4.40 ± 0.25	0.464 (8.51)	2.97 ± 0.20
100	0.000 ± 0.01	4.40 ± 0.25	0.447 (15.4)	3.42 ± 0.21
158	0.824 (16.4)	5.23 ± 0.28	1.00 (14.0)	4.42 ± 0.25
229	0.000 ± 0.04	5.23 ± 0.29	0.000 ± 0.04	4.42 ± 0.26

[a]Number in ( ) = 1σ percent counting uncertainty.
[b]For incremental fraction releases equal to zero, the error is based on the minimum detectable limit.

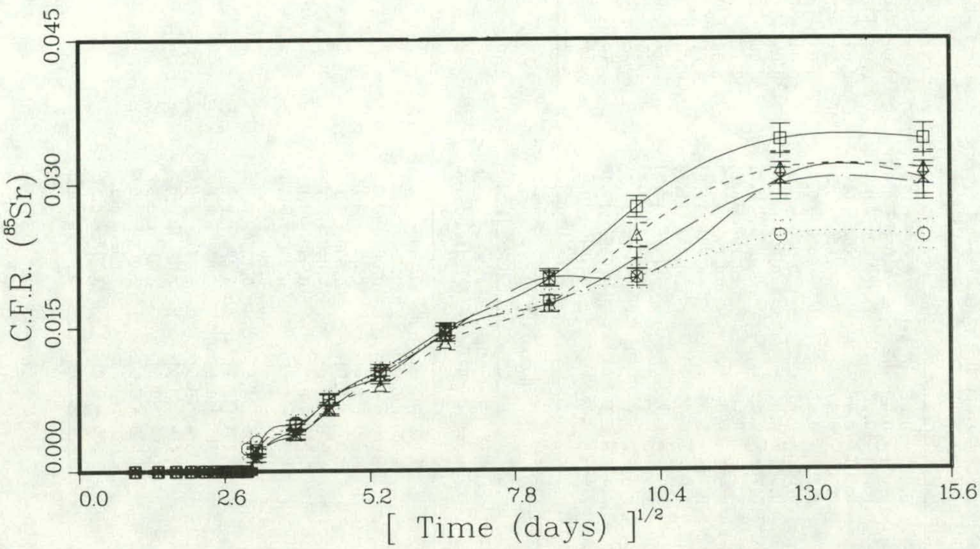

Figure 2.17 ^{85}Sr cumulative fractional release vs (time)$^{1/2}$ from 6% H_3BO_3 waste composites (w/c = 0.5; V/S = 0.94 cm).

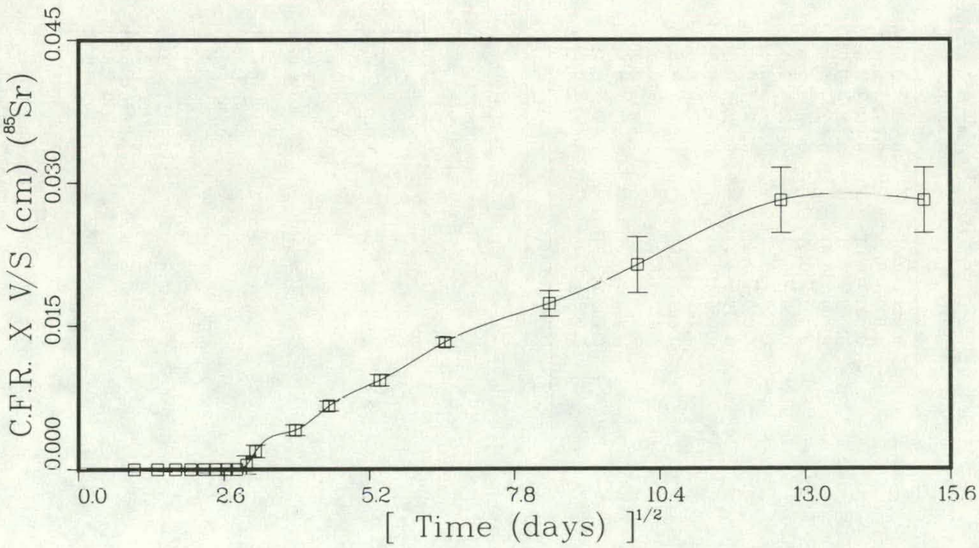

Figure 2.18 Average cumulative fractional release of ^{85}Sr vs (time)$^{1/2}$ from 6% H_3BO_3 waste composites (w/c = 0.5; V/S = 0.94 cm).

Table 2.13

^{85}Sr Incremental and Cumulative Fractions Released From
Boric Acid/Portland III Cement Composites (6% Boric Acid Solution and w/c Ratio of 0.7)

	Composite #1		Composite #2		Composite #3	
Time Days	Incremental Fraction Released x 100[a,b]	Cumulative Fraction Released x 100	Incremental Fraction Released x 100[a,b]	Cumulative Fraction Released x 100	Incremental Fraction Released x 100[a,b]	Cumulative Fraction Released x 100
1	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01
2	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.01
3	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.01
4	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.01
5	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.02
6	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.02
7	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03
8	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.04	0.000 ± 0.01	0.000 ± 0.03
9	0.000 ± 0.01	0.000 ± 0.03	0.232 (32.1)	0.232 ± 0.08	0.000 ± 0.01	0.000 ± 0.04
10	0.219 (11.1)	0.219 ± 0.04	0.077 (20.0)	0.309 ± 0.08	0.192 (13.2)	0.192 ± 0.04
15	0.266 (10.0)	0.485 ± 0.05	0.193 (13.0)	0.503 ± 0.09	0.192 (13.2)	0.383 ± 0.05
20	0.258 (10.3)	0.743 ± 0.05	0.242 (11.6)	0.745 ± 0.09	0.272 (11.5)	0.655 ± 0.06
29	0.305 (9.5)	1.05 ± 0.06	0.290 (10.7)	1.04 ± 0.10	0.232 (12.2)	0.887 ± 0.07
43	0.422 (8.0)	1.47 ± 0.07	0.387 (9.3)	1.42 ± 0.10	0.444 (8.9)	1.33 ± 0.08
71	0.524 (7.2)	1.99 ± 0.08	0.348 (9.7)	1.77 ± 0.11	0.403 (9.3)	1.73 ± 0.09
100	0.748 (10.6)	2.74 ± 0.11	0.238 (20.7)	2.01 ± 0.12	0.714 (12.3)	2.45 ± 0.12
158	0.702 (14.9)	3.45 ± 0.15	0.429 (21.0)	2.44 ± 0.15	0.692 (17.1)	3.14 ± 0.17
229	0.000 ± 0.01	3.45 ± 0.16	0.000 ± 0.05	2.44 ± 0.15	0.000 ± 0.01	3.14 ± 0.17

	Composite #4		Composite #5	
Time Days	Incremental Fraction Released x 100[a,b]	Cumulative Fraction Released x 100	Incremental Fraction Released x 100[a,b]	Cumulative Fraction Released x 100
1	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01
2	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01
3	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01
4	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.01
5	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.02
6	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.02
7	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03
8	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03
9	0.000 ± 0.01	0.000 ± 0.04	0.000 ± 0.01	0.000 ± 0.04
10	0.141 (15.7)	0.141 ± 0.05	0.136 (14.6)	0.136 ± 0.04
15	0.292 (10.7)	0.433 ± 0.05	0.234 (12.1)	0.370 ± 0.05
20	0.312 (10.3)	0.745 ± 0.06	0.263 (11.5)	0.633 ± 0.06
29	0.232 (12.2)	0.977 ± 0.07	0.370 (9.5)	1.00 ± 0.07
43	0.453 (8.7)	1.43 ± 0.08	0.419 (8.9)	1.42 ± 0.09
71	0.302 (10.7)	1.73 ± 0.09	0.584 (7.5)	2.01 ± 0.09
100	0.471 (15.0)	2.20 ± 0.11	0.000 + 0.08	2.01 ± 0.09
158	0.770 (16.0)	2.97 ± 0.17	1.03 (13.8)	3.03 ± 0.17
229	0.000 ± 0.01	2.97 ± 0.17	0.000 ± 0.01	3.03 ± 0.17

[a] Number in ( ) = 1σ percent counting uncertainty.
[b] For incremental fraction releases equal to zero, the error is based on the minimum detectable limit.

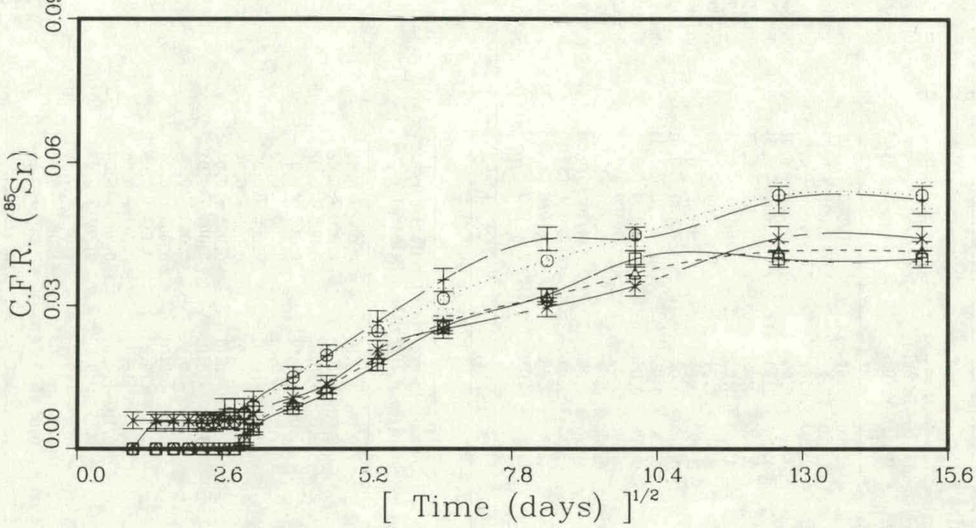

Figure 2.19 ^{85}Sr cumulative fractional release vs $(time)^{1/2}$ from 6% H_3BO_3 waste composites (w/c = 0.7; V/S = 0.94 cm).

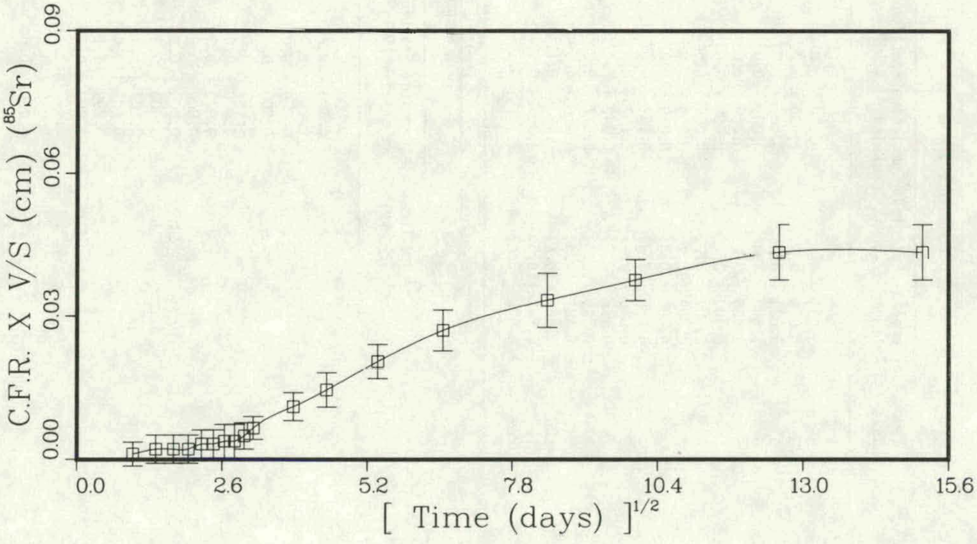

Figure 2.20 Average cumulative fractional release of ^{85}Sr vs $(time)^{1/2}$ from 6% H_3BO_3 waste composites (w/c = 0.7; V/S = 0.94 cm).

Table 2.14

^{85}Sr Incremental and Cumulative Fractions Released From
Boric Acid/Portland III Cement Composites (12% Boric Acid Solution and w/c Ratio of 0.5)

Time Days	Composite #1 Incremental Fraction Released x 100[a,b]	Composite #1 Cumulative Fraction Released x 100	Composite #2 Incremental Fraction Released x 100[a,b]	Composite #2 Cumulative Fraction Released x 100	Composite #3 Incremental Fraction Released x 100[a,b]	Composite #3 Cumulative Fraction Released x 100
1	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01
2	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.02
3	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.02
4	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03
5	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03
6	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03
7	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03
8	0.000 ± 0.01	0.000 ± 0.04	0.000 ± 0.01	0.000 ± 0.04	0.000 ± 0.01	0.000 ± 0.04
9	0.059 (91.7)	0.059 ± 0.06	0.000 ± 0.01	0.000 ± 0.04	0.000 ± 0.01	0.000 ± 0.04
10	0.000 ± 0.01	0.059 ± 0.07	0.062 (23.3)	0.062 ± 0.04	0.000 ± 0.01	0.000 ± 0.04
15	0.098 (18.0)	0.157 ± 0.07	0.156 (14.7)	0.218 ± 0.05	0.110 (17.3)	0.110 ± 0.05
20	0.000 ± 0.01	0.157 ± 0.07	0.208 (13.0)	0.425 ± 0.05	0.100 (18.0)	0.210 ± 0.05
29	0.186 (13.2)	0.342 ± 0.07	0.166 (14.4)	0.591 ± 0.06	0.320 (10.3)	0.530 ± 0.06
43	0.235 (11.7)	0.577 ± 0.08	0.301 (11.1)	0.892 ± 0.07	0.240 (11.7)	0.770 ± 0.07
71	0.381 (9.3)	0.958 ± 0.09	0.343 (10.3)	1.24 ± 0.08	0.390 (9.3)	0.116 ± 0.09
100	0.488 (14.4)	1.45 ± 0.11	0.000 ± 0.01	1.24 ± 0.08	0.184 (23.9)	1.34 ± 0.09
158	0.863 (14.9)	2.31 ± 0.17	0.000 ± 0.01	1.24 ± 0.08	0.438 (21.0)	1.78 ± 0.13
229	0.000 ± 0.03	2.31 ± 0.17	0.000 ± 0.01	1.24 ± 0.09	0.000 ± 0.04	1.78 ± 0.13

Time Days	Composite #4 Incremental Fraction Released x 100[a,b]	Composite #4 Cumulative Fraction Released x 100	Composite #5 Incremental Fraction Released x 100[a,b]	Composite #5 Cumulative Fraction Released x 100
1	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01
2	0.608 (29.2)	0.608 ± 0.18	0.000 ± 0.01	0.000 ± 0.02
3	0.000 ± 0.01	0.608 ± 0.18	0.000 ± 0.01	0.000 ± 0.02
4	0.000 ± 0.01	0.608 ± 0.18	0.000 ± 0.01	0.000 ± 0.03
5	0.000 ± 0.01	0.608 ± 0.18	0.000 ± 0.01	0.000 ± 0.03
6	0.000 ± 0.01	0.608 ± 0.18	0.000 ± 0.01	0.000 ± 0.03
7	0.000 ± 0.01	0.608 ± 0.18	0.000 ± 0.01	0.000 ± 0.04
8	0.000 ± 0.01	0.608 ± 0.18	0.000 ± 0.01	0.000 ± 0.04
9	0.000 ± 0.01	0.608 ± 0.18	0.000 ± 0.01	0.000 ± 0.04
10	0.000 ± 0.01	0.608 ± 0.18	0.000 ± 0.01	0.000 ± 0.04
15	0.000 ± 0.01	0.608 ± 0.18	0.000 ± 0.01	0.000 ± 0.04
20	0.124 (16.7)	0.731 ± 0.18	0.134 (16.2)	0.134 ± 0.05
29	0.206 (13.0)	0.937 ± 0.18	0.144 (15.7)	0.277 ± 0.05
43	0.299 (11.1)	1.24 ± 0.19	0.103 (18.0)	0.380 ± 0.06
71	0.000 ± 0.01	1.24 ± 0.19	0.421 (9.1)	0.802 ± 0.07
100	0.440 (15.7)	1.68 ± 0.20	0.292 (19.0)	1.09 ± 0.09
158	0.985 (14.5)	2.66 ± 0.25	0.000 ± 0.01	1.09 ± 0.09
229	0.000 ± 0.04	2.66 ± 0.25	0.000 ± 0.04	1.09 ± 0.10

[a]Number in ( ) = 1σ percent counting uncertainty.
[b]For incremental fraction releases equal to zero, the error is based on the minimum detectable limit.

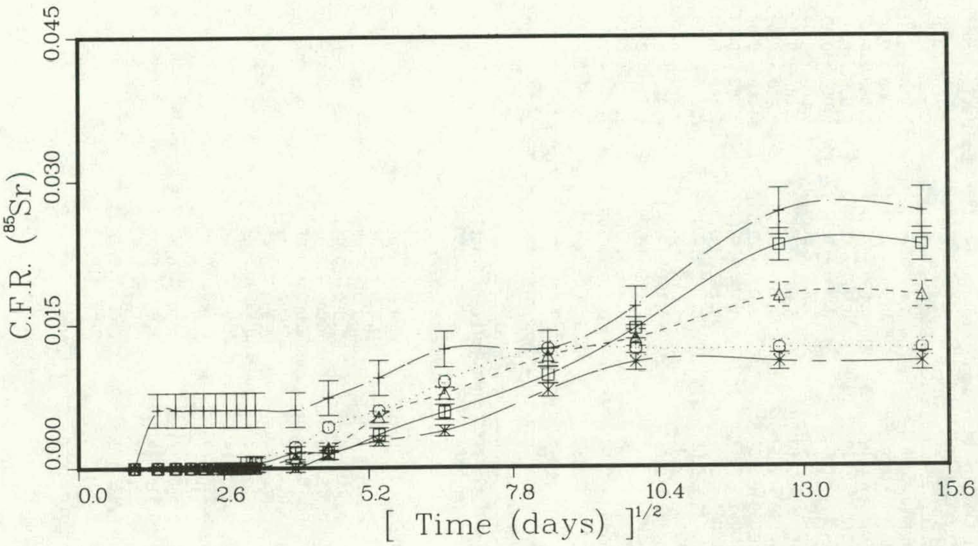

Figure 2.21 ^{85}Sr cumulative fractional release vs $(time)^{1/2}$ from 12% H_3BO_3 waste composites (w/c = 0.5; V/S = 0.94 cm).

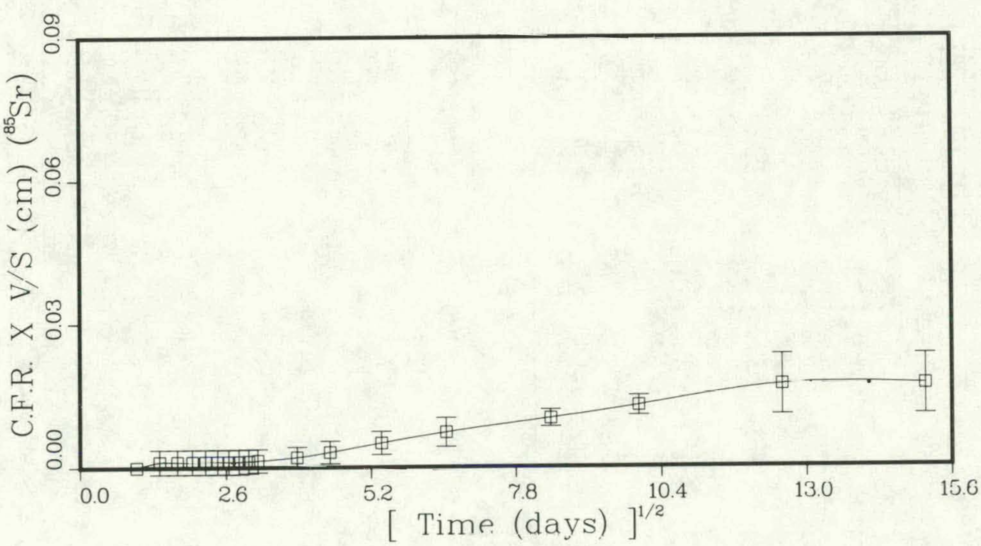

Figure 2.22 Average cumulative fractional release of ^{85}Sr vs $(time)^{1/2}$ from 12% H_3BO_3 waste composites (w/c = 0.5; V/S = 0.94 cm).

Table 2.15

^{85}Sr Incremental and Cumulative Fractions Released From
Boric Acid/Portland III Cement Composites (12% Boric Acid Solution and w/c Ratio of 0.7)

Time Days	Composite #1 Incremental Fraction Released x 100[a,b]	Composite #1 Cumulative Fraction Released x 100	Composite #2 Incremental Fraction Released x 100[a,b]	Composite #2 Cumulative Fraction Released x 100	Composite #3 Incremental Fraction Released x 100[a,b]	Composite #3 Cumulative Fraction Released x 100
1	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01
2	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.02
3	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.02
4	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.02
5	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03
6	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03
7	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03
8	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03
9	0.000 ± 0.01	0.000 ± 0.04	0.000 ± 0.01	0.000 ± 0.04	0.000 ± 0.01	0.000 ± 0.04
10	0.134 (16.2)	0.134 ± 0.04	0.064 (21.4)	0.064 ± 0.04	0.000 ± 0.01	0.000 ± 0.04
15	0.124 (16.7)	0.258 ± 0.05	0.000 ± 0.01	0.064 ± 0.04	0.142 (15.7)	0.142 ± 0.04
20	0.289 (11.1)	0.546 ± 0.06	0.164 (13.3)	0.227 ± 0.05	0.162 (14.4)	0.304 ± 0.05
29	0.206 (13.0)	0.752 ± 0.06	0.227 (11.6)	0.455 ± 0.05	0.253 (11.6)	0.556 ± 0.06
43	0.299 (11.1)	1.05 ± 0.07	0.218 (11.7)	0.673 ± 0.06	0.364 (9.74)	0.921 ± 0.07
71	0.412 (9.27)	1.46 ± 0.08	0.391 (8.86)	1.06 ± 0.07	0.455 (8.69)	1.38 ± 0.08
100	0.000 ± 0.01	1.46 ± 0.08	0.213 (20.9)	1.28 ± 0.08	0.435 (15.8)	1.81 ± 0.10
158	0.891 (15.9)	2.28 ± 0.15	0.000 ± 0.01	1.28 ± 0.08	0.000 ± 0.01	1.81 ± 0.11
229	0.000 ± 0.01	2.28 ± 0.16	0.000 ± 0.04	1.28 ± 0.09	0.000 ± 0.04	1.81 ± 0.11

Time Days	Composite #4 Incremental Fraction Released x 100	Composite #4 Cumulative Fraction Released x 100	Composite #5 Incremental Fraction Released x 100	Composite #5 Cumulative Fraction Released x 100
1	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01	0.000 ± 0.01
2	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.01
3	0.000 ± 0.01	0.000 ± 0.02	0.000 ± 0.01	0.000 ± 0.02
4	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.02
5	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.02
6	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.02
7	0.000 ± 0.01	0.000 ± 0.03	0.000 ± 0.01	0.000 ± 0.03
8	0.000 ± 0.01	0.000 ± 0.04	0.000 ± 0.01	0.000 ± 0.03
9	0.000 ± 0.01	0.000 ± 0.04	0.000 ± 0.01	0.000 ± 0.03
10	0.000 ± 0.01	0.000 ± 0.04	0.132 (14.4)	0.132 ± 0.04
15	0.136 (15.7)	0.136 ± 0.05	0.140 (14.1)	0.272 ± 0.04
20	0.300 (10.3)	0.436 ± 0.05	0.296 (9.74)	0.568 ± 0.05
29	0.291 (10.7)	0.726 ± 0.06	0.370 (8.69)	0.938 ± 0.06
43	0.262 (11.1)	0.988 ± 0.07	0.362 (8.88)	1.30 ± 0.07
71	0.087 (18.9)	1.08 ± 0.07	0.519 (5.75)	1.82 ± 0.07
100	0.000 ± 0.01	1.08 ± 0.07	0.291 (17.2)	2.11 ± 0.09
158	1.17 (12.7)	2.25 ± 0.17	0.522 (17.7)	2.63 ± 0.13
229	0.000 ± 0.04	2.25 ± 0.17	0.000 ± 0.03	2.63 ± 0.13

[a]Number in ( ) = 1σ percent counting uncertainty.
[b]For incremental fraction releases equal to zero, the error is based on the minimum detectable limit.

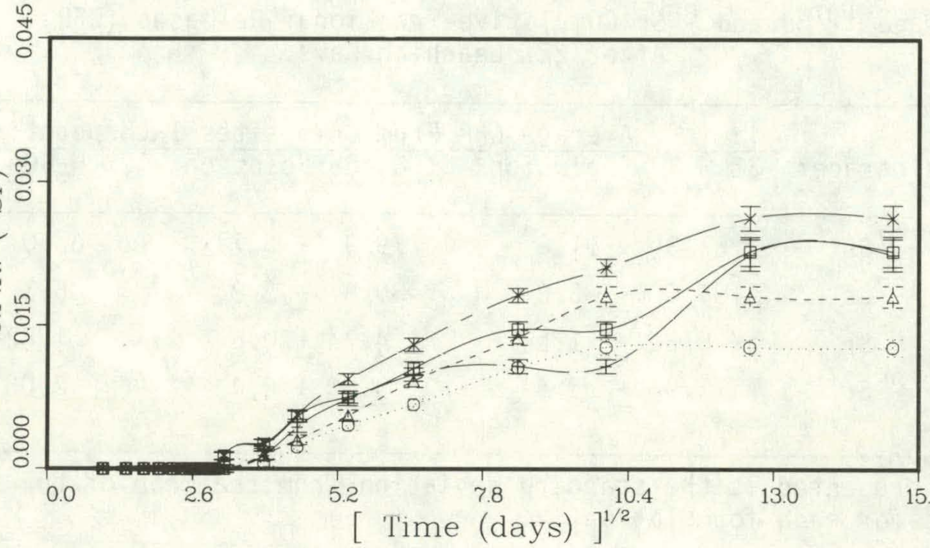

Figure 2.23 ^{85}Sr cumulative fractional release vs $(time)^{1/2}$ from 12% H_3BO_3 waste composites (w/c = 0.7; V/S = 0.94 cm).

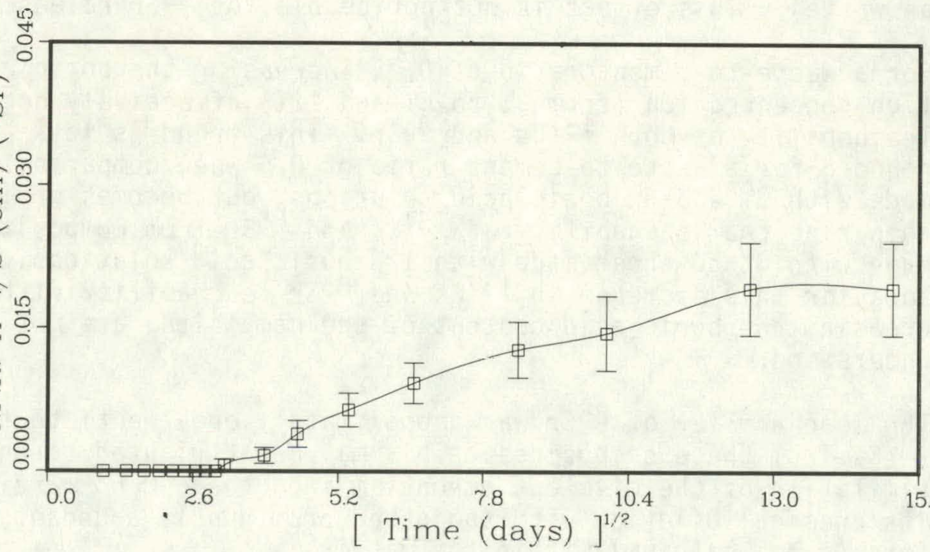

Figure 2.24 Average cumulative fractional release of ^{85}Sr vs $(time)^{1/2}$ from 12% H_3BO_3 waste composites (w/c = 0.7; V/S = 0.94 cm).

The average cumulative fractional releases of each five replicates for a given formulation are summarized in Table 2.16.

Table 2.16

Average ^{137}Cs and ^{85}Sr Cumulative Fractional Releases (CFR) After 227 Leaching Days.

Waste/ Cement	Radiotracer	Average CFR From Composites Incorporating: 3% H_3BO_3 Solution	6% H_3BO_3 Solution	12% H_3BO_3 Solution
0.5	^{137}Cs	83.3 $\pm$ 11.8[a]	79.9 $\pm$ 5.7[a]	63.0 $\pm$ 3.2[a]
0.7	^{137}Cs	105.6 $\pm$ 3.8	89.8 $\pm$ 3.8	86.1 $\pm$ 4.0
0.5	^{85}Sr	5.20 $\pm$ 1.2	4.74 $\pm$ 0.6	1.82 $\pm$ 0.7
0.7	^{85}Sr	7.98 $\pm$ 2.4	3.00 $\pm$ 0.4	2.05 $\pm$ 0.5

[a]The error presented is the standard deviation from the mean of the five replicates for each formulation.

The following observations and conclusions are noted:

- Increasing the waste-to-cement ratio from 0.5 to 0.7 resulted in an increase in the leachability of ^{137}Cs from the three boric acid/ cement composite formulations (3%, 6% and 12% boric acid solutions as waste). This effect is not noticeable for ^{85}Sr release.

- For a waste-to-cement ratio of 0.7, increasing the boric acid solution concentration (from 3% to 6% and 12%) effectively decreased the leachability of both ^{137}Cs and ^{85}Sr. This trend is less pronounced for a waste-to-cement ratio of 0.5 when comparing composites made with 3% and 6% boric acid solutions, but becomes prominent when comparing the leachability of ^{137}Cs and ^{85}Sr from composites made with 3% to those made with 12% boric acid solutions. The reasons for this decrease in ^{137}Cs and ^{85}Sr leachability with increasing the boric acid content of the composites are not presently understood.

- The leachability of ^{85}Sr was approximately one-twentieth that of ^{137}Cs from these composites. This may be attributed to the assimilation of the divalent strontium into the cement matrix and to its chemical dilution with the other prominently abundant divalent ions (e.g., calcium) within the matrix.

- ^{60}Co in the leachates from all samples was below the detection limit (3.0×10^{-2} μCi per 1.5 L sample) of the experimental method.

2.3.2 Compressive Strength Data

The compressive strength of some composites was measured immediately after curing. These samples included control samples (composed of Portland III cement and water), and samples of identical composition to those which were leached. All the composites, which were leached (for a duration of 352 days), were also evaluated for their compressive strength.

The compressive strength data from these measurements are summarized in Table 2.17. All reported values are an average of five replicates.

Table 2.17

Average Compressive Strength of H_3BO_3/Portland III Cement Composites Before and After 352 days Leaching.

	Compressive Strength (Psi)			
	Initially	After Leaching 352 (days)	Initially	After Leaching 352 (days)
Formulation	w/c = 0.5		w/c = 0.7	
Control[a]	3400 ± 2%	---	1400 ± 26%	---
3% Boric Acid	2600 ± 16%	1900 ± 16%	1100 ± 23%	1000 ± 12%
6% Boric Acid	2401 ± 35%	1200 ± 9%	1700 ± 18%	1400 ± 12%
12% Boric Acid	3300 ± 9%	1600 ± 14%	1907 ± 12%	1300 ± 17%

[a]Samples consisted of water and Portland III cement only.

The data indicate that, for a waste-to-cement ratio of 0.5, leaching for 352 days caused a substantial decrease (approx. 50%) in the compressive strength of the composites. The data derived from the composites with a waste-to-cement ratio of 0.7 indicate that, although their initial compressive strength is lower than those with a w/c ratio of 0.5 (by approx. 40 to 50%), their compressive strength did not further decrease after 352 days of leaching. It should be noted that the compressive strength of these composites is still approximately 20 to 38 times higher than the lower limit (50 psi) set forth in the proposed Code of Federal Regulations, 10CFR Part 61.56.

2.3.3 Leachate pH Data

The leachate average pH from each formulation (3%, 6% and 12% boric acid solutions), at each waste-to-cement ratio (0.5 and 0.7), are shown in Figure 2.25. The leachate pH values varied between 7 and 12, and were consistently lower for those from composites incorporating 3% boric acid solutions than those from the composites incorporating 6% and 12% boric acid solutions.

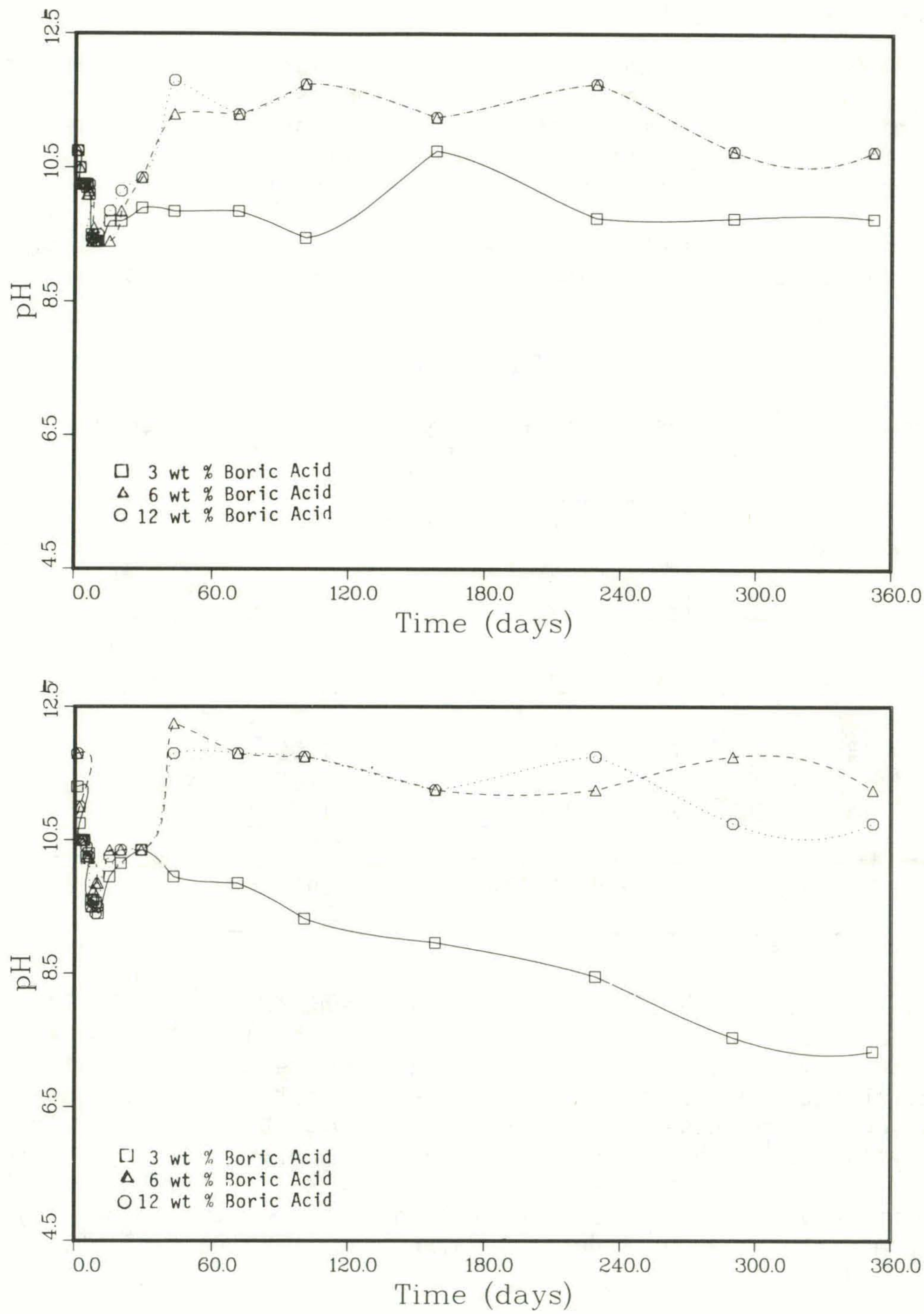

Figure 2.25 Average leachate pH values for 3%, 6%, and 12% H_3BO_3 waste composites at waste-to-cement ratios of 0.5 and 0.7. Upper figure is for w/c ratio of 0.5, and lower figure is for w/c ratio of 0.7.

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V. Stagliola
R. Steen
J. Steger
J. Stouky
D. Strawson
E. Tarnuzzer
H. Thrash
G. Tidrick
D. Villacres
M. Wacks
R. Wild
R. Williams

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S. Bieber
R. Bonniaud
J. Buckley
O. Heinonen
K. Johnson
H. Krause
V. Morozov
S. Pettersson
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J. Schofield
C. Smitton

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