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Direct Grout Stabilization of High Cesium Salt Waste: Cesium Leaching Studies

by

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SUMMARY

The direct grout alternative is a viable option for treatment/stabilization and disposal of salt waste containing Cs-137 concentrations of 1-3 Ci/gal.

The significant difference between these waste solutions is that the high cesium salt solution will contain between 1 and 3 Curies of Cs-137 per gallon compared to a negligible amount in the current salt solution. This difference will require special engineering and shielding for a direct grout processing facility and disposal units to achieve acceptable radiation exposure conditions. The higher cesium concentrations in the direct grout also require that the cesium leaching be evaluated as a function of curing temperature. ANS 16.1 leaching results and distribution ratios (approximations of distribution coefficients) as a function of temperature are presented in this report.

About 77 wt.% of the cesium in the 6.4 M sodium salt waste is stabilized in the direct grout formulation after 90 days of leaching in deionized water per the ANS16.1 test. This is consistent with the amount of cesium retained in powdered direct grout (-200 mesh) leached in the 18 hour TCLP test.[1] The average effective diffusion coefficient for cesium in the direct grout was determined to be about 2E-09 cm/sec^2. This is more than an order of magnitude (30 X) less than the average value measured for nitrate which was about 6E-08 cm/sec^2.

The cesium distribution coefficients, K_d's, for direct grout as a function of curing temperature were approximated as the distribution ratios, R_d's. The last (longest) three leach intervals were used as the closest approach to equilibrium conditions. The averaged R_d's for cesium in direct grout ranged from 228 to 255 ml/g over the temperature range 24 to 90°C. Based on these results, a conservative cesium K_d of 200 ml/g is proposed for both Saltstone and direct grout cured between 24 and 90°C. This value is two orders of magnitude higher than the value of 2 ml/g used in the Saltstone Performance Assessment. This K_d value for cesium applies to Class A, B, or C Saltstone (direct grout) since it is independent of the amount of cesium in the waste up to concentrations of at least 3.3x 10^{-3} molar cesium.

The stabilization mechanism has not been determined. However, the cesium is most likely incorporated (chemically bonded) in the matrix phases of the waste form. The cesium ion probably substitutes for another alkali ion such as potassium or sodium in the crystal structure or non-crystalline structure of the alumino silicate and silicate matrix phases.

The composition of the direct grout salt solution is higher in sodium salts and contains approximately 10^4 times more of each of the cesium isotopes than the current reference salt solution. However it is still similar to the composition of the current reference salt solution. Consequently, the processing, setting, and leaching properties (including TCLP for Cr and Hg) of the direct grout and current saltstone waste forms are very similar.[1]

RECOMMENDATIONS

Data generated in this study justify the use of the following values for modeling the transport of cesium in the direct grout waste form:

Cesium	D_{eff}	2E-09 cm^2/sec
	$R_d \cong K_d$	200 ml/g

Data generated in this study also support the following values for modeling the transport of nitrate in the direct grout waste form:

Nitrate	D_{eff}	3E-08 cm^2/sec for curing temperatures between 24 and 70°C
	6E-08 cm^2/sec for curing temperatures between 70 and 90°C.	

If Direct Grout is selected as the salt alternative, modify the direct grout formulation to specifically include cesium stabilization so that more of the cesium is retained in the matrix as the result of precipitation and/or adsorption. (A program plan has been written for the formulation modification studies.)

BACKGROUND

Direct disposal of the cesium in grout is one of the alternatives identified in WSRC-RP-98-00166.[2] and WSRC-RP-98-00168 Rev.1[3]. In this proposed process, Cs-137 is not separated from the concentrated salt waste. It is instead sent to a new, shielded Saltstone Facility. The resulting waste form would be classified as Class C low-level waste if disposal were to be regulated by the NRC. A new grout production facility is needed for this option. The new facility requires remote maintenance capabilities and a shielded cell for the grout production equipment. A new disposal facility may also needed for the direct grout option.

A Feasibility Study was conducted to evaluate the direct grout option. Processing and properties of the cured grout were determined as a function of curing time.[1] Cesium leaching data for the direct grout were not included in the feasibility study. However, cesium leaching as a function of curing temperature is presented in this report.

The technical task and quality assurance plans for this effort are presented elsewhere.[4,5]

Comparison of Reference Z-Area Salt Solution and High-Cesium Salt Solution
The average composition of the direct grout salt solution is listed in Table 1 and compared to the current reference salt solution composition. The average cesium concentration in the direct grout waste stream is estimated to be 1.65E-4M (1.5 Ci/gal).[6] This waste and the resulting direct grout waste form which has about 40 % less curies per unit volume (about 250 Ci/cubic meter of saltstone) due to dilution with the cementing reagents fall within the NRC Class C waste category. The range of cesium concentration for Class C low-level waste is 44 to 4600 curies of cubic meter.[7] Consequently, the estimated cesium concentration of the direct grout of 1.5 Ci/gal (255 Ci/m3) is at the lower end of the Class C range.

Table 1. Compositions of the Reference Salt Solution and the Direct Grout High-Cesium Salt Solution.[6,8]

Component	Reference Salt Solution (Molar)	Direct Grout High Cesium Salt Solution (Molar)
NO_3^-	2.04	2.49
NO_2^-	0.62	0.581
OH^-	1.17	2.181
CO_3^{-2}	0.15	0.181
AlO^{-2}	0.41	0.355
SO_4^{-2}	0.15	0.169
F^-	0.0015	0.0361
Cl^-	0.023	0.0282
$C_2O_4^{-2}$	0.025	0.0136
PO_4^{-2}	0.01	0.009
Na+	4.94	6.44
K^+	-	0.0168
Cs^+	20 n Ci/g	0.000165
Hg	0.012 mg/L	33 mg/L
Cr	161 mg/L	161 mg/L

EXPERIMENTAL METHOD

Preparation of the Reference Salt Solution and Direct Grout High-Cesium Salt Solution
Simulated salt solutions were made according to the following recipes. Cesium, mercury and chromium were spiked in amounts greater than the concentrations listed in Table 1 in order to determine differences between leaching performance in the various leaching tests. In addition, the detection level for non radioactive cesium measured by ICPMS was 0.0750 mg/L. The higher cesium loadings were necessary assuming a diffusion coefficient of 10 E-08 cm^2/sec over the 90 day leach period.

Table 2. Ingredients in the Reference Salt Solution and the Direct Grout High-Cesium Salt Solution.

Ingredient	Reference Salt Solution (g/L)	Direct Grout High Cesium Salt Solution (g/L)
$NaNO_3$	173.4	211.6
$NaNO_2$	43.1	40.09
NaOH	46.7	87.24
$Na_2CO_3H_2O$	18.5	22.44
$NaAlO_2H_2O$	40.6	34.48
Na_2SO_4	20.9	24.00
NaF	0.62	1.52
NaCl	1.35	1.65
$Na_2C_2O_4$	3.44	1.82
Na_3PO_4	2.9	-
$Na_2PO_412H_20$	-	3.42
KNO_3	-	1.69
$CsNO_3$	-	0.643*
$HgCl_2$	0.338**	0.338**
Na_2CrO_4	0.623 ***	0.623***

* Cs spiked at 0.0033 M Cs using $CsNO_3$. This is 20 times more than the concentration projected for the direct grout case.
** Hg spiked at 250 ppm as $HgCl_2$ in direct grout solution prepared for this feasibility study.
*** Cr spiked at 1830 mg/L as Na2CrO4.

Preparation of Reference Saltstone and High-Cesium Direct Grout

The ingredients and proportions in the reference saltstone are shown below:

Cement Type I/II	4	wt %
Fly ash Class F	25	wt %
Slag Grade 120	25	wt %
Salt solution (containing 71 wt % water)	46	wt %

The water to total cementitious solids weight ratio of this mixture is 0.6048.

The ingredients and proportions used in the direct grout saltstone containing the high cesium loading are shown below. The water to the total cementitious solids ratio is 0.6092 and is similar to that of the reference saltstone.

Cement Type I	4	wt %
Fly ash Class F	24	wt %
Slag Grade 120	24	wt %
Salt solution	48	wt %
(containing 66 wt. % water)		

The water to total cementitious solids weight ratio of this mixture is 0.6092.

The dry cementitious reagents were premixed to simulate the Z-Area process, then added to the salt solution. Mixing was done in a Waring blender for one minute at low speed. Samples were immediately cast into the appropriate containers for the various tests.

Waste Form Curing

The curing was conducted at ambient temperature (24°), 45°, 70° and 90° C +/-5° C in sealed containers. This curing range is representative of the range of initial and long-term curing temperatures which could be encountered under actual field conditions.

The relative humidity was maintained at 100 % except for the samples cured at 90^0C. At this temperature, the seals were not adequately maintained and excessive drying of the samples was observed. This was very apparent from the physical appearance of the samples and from the cracking pattern after curing.[1]

Samples were prepared on August 4 to 6, 1998. They were removed from the curing chambers 28 days later and tested for strength and TCLP leaching. The microstructure and mineralogy of the direct grout waste forms were previously characterized.[1] The samples were stored in sealed plastic bags at room temperature (22-25^0C) to minimize dehydration, from the time the samples were removed from the controlled temperature curing chambers and the time they were prepared for the ANS 16.1 leaching experiments. Samples were labeled with the formulation and curing temperature. For example, DGRT refers to direct grout cured at room temperature. DG45 represents a direct grout sample cured at 45^0C, and Ref70 represents a reference saltstone sample cured at 70^0C.

ANS 16.1 Leaching

The American Nuclear Society ANS 16.1 leaching test[9] was used to obtain effective diffusion coefficients and fractions leached as a function of leaching time. Preparation of the leach specimens involved cutting the material into discs or wafers, which fit into the SRTC leach vessels. The vessels provide a leachate volume to sample surface area ratio of 10 +/- 0.2(cm). Deionized water was used as the leachate. The samples were prepared for leaching between February 10 to 12, 1999. Leaching began on February 16, 1999 and continued for 90 days. The leach sequential intervals were 30 seconds, 2, 7, 24, 48, 72, 96, 120, 456, 1128, and 2160 hours. The leachate was changed after each leach interval and the leachates analyzed for cesium and nitrate. Duplicate samples were leached for each curing time.

RESULTS AND DISCUSSION

Cesium and nitrate leaching results for the direct grout samples are presented in Appendices A and B, respectively. Results for the reference saltstone formulation are presented in Appendices C and D. The information required to calculate the effective diffusion coefficients and the cumulative fractions leached for each sample are given in Appendices E to H. Data for only one sample is given in Appendix G, since the detection limit for cesium was too high to obtain useful information from the reference saltstone sample, which was not spiked with extra cesium.

For the purpose of calculating the cumulative fractions leached, detection limit values were used for leachate concentrations which were reported as less than the detection limit. Consequently, the cumulative fractions leached and the effective diffusion coefficients are conservative values. Results of the leaching data are summarized in Table 3.

Calculation of Effective Diffusion Coefficients

The diffusion coefficients were calculated according to equation (1):

(1) $$D = \pi \left[\frac{a_n / A_0}{(\Delta t)_n} \right]^2 \left[\frac{V}{S} \right]^2 T$$

where

D = effective diffusivity (effective diffusion coefficient), cm^2/s
V = volume of specimen, cm^3
S = geometric surface area of the specimen as calculated from measured dimensions, cm^2
$T = \left[\frac{1}{2}(t_n^{1/2} + t_{n-1}^{1/2}) \right]^2$
leaching time representing the "mean time" of the leaching interval, s
a_n = amount of the species released from the specimen during the leaching interval n, (g)
A_0 = total amount of a given species in the specimen at the beginning of the first leaching interval (g).

If more than 20 % of the leachable species was removed by any time, t, the effective diffusivity can only be calculated from a shape specific solution of the mass transport equation. The ANS 16.1 procedure provides a table of dimensionless correction factors, G, as a function of the fraction leached and length to diameter ratio for the unique sample geometry. These values are listed in Appendices E to H and were used to calculate the effective diffusion coefficients when more than 20 percent of the chemical species was leached.

Table 3. Summary of Leaching Results Including Effective Cesium and Nitrate Diffusion Coefficients and Cumulative Fractions Leached for Direct Grout and Reference Saltstone Cured at Room Temperature (24°C), 45,70, and 90°C.

	Average of 10 leach intervals				Cumulative Fraction Leached After 10 Leach Intervals			
Sample ID	D_{eff} Cesium (cm²/sec)		D_{eff} Nitrate (cm²/sec)		Cesium		Nitrate	
		Average		Average		Average		Average
DGRT 1	3.91E-09	3.78E-09	3.96E-08	3.775E-08	2.42E-01	2.32E-01	7.50E-01	6.88E-01
DGRT 2	3.65E-09		3.59E-08		2.22E-01		6.25E-01	
DG45 1	3.49E-09	3.065E-09	3.12E-08	3.065E-08	2.27E-01	2.20E-01	5.84E-01	5.50E-01
DG45 2	2.64E-09		3.01E-08		2.12E-01		5.16E-01	
DG70 1	2.68E-09	2.445E-09	3.11E-08	2.555E-08	2.19E-01	2.07E-01	6.73E-01	6.17E-01
DG70 2	2.21E-09		2.00E-08		1.95E-01		5.61E-01	
DG90 1	3.49E-09	3.14E-09	4.42E-08	6.625E-08	2.27E-01	2.26E-01	7.41E-01	8.55E-01
DG90 2	2.79E-09		8.83E-08		2.25E-01		9.68E-01	
Ref RT 1	NA	NA	2.37E-08	2.785E-08	NA	NA	6.11E-01	6.68E-01
Ref RT 2	NA		3.2E-08		NA		7.25E-01	
Ref 45 1	NA	NA	1.73E-08	2.49E-08	NA	NA	8.42E-01	8.36E-01
Ref 45 2	NA		3.25E-08		NA		8.30E-01	
Ref 70 1	NA	NA	2.63E-08	2.49E-08	NA	NA	6.06E-01	6.27E-01
Ref 70 2	NA		2.35E-08		NA		6.47E-01	
Ref 90 1	NA	NA	6.05E-08	8.175E-08	NA	NA	9.00E-01	9.80E-01
Ref 90 2	NA		1.03E-07		NA		1.06E+00	

(2) $$G = \frac{Dt}{d^2}$$

and

(3) $$D = \frac{Gd^2}{t}$$

where

D = effective diffusivity (effective diffusion coefficient), cm^2/s,
G = a time factor for the cylinder, dimensionless,
d = the diameter of the cylinder, cm,
t = the elapsed leaching interval, s.

Cesium Versus Nitrate Leaching

The effective diffusion coefficients for cesium leached from the direct grout are about one order of magnitude lower than those for nitrate ($3.11 \times 10^{-9}{}_{ave}$ versus $4.01 \times 10^{-8}{}_{ave}$) over the temperature range studied. Previous studies indicated that the nitrate is not stabilized in either the direct grout or saltstone formulations. Consequently, the lower diffusion coefficients for cesium imply that a measurable degree of stabilization occurs for cesium in the direct grout (and saltstone). This is confirmed by a comparison of the cumulative fractions for cesium (22.6 wt. %) and nitrate (85.5 wt. %) leached after 90 days.

For the direct grout samples cured between 24 and 90°C, the effective cesium diffusion coefficients ranged from 2.44 to 3.78E-09 cm^2/sec. The average cesium value is 3.11E-09 cm^2/sec. There is no apparent trend with respect to curing temperatures. This implies that the mechanism responsible for stabilizing the cesium ion is constant over the temperature range studied.

Nitrate diffusion coefficients were calculated for the reference saltstone. These values ranged from 2.47 to 8.18E-08 cm^2/sec (4.49E-08_{ave} cm^2/sec). The average value is very consistent with the average nitrate D_{eff} for the direct grout, 4.01×10^{-8} cm^2/sec. Cesium diffusions were not calculated for the reference saltstone because the total concentration of cesium in the sample and in each of the leachates was below the detection limit.

Although there is no trend with respect to curing temperature for the cesium data, both the direct grout and the reference saltstone showed an increase in the nitrate D_{eff} for the samples cured at 90°C. This is attributed to the increased surface of the 90°C samples and was associated with the observed cracks in these samples. The 100% relative humidity condition was difficult to maintain at 90°C. Consequently, some drying and subsequent shrinkage occurred in these samples.

Calculation of Distribution Ratios

The parameter known as the distribution coefficient, K_d, is used to quantify sorption reactions for the purpose of environmental transport modeling of ionic species. The distribution coefficient is used to assess the degree to which a chemical species will be removed from solution as a fluid migrates through a media. In other words, the distribution coefficient provides an indication of how rapidly an ion can move relative to the rate of ground water movement under the geochemical conditions tested.

Justification of the distribution coefficient concept is generally acknowledged to be based on expediency in modeling, averaging the effects of one or more attenuation reactions. Measured partitioning reactions may include adsorption, ion exchange, co-precipitation and filtration processes that cannot be easily described by equations.

In reference to partitioning in soils, equilibrium is assumed (although not always achieved) and the equilibrium value is referred to as the K_d. In these laboratory experiments, the distribution ratio, R_d, is calculated which may be used for estimating the value of the distribution coefficient for a given set of site specific geochemical conditions. Although short-term laboratory tests and the attainment of equilibrium in the laboratory is not presumed, the R_d values can be used as approximations of the equilibrium K_d values. Cesium dsitribution ratios were calculated for the direct grout based on the following equations:

$$(4) \qquad R_d = \frac{\text{(mass of the solute on the solid phase per unit mass of the solid phase)}}{\text{(mass of the solute in solution per unit volume of the liquid phase)}}$$

where

R_d = distribution ratio, ml/g,
Mass of the solute on the solid = 1- the total fraction leached into solution,
Unit mass of the solid phase = concentration in the solid,
Mass of the solute in solution per unit volume of liquid phase = leachate concentration at each leach interval.

Based on the data tabulated in Appendix E, distribution ratios were calculated for cesium in direct grout samples cured over the temperature range 24 to 90°C. Results are summarized in Table 4. The lowest values correlate with the longest leaching intervals, 456, 1128, and 2160 hours. These values more closely approach equilibrium condition than do the shorter leaching intervals. Consequently, they were averaged and can be considered conservative approximations of the cesium distribution ratios for direct grout cured over the temperature range of this study.

The averaged R_d values for the three longest leach intervals range from 228 to 255 ml/g. These values do not appear to be affected by the direct grout curing temperature over the range studies. These values are two orders of magnitude higher than the cesium K_d used

Table 4. Summary of the Distribution Ratios for the Direct Grout Cured at Room Temperature (24°C), 45, 70, and 90°C. Average values were calculated for each temperature for each leaching interval (highlighted). In addition, the averaged values for the last three (longest) leach intervals were also calculated and are highlighted in bold type. Distribution ratios approximate distribution coefficients (K_d) as equilibrium is approached.

Cesium Distribution Ratios for Direct Grout (R_d) (ml/g)

Cumulative Leach Time	DGRT 1	DGRT 2	DGRT ave	DG45 1	DG45 2	DG45 ave	DG70 1	DG70 2	DG70 ave	DG90 1	DG90-2	DG90 ave
30 sec	2187	2187	2187	2187	2187	2187	2187	2187	2187	2187	2187	2187
2 hr	2038	1917	1977	1479	2175	1827	1917	1714	1816	1479	2173	1826
7 hr	2161	1616	1889	1699	1619	1659	2160	2159	2160	1699	1617	1658
24 hr	636	544	590	1029	1336	1183	1234	1459	1346	1029	1334	1181
48 hr	824	818	821	747	1093	920	959	1177	1068	747	1091	919
72 hr	936	1058	997	967	1256	1111	1160	1576	1368	967	1252	1110
96 hr	1052	1167	1110	1093	1243	1168	1240	1420	1330	1093	1238	1166
120 hr	1259	1505	1382	1444	1623	1534	1396	2070	1733	1444	1616	1530
456 hr	169	200	185	194	197	196	196	198	197	194	195	195
1128 hr	184	222	203	218	199	209	194	226	210	218	196	207
2160 hr	250	330	290	234	261	247	255	310	282	234	256	245
	Average of last three leach intervals		**255**			**230**			**254**			**228**

in the Z-Area Performance Assessment and are consistent with the effective diffusion coefficient of 10^{-9} cm^2/sec.

The K_d value of 2 used in the PA was taken from the literature on concrete and was used as a worst case. The literature value used in the Saltstone PA is based on sorption of cesium onto cured concrete rather than leaching from a cement or slag (Saltstone and direct grout) waste form prepared with aqueous waste containing soluble cesium. (At the time the Saltstone PA was written, the low concentration of cesium in the salt solution required no stabilization in the waste form to meet the ground water requirements.) Since saltstone is a slag-based material as opposed to a portland cement-based material, and since saltstone contains no inert aggregate (concrete contains about 90 volume % sand and gravel), more cesium retention is expected from the saltstone compared to concrete.

CONCLUSIONS

Cesium is stabilized (retained in the waste form relative to nitrate) in the direct grout and the saltstone formulations. This is based on the cesium effective diffusion coefficients, cumulative fractions of cesium leached as a function of curing times, and the cesium distribution ratios (approximations of distribution coefficients, K_d) determined in this study.

After 90 days of leaching, over 77 wt. % of the cesium was retained in the direct grout compared to 14 wt. % of the nitrate. After 90 days of leaching, only 2 wt. % of the nitrate was retained in the reference saltstone. These results are consistent with the earlier TCLP results (18 hour test of a –200 mesh crushed sample), which indicated that more than 80 wt.% of the cesium was retained after 18 hours leaching in an acetic acid solution.

The effective cesium diffusion coefficients for direct grout are about one order of magnitude lower than those for nitrate. Average values were calculated to be 2E-09 versus 6E-08 cm^2/sec, respectively. Curing temperatures between 24 and 90°C did not affect the cesium leaching for the direct grout. However, samples cured at 90°C did show an increase in the amount of nitrate leached. This was attributed to an increase in surface area of the samples due to drying shrinkage cracking and to the fact that nitrate is not chemically stabilized in the direct grout and saltstone matrices.

Distribution coefficients, K_d, were approximated as distribution ratios, R_d. The distribution ratios were calculated from data generated in the ANS 16.1 leaching protocol. The lowest Rd values were obtained for the longest curing times. The data for the last three leach intervals were averaged to obtain conservative values indicative of the measurable cesium stabilization observed in this study. Conservative cesium R_d (K_d) values calculated for the direct grout ranged from 228 to 255 ml/g over the range of curing temperatures studied. These values are more than 100 times greater than the value used in the saltstone Performance Assessment. The PA value of 2 was based on literature values for cesium sorbed onto portland cement concrete.

QUALITY ASSURANCE

Results are recorded in WSRC-NB-98-00204. Testing was conducted in accordance with SRTC procedures.

REFERENCES

1. C. A. Langton, "Direct Grout Stabilization of High Cesium Salt Waste: Salt Waste Alternative Phase III Feasibility Study" (U), WSRC-TR-98-00337, 9-30-1998.

2. P. L. Rutland, et al., "Bases, Assumptions, and Results of the Flowsheet Calculations for the Initial Eighteen Salt Disposition Alternatives," WSRC-RP-98-00166, June 15, 1998.

3. K. Reuter, et al., "Bases, Assumptions, and Results of the Flowsheet Calculations for the Short List Salt Disposition" (U), USRC-RP-98-00168, Rev. 1, October, 29, 1998.

4. C. A. Langton, "Task Technical Plan for Cesium Leaching Studies for Saltstone and Direct Grout" (U), WSRC-RP-99-00186, 2-10-99.

5. C. A. Langton, "Task Quality Assurance Plan for Cesium Leaching Studies for Saltstone and Direct Grout" (U), WSRC-RP-99-00187, 2-10-99.

6. D. D. Walker, E-Mail correspondence, 7-27-98.

7. CFR Part 61.55.

8. D. D. Walker, E-Mail correspondence, 7-29-98.

9. American Nuclear Society, Measurement of the Leachability of Solidified Low-Level Radioactive Wastes by a Short-Term Test Procedure, ANSI/ANS-16.1, 1986.

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APPENDIX A

Cesium Leaching Results for Direct Grout as a Function of Curing Temperature

Table A-1. Cesium Concentrations in the ANS 16.1 Leachates of Direct Grout Samples Cured at Room Temperature, 24^{0}C, as a Function of Total Leaching Time.

Cumulative Leach Time	DG RT 1	DG RT 2	DG RT Ave.	Cumulative Leached
	Cesium mg/L			
30 sec	<0.0750	<0.0750	0.075	0.0750
2 hr	<0.0800	<0.0850	0.08	0.1550
7 hr	<0.0750	<0.1000	0.075	0.2300
24 hr	0.2500	0.2900	0.2700	0.5000
48 hr	0.1900	0.1900	0.1900	0.6900
72 hr	0.1650	0.1450	0.1550	0.8450
96 hr	0.1450	0.1300	0.1375	0.9825
120 hr	0.1200	<0.1000	0.1100	1.0925
456 hr	0.829	0.706	0.7675	1.8600
1128 hr	0.715	0.601	0.6580	2.5180
2160 hr	0.5	0.389	0.4445	2.9625

Table A-2. Cesium Concentrations in the ANS 16.1 Leachates of Direct Grout Samples Cured at 45^{0}C as a Function of Total Leaching Time.

Cumulative Leach Time	DG 45 1	DG 45 2	DG 45 Ave.	Cumulative Leached
	Cesium mg/L			
30 sec	<0.0750	<0.0750	0.075	0.0750
2 hr	0.11	<0.0750	0.08	0.1550
7 hr	<0.0950	<0.1000	0.075	0.2300
24 hr	0.1550	0.1200	0.1375	0.3675
48 hr	0.2100	0.1450	0.1775	0.5450
72 hr	0.1600	0.1250	0.1425	0.6875
96 hr	0.1400	0.1250	0.1325	0.8200
120 hr	<0.1050	<0.0950	0.1100	0.9300
456 hr	0.732	0.736	0.7340	1.6640
1128 hr	0.616	0.686	0.6510	2.3150
2160 hr	0.546	0.499	0.5225	2.8375

Table A-3. Cesium Concentrations in the ANS 16.1 Leachates of Direct Grout Samples Cured at 70^{0}C as a Function of Total Leaching Time.

Cumulative Leach Time	DG 70 1	DG 70 2	DG 70 Ave.	Cumulative Leached
	Cesium mg/L			
30 sec	<0.0750	<0.0750	0.075	0.0750
2 hr	<0.0850	<0.0950	0.08	0.1550
7 hr	<0.0750	<0.0750	0.075	0.2300
24 hr	0.1300	0.1100	0.1200	0.3500
48 hr	0.1650	0.1350	0.1500	0.5000
72 hr	0.1350	<0.1	0.1175	0.6175
96 hr	0.1250	0.1100	0.1175	0.7350
120 hr	0.1100	<0.0750	0.1000	0.8350
456 hr	0.736	0.736	0.7360	1.5710
1128 hr	0.696	0.611	0.6535	2.2245
2160 hr	0.0506	0.429	0.2398	2.4643

Table A-4. Cesium Concentrations in the ANS 16.1 Leachates of Direct Grout Samples Cured at 90^{0}C as a Function of Total Leaching Time.

Cumulative Leach Time	DG 90 1	DG 90 2	DG 90 Ave.	Cumulative Leached
	Cesium mg/L			
30 sec	<0.0750	<0.0750	0.075	0.0750
2 hr	<0.0750	<0.0950	0.08	0.1550
7 hr	<0.0750	<0.0750	0.08	0.2350
24 hr	0.1150	0.1300	0.1225	0.3575
48 hr	0.1200	0.1550	0.1375	0.4950
72 hr	<0.0950	0.1300	0.1175	0.6125
96 hr	<0.0850	0.1250	0.1050	0.7175
120 hr	<0.0800	0.1050	0.1000	0.8175
456 hr	0.509	0.623	0.5660	1.3835
1128 hr	0.485	0.549	0.5170	1.9005
2160 hr	0.384	0.364	0.3740	2.2745

APPENDIX B

Nitrate Leaching Results for Direct Grout as a Function of Curing Temperature

Table B-1. Nitrate Concentrations in the ANS 16.1 Leachates of Direct Grout Samples Cured at Room Temperature, 24°C, as a Function of Total Leaching Time.

Cumulative Leach Time	DGRT 1	DGRT 2	DGRT Ave.	Cumulative Leached
	Nitrate (NO_3) mg/L			
30 sec	5	9	7	7
2 hr	107	80	94	101
7 hr	71	97	84	185
24 hr	217	253	235	420
48 hr	222	208	215	635
72 hr	179	146	163	797
96 hr	151	113	132	929
120 hr	117	92	105	1034
456 hr	1180	861	1021	2054
1128 hr	690	541	616	2670
2160 hr	469	369	419	3089

Table B-2. Nitrate Concentrations in the ANS 16.1 Leachates of the Direct Grout Samples Cured at 45°C as a Function of Total Leaching Time.

Cumulative Leach Time	DG 45 1	DG 45 2	DG 45 Ave.	Cumulative Leached
	Nitrate (NO_3) mg/L			
30 sec	5	5	5	5
2 hr	121	160	141	146
7 hr	85	42	64	209
24 hr	198	124	161	370
48 hr	197	136	167	537
72 hr	141	111	126	663
96 hr	107	103	105	768
120 hr	87	79	83	851
456 hr	625	638	632	1482
1128 hr	548	573	561	2043
2160 hr	433	396	415	2457

Table B-3. Nitrate Concentrations in the ANS 16.1 Leachates of the Direct Grout Samples Cured at 70°C as a Function of Total Leaching Time.

Cumulative Leach Time	DG 70 1	DG 70 2	DG 70 Ave.	Cumulative Leached
	Nitrate (NO_3) mg/L			
30 sec	6	7	7	7
2 hr	87	95	91	98
7 hr	71	59	65	163
24 hr	181	138	160	323
48 hr	183	146	165	487
72 hr	143	114	129	616
96 hr	135	149	142	758
120 hr	101	79	90	848
456 hr	821	657	739	1587
1128 hr	740	645	693	2279
2160 hr	523	486	505	2784

Table B-4. Nitrate Concentrations in the ANS 16.1 Leachates of the Direct Grout Samples Cured at 90°C as a Function of Total Leaching Time.

Cumulative Leach Time	DG 90 1	DG 90 2	DG 90 Ave.	Cumulative Leached
	Nitrate (NO_3) mg/L			
30 sec	3	4	4	4
2 hr	151	160	156	160
7 hr	110	138	124	284
24 hr	235	316	276	559
48 hr	214	297	256	815
72 hr	163	225	194	1009
96 hr	153	205	179	1188
120 hr	114	158	136	1324
456 hr	919	1397	1158	2482
1128 hr	816	927	872	3353
2160 hr	469	369	419	3772

APPENDIX C

Cesium Leaching Results for Reference Saltstone as a Function of Curing Temperature

Table C-1. Cesium Concentrations in the ANS 16.1 Leachates of Reference saltstone Samples Cured at 24°C as a Function of Total Leaching Time.

Cumulative Leach Time	Ref RT 1	Ref RT 2	Ref RT Ave.	Cumulative Leached
	Cesium mg/L			
30 sec	<0.0750	<0.0750	<0.0750	
2 hr	<0.0750	<0.0750	<0.0800	
7 hr	<0.0750	<0.0750	<0.0750	
24 hr	<0.0750	<0.0750	<0.0750	
48 hr	<0.0750	<0.0750	<0.0750	
72 hr	<0.0750	<0.0750	<0.0750	
96 hr	<0.0750	<0.0750	<0.0750	
120 hr	<0.0750	<0.0750	<0.0750	
456 hr				
1128 hr				
2160 hr				

Table C-2. Cesium Concentrations in the ANS 16.1 Leachates of Reference Saltstone Samples Cured at 45°C as a Function of Total Leaching Time.

Cumulative Leach Time	Ref 45 1	Ref 45 2	Ref 45 Ave.	Cumulative Leached
	Cesium mg/L			
30 sec	<0.0750	<0.0750	<0.0750	
2 hr	<0.0750	<0.0750	<0.0800	
7 hr	<0.0750	<0.0750	<0.0750	
24 hr	<0.0750	<0.0750	<0.0750	
48 hr	<0.0750	<0.0750	<0.0750	
72 hr	<0.0750	<0.0750	<0.0750	
96 hr	<0.0750	<0.0750	<0.0750	
120 hr	<0.0750	<0.0750	<0.0750	
456 hr				
1128 hr				
2160 hr				

TableC-3. Cesium Concentrations in the ANS 16.1 Leachates of Reference Saltstone Samples Cured at 70°C as a Function of Total Leaching Time.

Cumulative Leach Time	Ref 70 1	Ref 70 2	Ref 70 Ave.	Cumulative Leached
	Cesium mg/L			
30 sec	<0.0750	<0.0750	<0.0750	
2 hr	<0.0750	<0.0750	<0.0800	
7 hr	<0.0750	<0.0750	<0.0750	
24 hr	<0.0750	<0.0750	<0.0750	
48 hr	<0.0750	<0.0750	<0.0750	
72 hr	<0.0750	<0.0750	<0.0750	
96 hr	<0.0750	<0.0750	<0.0750	
120 hr	<0.0750	<0.0750	<0.0750	
456 hr				
1128 hr				
2160 hr				

Table C-4. Cesium Concentrations in the ANS 16.1 Leachates of Reference Saltstone Samples Cured at 90°C as a Function of Total Leaching Time.

Cumulative Leach Time	Ref 90 1	Re f 90 2	Ref 90 Ave.	Cumulative Leached
	Cesium mg/L			
30 sec	<0.0750	<0.0750	<0.0750	
2 hr	<0.0750	<0.0750	<0.0800	
7 hr	<0.0750	<0.0750	<0.0750	
24 hr	<0.0750	<0.0750	<0.0750	
48 hr	<0.0750	<0.0750	<0.0750	
72 hr	<0.0750	<0.0750	<0.0750	
96 hr	<0.0750	<0.0750	<0.0750	
120 hr	<0.0750	<0.0750	<0.0750	
456 hr				
1128 hr				
2160 hr				

APPENDIX D

Nitrate Leaching Results for Reference Saltstone as a Function of Curing Temperature

Table D1. Nitrate Concentrations in the ANS 16.1 Leachates of the Reference Saltstone Samples Cured at 24^oC as a Function of Total Leaching Time.

Cumulative Leach Time	Ref RT 1	Ref RT 2	Ref RT Ave.	Cumulative Leached
	Nitrate (NO_3) mg/L			
30 sec	2	2	2	2
2 hr	71	74	73	75
7 hr	*23*	80	52	126
24 hr	156	161	159	285
48 hr	145	147	146	431
72 hr	106	113	110	540
96 hr	88	84	86	626
120 hr	82	81	82	708
456 hr	612	613	613	1320
1128 hr	503	539	521	1841
2160 hr	486	733	610	2451

Table D-2. Nitrate Concentrations in the ANS 16.1 Leachates of the Reference Saltstone Samples Cured at 45^oC as a Function of Total Leaching Time.

Cumulative Leach Time	Ref 45	Ref 45	Ref 45	Cumulative Leached
	Nitrate (NO_3) mg/L			
30 sec	1	3	2	3
2 hr	134	145	140	143
7 hr	57	54	56	198
24 hr	117	131	124	322
48 hr	110	126	118	440
72 hr	88	96	92	532
96 hr	63	79	71	603
120 hr	63	78	71	674
456 hr	458	528	493	1167
1128 hr	437	430	434	1600
2160 hr	1483	1318	1401	3001

Table D-3. Nitrate Concentrations in the ANS 16.1 Leachates of the Reference Saltstone Samples Cured at 70^oC as a Function of Total Leaching Time.

Cumulative Leach Time	Ref 70 1	Ref 70 2	Ref 70 Ave.	Cumulative Leached
	Nitrate (NO_3) mg/L			
30 sec	2	2	2	2
2 hr	121	96	109	111
7 hr	62	60	61	172
24 hr	136	134	135	307
48 hr	129	131	130	437
72 hr	102	97	100	536
96 hr	79	82	81	617
120 hr	72	75	74	690
456 hr	539	522	531	1221
1128 hr	529	556	543	1763
2160 hr	431	676	554	2317

Table D-4. Nitrate Concentrations in the ANS 16.1 Leachates of the Reference Saltstone Samples Cured at 90^oC as a Function of Total Leaching Time.

Cumulative Leach Time	Ref 90 1	Ref 90 2	Ref 90 Ave.	Cumulative Leached
	Nitrate (NO_3) mg/L			
30 sec	2	3	3	3
2 hr	88	83	86	89
7 hr	80	101	91	179
24 hr	207	284	246	425
48 hr	223	292	258	682
72 hr	174	215	195	877
96 hr	149	169	159	1036
120 hr	120	138	129	1165
456 hr	889	1013	951	2116
1128 hr	837	938	888	3003
2160 hr	562	523	543	3546

APPENDIX E

Cesium Effective Diffusion Coefficients Calculated for Direct Grout as a Function of Curing Temperature

Table E-1 Cesium Effective Diffusion Coefficients for Direct Grout Sample 1 Calculated as a Function of Leaching Time. This sample Was Cured at Room Temperature, 24°C.

DGRT 1	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt_n (sec)	Mean Time Leach Interval T (sec)	DGRT 1 Leachate [Cs] a_n (mg/L)	Cumulative Cesium Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate $[(a_n/A_o)/(\Delta t)_n]$	Cumulative Fraction Leached $(\Sigma a_n/A_o)$	D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape* (cm^2/sec)
diameter (cm)	30 sec	30			0.075	0.075			5.78E-03		
4.865	2	7,200	7,200	2,040	0.08	0.155	6.16E-03	8.56E-07	1.19E-02	1.75E-09	
height (cm)	7	25,200	18,000	14,835	0.075	0.23	5.78E-03	3.21E-07	1.77E-02	1.79E-09	
2.521	24	86,400	61,200	51,231	0.2500	0.48	1.93E-02	3.15E-07	3.70E-02	5.94E-09	
surface area (cm^2)	48	172,800	86,400	125,894	0.1900	0.67	1.46E-02	1.69E-07	5.16E-02	4.23E-09	
75.750	72	259,200	86,400	213,818	0.1650	0.835	1.27E-02	1.47E-07	6.43E-02	5.42E-09	
volume (cm^3)	96	345,600	86,400	300,849	0.1450	0.98	1.12E-02	1.29E-07	7.55E-02	5.89E-09	
46.282	120	432,000	86,400	387,596	0.1200	1.1	9.24E-03	1.07E-07	8.47E-02	5.20E-09	
V/S (cm)	456	1,641,600	1,209,600	939,462	0.829	1.929	6.38E-02	5.28E-08	1.49E-01	3.07E-09	
0.611	1,128	4,060,800	2,419,200	2,716,550	0.715	2.644	5.51E-02	2.28E-08	2.04E-01	1.65E-09	3.27E-09
weight (g)	2,160	7,776,000	3,715,200	5,768,861	0.5	3.144	3.85E-02	1.04E-08	2.42E-01	7.27E-10	2.53E-09
78.69											
Initial Cs Concentration (ug/g) 165											
Total Cs A_o (mg) 12.98											

* $D = Gd^2/t$

G =5.62E-4 for l/d = 0.52, fraction leached = 0.204

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.2	5.59E-04	5.59E-04	9.98E-04
0.204	5.61E-04	5.62E-04	1.00E-03
0.21	6.21E-04	6.21E-04	1.11E-03

G =8.31E-4 for l/d = 0.52, fraction leached = 0.242

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.24	8.28E-04	8.28E-04	1.48E-03
0.242	8.31E-04	8.31E-04	1.49E-03
0.25	9.05E-04	9.05E-04	1.62E-03

Table E-2 Cesium Effective Diffusion Coefficients for Direct Grout Sample 2 Calculated as a Function of Leaching Time. This sample Was Cured at Room Temperature, 24°C.

DGRT 2	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt (sec)	Mean time Leach Interval T (sec)	DGRT 2 Leachate [Cs] a_n (mg/L)	Cumulative Cesium Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate $[(a_n/A_o)/(\Delta t)_n]$	Cumulative Fraction Leached $(\Sigma a_n/Ao)$	D_{eff} (cm²/sec)	D_{eff} Corrected for Shape * (cm²/sec)
diameter (cm)	30 sec	30			0.075	0.075			5.93E-03		
4.803	2	7,200	7,200	2,040	0.085	0.16	6.72E-03	9.33E-07	1.26E-02	2.14E-09	
height (cm)	7	25,200	18,000	14,835	0.1	0.26	7.90E-03	4.39E-07	2.05E-02	3.45E-09	
2.560	24	86,400	61,200	51,231	0.2900	0.55	2.29E-02	3.74E-07	4.35E-02	8.66E-09	
surface area (cm²)	48	172,800	86,400	125,894	0.1900	0.74	1.50E-02	1.74E-07	5.85E-02	4.58E-09	
74.830	72	259,200	86,400	213,818	0.1450	0.885	1.15E-02	1.33E-07	6.99E-02	4.53E-09	
volume (cm³)	96	345,600	86,400	300,849	0.1300	1.015	1.03E-02	1.19E-07	8.02E-02	5.13E-09	
46.359	120	432,000	86,400	387,596	0.1000	1.115	7.90E-03	9.15E-08	8.81E-02	3.91E-09	
V/S (cm)	456	1,641,600	1,209,600	939,462	0.706	1.821	5.58E-02	4.61E-08	1.44E-01	2.41E-09	
0.620	1,128	4,060,800	2,419,200	2,716,550	0.601	2.422	4.75E-02	1.96E-08	1.91E-01	1.26E-09	
weight (g) 76.7	2,160	7,776,000	3,715,200	5,768,861	0.389	2.811	3.07E-02	8.27E-09	2.22E-01	4.76E-10	2.10E-09
Initial Cs Concentration (ug/g) 165											
Total Cs A_o (mg) 12.66											

* $D = Gd^2/t$

G =6.89E-4 for l/d = 0.53,fraction leached = 0.222

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.22	6.86E-04	6.86E-04	1.23E-03
0.222	6.89E-04	6.89E-04	1.23E-03
0.23	7.55E-04	7.55E-04	1.35E-03

Table E-3 Cesium Effective Diffusion Coefficients for Direct Grout Sample 1 Calculated as a Function of Leaching Time. This sample Was Cured at Room Temperature, 45°C.

DG 45 1	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt_n (sec)	Mean Time Leach Interval T (sec)	DG 45 1 Leachate [Cs] a_n (mg/L)	Cum Cs Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate $[(a_n/A_o)/(\Delta t)_n]$	Cumulative Fraction Leached $(\Sigma a_n/A_o)$	D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape* (cm^2/sec)
diameter (cm)	30 sec	30			0.075	0.075			5.78E-03		
4.812	2	7,200	7,200	2,040	0.11	0.185	8.47E-03	1.18E-06	1.42E-02	3.31E-09	
height (cm)	7	25,200	18,000	14,835	0.095	0.28	7.32E-03	4.06E-07	2.16E-02	2.87E-09	
2.528	24	86,400	61,200	51,231	0.1550	0.435	1.19E-02	1.95E-07	3.35E-02	2.28E-09	
surface area (cm^2)	48	172,800	86,400	125,894	0.2100	0.645	1.62E-02	1.87E-07	4.97E-02	5.17E-09	
74.551	72	259,200	86,400	213,818	0.1600	0.805	1.23E-02	1.43E-07	6.20E-02	5.10E-09	
volume (cm^3)	96	345,600	86,400	300,849	0.1400	0.945	1.08E-02	1.25E-07	7.28E-02	5.49E-09	
46.282	120	432,000	86,400	387,596	0.1050	1.05	8.09E-03	9.36E-08	8.09E-02	3.98E-09	
V/S (cm)	456	1,641,600	1,209,600	939,462	0.732	1.782	5.64E-02	4.66E-08	1.37E-01	2.39E-09	
0.621	1,128	4,060,800	2,419,200	2,716,550	0.616	2.398	4.74E-02	1.96E-08	1.85E-01	1.22E-09	
weight (g)	2,160	7,776,000	3,715,200	5,768,861	0.546	2.944	4.21E-02	1.13E-08	2.27E-01	8.66E-10	3.04E-09
75.58											
Initial Cs Concentration (ug/g) 165											
Total Cs A_o (mg) 12.47											
Sample l/d 0.53											

* $D = Gd^2/t$

G =1.02E-3 for l/d = 0.53,fraction leached = 0.227

F Leached	l/d = 0.5	l/d = 0.53	l/d =1.0
0.22	6.86E-04	1.01E-03	1.23E-03
0.227	6.91E-04	1.02E-03	1.24E-03
0.23	7.55E-04	1.11E-03	1.35E-03

Table E-4 Cesium Effective Diffusion Coefficients for Direct Grout Sample 2 Calculated as a Function of Leaching Time. This sample Was Cured at 45°C.

DG 45 2	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt (sec)	Mean time Leach Interval T (sec)	DG 45 2 Leachate [Cs] a_n (mg/L)	Cum Cs Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate $[(a_n/A_o)/(\Delta t)_n]$	Cumulative Fraction Leached $(\Sigma a_n/Ao)$	D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape * (cm^2/sec)
diameter (cm)	30 sec	30			0.075	0.075			5.72E-03		
4.865	2	7,200	7,200	2,040	0.075	0.15	5.93E-03	8.23E-07	1.14E-02	1.67E-09	
height (cm)	7	25,200	18,000	14,835	0.1	0.25	7.90E-03	4.39E-07	1.91E-02	3.45E-09	
2.512	24	86,400	61,200	51,231	0.1200	0.37	9.48E-03	1.55E-07	2.82E-02	1.48E-09	
surface area (cm^2)	48	172,800	86,400	125,894	0.1450	0.515	1.15E-02	1.33E-07	3.93E-02	2.67E-09	
75.533	72	259,200	86,400	213,818	0.1250	0.64	9.88E-03	1.14E-07	4.88E-02	3.37E-09	
volume (cm^3)	96	345,600	86,400	300,849	0.1250	0.765	9.88E-03	1.14E-07	5.83E-02	4.74E-09	
46.282	120	432,000	86,400	387,596	0.0950	0.86	7.51E-03	8.69E-08	6.56E-02	3.53E-09	
V/S (cm)	456	1,641,600	1,209,600	939,462	0.736	1.596	5.82E-02	4.81E-08	1.22E-01	2.62E-09	
0.613	1,128	4,060,800	2,419,200	2,716,550	0.686	2.282	5.42E-02	2.24E-08	1.74E-01	1.64E-09	
weight (g)	2,160	7,776,000	3,715,200	5,768,861	0.499	2.781	3.94E-02	1.06E-08	2.12E-01	7.83E-10	1.27E-09
79.48											
Initial Cs Concentration (ug/g) 165											
Total Cs A_0 (mg) 13.11											
Sample l/d 0.52											

$* D = Gd^2/t$

G =4.37E-4 for l/d = 0.52,fraction leached = 0.212

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.21	6.21E-04	4.17E-04	1.11E-04
0.212	6.24E-04	4.37E-04	1.56E-04
0.22	6.86E-04	9.04E-04	1.23E-03

Table E-5 Cesium Effective Diffusion Coefficients for Direct Grout Sample 1 Calculated as a Function of Leaching Time. This sample Was Cured at 70°C.

DG70 1	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt_n (sec)	Mean Time Leach Interval T (sec)	DG 70 1 Leachate [Cs] a_n (mg/L)	Cum Cs Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate $[(a_n/A_o)/(\Delta t)_n]$	Cumulative Fraction Leached $(\Sigma a_n/Ao)$	D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape* (cm^2/sec)
diameter (cm) 4.83	30 sec	30			0.075	0.075			5.78E-03		
	2	7,200	7,200	2,040	0.085	0.16	6.55E-03	9.09E-07	1.23E-02	1.98E-09	
height (cm) 2.557	7	25,200	18,000	14,835	0.075	0.235	5.78E-03	3.21E-07	1.81E-02	1.79E-09	
	24	86,400	61,200	51,231	0.1300	0.365	1.00E-02	1.64E-07	2.81E-02	1.61E-09	
surface area (cm^2) 75.406	48	172,800	86,400	125,894	0.1650	0.53	1.27E-02	1.47E-07	4.08E-02	3.19E-09	
	72	259,200	86,400	213,818	0.1350	0.665	1.04E-02	1.20E-07	5.12E-02	3.63E-09	
volume (cm^3) 46.827	96	345,600	86,400	300,849	0.1250	0.79	9.63E-03	1.11E-07	6.08E-02	4.38E-09	
	120	432,000	86,400	387,596	0.1100	0.9	8.47E-03	9.81E-08	6.93E-02	4.37E-09	
V/S (cm) 0.621	456	1,641,600	1,209,600	939,462	0.736	1.636	5.67E-02	4.69E-08	1.26E-01	2.42E-09	
	1,128	4,060,800	2,419,200	2,716,550	0.696	2.332	5.36E-02	2.22E-08	1.80E-01	1.56E-09	
weight (g) 76.97	2,160	7,776,000	3,715,200	5,768,861	0.506	2.838	3.90E-02	1.05E-08	2.19E-01	7.44E-10	1.86E-09
Initial Cs Concentration (ug/g) 165											
Total Cs A_o (mg) 12.70											
Sample l/d 0.53											

* $D = Gd^2/t$

G =1.79E-4 for l/d = 0.53,fraction leached = 0.219

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.21	6.21E-04	6.21E-04	1.11E-03
0.219	6.24E-04	1.79E-04	1.11E-03
0.22	6.86E-04	6.86E-04	1.23E-03

Table E-6 Cesium Effective Diffusion Coefficients for Direct Grout Sample 2 Calculated as a Function of Leaching Time. This sample Was Cured 70^{o}C.

DG 70 2	
diameter (cm)	4.886
height (cm)	2.515
surface area (cm^2)	76.066
volume (cm^3)	46.282
V/S (cm)	0.608
weight (g)	79.42
Initial Cs Concentration (ug/g)	165
Total Cs A_o (mg)	13.10
Sample l/d	0.51

Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt (sec)	Mean Time Leach Interval T (sec)	DG 70 2 Leachate [Cs] a_n (mg/L)	Cum Cs Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate $[(a_n/A_o)/(\Delta t)_n]$	Cumulative Fraction Leached $(\Sigma a_n/Ao)$	D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape * (cm^2/sec)
30 sec	30			0.075	0.075			5.72E-03		
2	7,200	7,200	2,040	0.095	0.17	7.51E-03	1.04E-06	1.30E-02	2.67E-09	
7	25,200	18,000	14,835	0.075	0.245	5.93E-03	3.29E-07	1.87E-02	1.94E-09	
24	86,400	61,200	51,231	0.1100	0.355	8.69E-03	1.42E-07	2.71E-02	1.25E-09	
48	172,800	86,400	125,894	0.1350	0.49	1.07E-02	1.23E-07	3.74E-02	2.31E-09	
72	259,200	86,400	213,818	0.1000	0.59	7.90E-03	9.15E-08	4.50E-02	2.16E-09	
96	345,600	86,400	300,849	0.1100	0.7	8.69E-03	1.01E-07	5.34E-02	3.67E-09	
120	432,000	86,400	387,596	0.0750	0.775	5.93E-03	6.86E-08	5.91E-02	2.20E-09	
456	1,641,600	1,209,600	939,462	0.736	1.511	5.82E-02	4.81E-08	1.15E-01	2.62E-09	
1,128	4,060,800	2,419,200	2,716,550	0.611	2.122	4.83E-02	2.00E-08	1.62E-01	1.30E-09	
2,160	7,776,000	3,715,200	5,768,861	0.429	2.551	3.39E-02	9.12E-09	1.95E-01	5.79E-10	1.99E-09

* D = Gd2/t

G =6.47E-4 for l/d = 0.51, fraction leached = 0.20 ~0.195

F Leached	l/d = 0.5	l/d = 0.51	l/d =1.0
0.2	5.59E-04	6.47E-04	9.98E-04

Table E-7 Cesium Effective Diffusion Coefficients for Direct Grout Sample 2 Calculated as a Function of Leaching Time. This sample Was Cured at Room Temperature, 90°C.

DG 90 1	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt_n (sec)	Mean Time Leach Interval T (sec)	DG 90 2 Leachate [Cs] a_n (mg/L)	Cum Cs Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate $[(a_n/A_o)/(\Delta t)_n]$	Cumulative Fraction Leached $(\Sigma a_n/Ao)$	D_{eff} (cm²/sec)	D_{eff} Corrected for Shape* (cm²/sec)
diameter (cm)	30 sec	30			0.075	0.075			5.78E-03		
4.847	2	7,200	7,200	2,040	0.11	0.185	8.47E-03	1.18E-06	1.42E-02	3.31E-09	
height (cm)	7	25,200	18,000	14,835	0.095	0.28	7.32E-03	4.06E-07	2.16E-02	2.87E-09	
2.515	24	86,400	61,200	51,231	0.1550	0.435	1.19E-02	1.95E-07	3.35E-02	2.28E-09	
surface area (cm²)	48	172,800	86,400	125,894	0.2100	0.645	1.62E-02	1.87E-07	4.97E-02	5.17E-09	
75.162	72	259,200	86,400	213,818	0.1600	0.805	1.23E-02	1.43E-07	6.20E-02	5.10E-09	
volume (cm³)	96	345,600	86,400	300,849	0.1400	0.945	1.08E-02	1.25E-07	7.28E-02	5.49E-09	
46.282	120	432,000	86,400	387,596	0.1050	1.05	8.09E-03	9.36E-08	8.09E-02	3.98E-09	
V/S (cm)	456	1,641,600	1,209,600	939,462	0.732	1.782	5.64E-02	4.66E-08	1.37E-01	2.39E-09	
0.616	1,128	4,060,800	2,419,200	2,716,550	0.616	2.398	4.74E-02	1.96E-08	1.85E-01	1.22E-09	
weight (g)	2,160	7,776,000	3,715,200	5,768,861	0.546	2.944	4.21E-02	1.13E-08	2.27E-01	8.66E-10	3.0798E-09
78.2											
Initial Cs Concentration (ug/g) 165											
Total Cs A_o (mg) 12.90											
Sample l/d 0.52											

* $D = Gd^2/t$

G =5.62E-4 for l/d = 0.52, fraction leached = 0.227

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.22	6.86E-04	9.04E-04	1.23E-03
0.227	6.91E-04	1.02E-03	1.24E-03
0.23	7.55E-04	9.93E-04	1.35E-03

Table E-8 Cesium Effective Diffusion Coefficients for Direct Grout Sample 2 Calculated as a Function of Leaching Time. This sample Was Cured at Room Temperature, 90°C.

DG 90 2	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt (sec)	Mean Time Leach Interval T (sec)	DG 90 2 Leachate [Cs] a_n (mg/L)	Cum Cs Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate $[(a_n/A_o)/(\Delta t)_n]$	Cumulative Fraction Leached $(\Sigma a_n/Ao)$	D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape * (cm^2/sec)
diameter (cm)	30 sec	30			0.075	0.075			6.06E-03		
4.895	2	7,200	7,200	2,040	0.075	0.15	5.93E-03	8.23E-07	1.21E-02	1.67E-09	
height (cm)	7	25,200	18,000	14,835	0.1	0.25	7.90E-03	4.39E-07	2.02E-02	3.45E-09	
2.548	24	86,400	61,200	51,231	0.1200	0.37	9.48E-03	1.55E-07	2.99E-02	1.48E-09	
surface area (cm^2)	48	172,800	86,400	125,894	0.1450	0.515	1.15E-02	1.33E-07	4.16E-02	2.67E-09	
76.782	72	259,200	86,400	213,818	0.1250	0.64	9.88E-03	1.14E-07	5.17E-02	3.37E-09	
volume (cm^3)	96	345,600	86,400	300,849	0.1250	0.765	9.88E-03	1.14E-07	6.18E-02	4.74E-09	
46.282	120	432,000	86,400	387,596	0.0950	0.86	7.51E-03	8.69E-08	6.94E-02	3.53E-09	
V/S (cm)	456	1,641,600	1,209,600	939,462	0.736	1.596	5.82E-02	4.81E-08	1.29E-01	2.62E-09	
0.603	1,128	4,060,800	2,419,200	2,716,550	0.686	2.282	5.42E-02	2.24E-08	1.84E-01	1.64E-09	
weight (g)	2,160	7,776,000	3,715,200	5,768,861	0.499	2.781	3.94E-02	1.06E-08	2.25E-01	7.83E-10	2.78E-09
75.06											
Initial Cs Concentration (ug/g) 165											
Total Cs A_o (mg) 12.38											
Sample l/d 0.52											

* $D = Gd^2/t$

G =9.08E-4 for l/d = 0.52,fraction leached = 0.225

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.22	6.86E-04	9.04E-04	1.23E-03
0.225	6.89E-04	9.08E-04	1.23E-03
0.23	7.55E-04	7.55E-04	1.35E-03

APPENDIX F

Nitrate Effective Diffusion Coefficients Calculated for Direct Grout as a Function of Curing Temperature

Table F-1 Nitrate Effective Diffusion Coefficients for Direct Grout Sample 1 Calculated as a Function of Leaching Time. This Sample Was Cured at Room Temperature, 24°C.

DGRT 1	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt_n (sec)	Mean time Leach Interval T (sec)	DGRT 1 Leachate $[NO_3]$ a_n (mg/L)	Cum $[NO_3]$ Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate $[(a_n/A_o)/(\Delta t)_n]$	Cumulative Fraction Leached $(\Sigma a_n/Ao)$	D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape* (cm^2/sec)
diameter (cm)	30 sec	30			5	5					
4.865	2	7,200	7,200	2,040	107	112	2.35E-02	3.27E-06	2.46E-02	2.56E-08	
height (cm)	7	25,200	18,000	14,835	71	183	1.56E-02	8.68E-07	4.03E-02	1.31E-08	
2.526	24	86,400	61,200	51,231	217	400	4.78E-02	7.80E-07	8.80E-02	3.66E-08	
surface area (cm^2)	48	172,800	86,400	125,894	222	622	4.89E-02	5.65E-07	1.37E-01	4.72E-08	
75.747	72	259,200	86,400	213,818	179	801	3.94E-02	4.56E-07	1.76E-01	5.21E-08	
volume (cm^3)	96	345,600	86,400	300,849	151	952	3.32E-02	3.85E-07	2.10E-01	5.22E-08	4.39E-08
46.282	120	432,000	86,400	387,596	117	1069	2.57E-02	2.98E-07	2.35E-01	4.04E-08	1.84E-08
V/S (cm)	456	1,641,600	1,209,600	939,462	1180	2249	2.60E-01	2.15E-07	4.95E-01	5.08E-08	6.27E-08
0.611	1,128	4,060,800	2,419,200	2,716,550	690	2939	1.52E-01	6.28E-08	6.47E-01	1.25E-08	5.32E-08
weight (g)	2,160	7,776,000	3,715,200	5,768,861	469	3408	1.03E-01	2.78E-08	7.50E-01	5.22E-09	4.31E-08
78.69											
Initial Cs Concentration (ug/g) 57,744											
Total Cs A_0 (mg) 4543.88											

* $D = Gd^2/t$

G =6.41E-4 for l/d = 0.52,fraction leached = 0.210

F Leached	l/d = 0.5	l/d = 0.52	l/d = 1.0
0.21	6.21E-04	6.41E-04	1.11E-03

G =8.19E-4 for l/d = 0.52,fraction leached = 0.235

F Leached	l/d = 0.5	l/d = 0.52	l/d = 1.0
0.23	7.55E-04	7.84E-04	1.35E-03
0.235	7.92E-04	8.19E-04	1.42E-03
0.24	8.28E-04	8.54E-04	1.48E-03

G =4.35E-3 for l/d = 0.52,fraction leached = 0.495

F Leached	l/d = 0.5	l/d = 0.52	l/d = 1.0
0.49	4.26E-03	4.40E-03	7.70E-03
0.495	4.37E-03	4.35E-03	3.85E-03
0.5	4.48E-03	4.30E-03	8.10E-03

* $D = Gd^2/t$

G =9.12E-3 for l/d = 0.52,fraction leached = 0.647

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.64	8.56E-03	8.84E-03	1.56E-02
0.647	8.83E-03	9.12E-03	1.62E-02
0.65	8.94E-03	9.24E-03	1.64E-02

G =1.42E-2 for l/d = 0.52,fraction leached = 0.75

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.75	1.37E-02	1.42E-02	2.54E-02

Table F-2 Nitrate Effective Diffusion Coefficients for Direct Grout Sample 2 Calculated as a Function of Leaching Time. This Sample Was Cured at Room Temperature, 24^{0}C.

DGRT 2	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt (sec)	Mean Time Leach Interval T (sec)	DGRT 2 Leachate [NO_3] a_n (mg/L)	Cum [NO_3] Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate [(a_n/A_o)/(Δt)$_n$]	Cumulative Fraction Leached (Σa_n/Ao)	D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape * (cm^2/sec)
diameter (cm)	30 sec	30			9	9					
4.803	2	7,200	7,200	2,040	80	89	1.81E-02	2.51E-06	2.01E-02	1.55E-08	
height (cm)	7	25,200	18,000	14,835	97	186	2.19E-02	1.22E-06	4.20E-02	2.65E-08	
2.560	24	86,400	61,200	51,231	253	439	5.71E-02	9.33E-07	9.91E-02	5.38E-08	
surface area (cm^2)	48	172,800	86,400	125,894	208	647	4.70E-02	5.44E-07	1.46E-01	4.48E-08	
74.830	72	259,200	86,400	213,818	146	793	3.30E-02	3.82E-07	1.79E-01	3.75E-08	
volume (cm^3)	96	345,600	86,400	300,849	113	906	2.55E-02	2.95E-07	2.05E-01	3.16E-08	4.12E-08
46.359	120	432,000	86,400	387,596	92	998	2.08E-02	2.40E-07	2.25E-01	2.70E-08	3.97E-08
V/S (cm)	456	1,641,600	1,209,600	939,462	861	1859	1.94E-01	1.61E-07	4.20E-01	2.92E-08	4.32E-08
0.620	1,128	4,060,800	2,419,200	2,716,550	541	2400	1.22E-01	5.05E-08	5.42E-01	8.35E-09	3.22E-08
weight (g)	2,160	7,776,000	3,715,200	5,768,861	369	2769	8.33E-02	2.24E-08	6.25E-01	3.50E-09	2.44E-08
76.7											
Initial Cs Concentration (ug/g) 57,744											
Total Cs A_0 (mg) 4428.96											
l/d 0.53											

* $D = Gd^2/t$

G =6.18E-4 for l/d = 0.53, fraction leached = 0.205

F Leached	l/d = 0.5	l/d = 0.53	l/d = 1.0
0.2	5.59E-04	5.85E-04	9.98E-04
0.205	5.90E-04	6.18E-04	9.98E-04
0.21	6.21E-04	6.50E-04	1.11E-03

G =7.43E-4 for l/d = 0.53, fraction leached = 0.225

F Leached	l/d = 0.5	l/d = 0.52	l/d = 1.0
0.22	6.86E-04	7.08E-04	1.23E-03
0.225	7.21E-04	7.43E-04	1.29E-03
0.23	7.55E-04	7.79E-04	1.35E-03

G =4.35E-3 for l/d = 0.53,fraction leached = 0.420

F Leached	l/d = 0.5	l/d = 0.5	l/d = 1.0
0.42	2.93E-03	3.07E-03	5.28E-03

* $D = Gd^2/t$

G =5.67E-3 for l/d = 0.53,fraction leached = 0.54

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.54	5.44E-03	5.62E-03	9.86E-03
0.542	5.49E-03	5.67E-03	9.95E-03
0.55	5.70E-03	5.88E-03	1.03E-02

G =5.67E-3 for l/d = 0.53,fraction leached = 0.625

F Leached	l/d = 0.5	l/d = 0.53	l/d =1.0
0.62	7.84E-03	8.23E-03	1.43E-02
0.625	8.02E-03	8.41E-03	1.47E-02
0.63	8.19E-03	8.60E-03	1.50E-02

Table F-3 Nitrate Effective Diffusion Coefficients for Direct Grout Sample 1 Calculated as a Function of Leaching Time. This Sample Was Cured at 45^{0}C.

DG45 1	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt_n (sec)	Mean time Leach Interval T (sec)	DG45 1 Leachate [NO_3] a_n (mg/L)	Cum NO_3 Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate $[(a_n/A_o)/(\Delta t)_n]$	Cumulative Fraction Leached ($\Sigma a_n/Ao$)	D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape* (cm^2/sec)
diameter (cm)	30 sec	30			5	5					
4.812	2	7,200	7,200	2,040	121	126	2.77E-02	3.85E-06	2.89E-02	3.66E-08	
height (cm)	7	25,200	18,000	14,835	85	211	1.95E-02	1.08E-06	4.83E-02	2.10E-08	
2.528	24	86,400	61,200	51,231	198	409	4.54E-02	7.41E-07	9.37E-02	3.41E-08	
surface area (cm^2)	48	172,800	86,400	125,894	197	606	4.51E-02	5.22E-07	1.39E-01	4.16E-08	
74.551	72	259,200	86,400	213,818	141	747	3.23E-02	3.74E-07	1.71E-01	3.62E-08	
volume (cm^3)	96	345,600	86,400	300,849	107	854	2.45E-02	2.84E-07	1.96E-01	2.93E-08	
46.282	120	432,000	86,400	387,596	87	941	1.99E-02	2.31E-07	2.16E-01	2.50E-08	3.71E-08
V/S (cm)	456	1,641,600	1,209,600	939,462	625	1566	1.43E-01	1.18E-07	3.59E-01	1.59E-08	3.03E-08
0.621	1,128	4,060,800	2,419,200	2,716,550	548	2114	1.26E-01	5.19E-08	4.84E-01	8.86E-09	2.43E-08
weight (g)	2,160	7,776,000	3,715,200	5,768,861	433	2547	9.92E-02	2.67E-08	5.84E-01	4.98E-09	2.05E-08
75.58											
Initial Cs Concentration (ug/g) 57,744											
Total Cs A_0 (mg) 4364.29											
Sample l/d 0.53											

* $D = Gd^2/t$

G =6091E-4 for l/d = 0.53,fraction leached = 0.216

F Leached	l/d = 0.5	l/d = 0.53	l/d = 1.0
0.21	6.21E-04	6.50E-04	1.11E-03
0.216	6.60E-04	6.91E-04	1.18E-03
0.22	6.86E-04	7.19E-04	1.23E-03

G =2.15E-3 for l/d = 0.53,fraction leached = 0.359

F Leached	l/d = 0.5	l/d = 0.53	l/d = 1.0
0.35	1.92E-03	2.01E-03	3.44E-03
0.359	2.04E-03	2.15E-03	3.87E-03
0.36	2.05E-03	2.16E-03	3.92E-03

* $D = Gd^2/t$

G =4.25E-3 for l/d = 0.53,fraction leached = 0.484

F Leached	l/d = 0.5	l/d = 0.53	l/d =1.0
0.48	4.05E-03	4.25E-03	7.31E-03
0.484	4.06E-03	4.25E-03	7.33E-03
0.49	4.26E-03	4.47E-03	7.70E-03

G =6.88E-3 for l/d = 0.53,fraction leached = 0..584

F Leached	l/d = 0.5	l/d = 0.53	l/d =1.0
0.58	6.55E-03	6.87E-03	1.19E-02
0.584	6.56E-03	6.88E-03	1.19E-02
0.59	6.86E-03	7.20E-03	1.25E-02

Table F-4 Nitrate Effective Diffusion Coefficients for Direct Grout Sample 2 Calculated as a Function of Leaching Time. This Sample Was Cured at 45^0C.

DG45 2	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt (sec)	Mean time Leach Interval T (sec)	DG 45 2 Leachate $[NO_3]$ a_n (mg/L)	Cum NO_3 Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate $[(a_n/A_o)/(\Delta t)_n]$	Cumulative Fraction Leached $(\Sigma a_n/Ao)$	D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape * (cm^2/sec)
diameter (cm)	30 sec	30			5	5					
4.865	2	7,200	7,200	2,040	160	165	3.49E-02	4.84E-06	3.60E-02	5.64E-08	
height (cm)	7	25,200	18,000	14,835	42	207	9.15E-03	5.08E-07	4.51E-02	4.52E-09	
2.512	24	86,400	61,200	51,231	124	331	2.70E-02	4.41E-07	7.21E-02	1.18E-08	
surface area (cm^2)	48	172,800	86,400	125,894	136	467	2.96E-02	3.43E-07	1.02E-01	1.75E-08	
75.533	72	259,200	86,400	213,818	111	578	2.42E-02	2.80E-07	1.26E-01	1.98E-08	
volume (cm^3)	96	345,600	86,400	300,849	103	681	2.24E-02	2.60E-07	1.48E-01	2.39E-08	
46.282	120	432,000	86,400	387,596	79	760	1.72E-02	1.99E-07	1.66E-01	1.81E-08	
V/S (cm)	456	1,641,600	1,209,600	939,462	638	1398	1.39E-01	1.15E-07	3.05E-01	1.46E-08	2.39E-08
0.613	1,128	4,060,800	2,419,200	2,716,550	573	1971	1.25E-01	5.16E-08	4.29E-01	8.53E-09	1.85E-08
weight (g)	2,160	7,776,000	3,715,200	5,768,861	396	2367	8.63E-02	2.32E-08	5.16E-01	3.75E-09	1.52E-08
79.48											
Initial Cs Concentration (ug/g) 57,744											
Total Cs A_0 (mg) 4589.49											
Sample l/d 0.52											

* $D = Gd^2/t$

G =1.66E-3 for l/d = 0.52,fraction leached = 0.305

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.3	1.35E-03	1.39E-03	2.43E-03
0.305	1.41E-03	1.66E-03	2.52E-03
0.31	1.46E-03	1.92E-03	2.61E-03

* $D = Gd^2/t$

G =3.18E-3 for l/d = 0.52,fraction leached = 0.429

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.42	2.93E-03	3.02E-03	5.28E-03
0.429	3.08E-03	3.18E-03	5.56E-03
0.43	3.10E-03	3.20E-03	5.59E-03

G =4.37E-4 for l/d = 0.52,fraction leached = 0.516

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.51	4.71E-03	4.86E-03	8.52E-03
0.516	4.85E-03	5.01E-03	8.78E-03
0.52	4.94E-03	5.10E-03	8.95E-03

Table F-5 Nitrate Effective Diffusion Coefficients for Direct Grout Sample 1 Calculated as a Function of Leaching Time. This Sample Was Cured at 70°C.

DG70 1	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt_n (sec)	Mean time Leach Interval T (sec)	DG 70 1 Leachate [NO_3] a_n (mg/L)	Cum NO_3 Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate $[(a_n/A_o)/(\Delta t)_n]$	Cumulative Fraction Leached (Σa_n/Ao)	D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape* (cm^2/sec)
diameter (cm)	30 sec	30			6	6			4.62E-01		
4.83	2	7,200	7,200	2,040	87	93	1.96E-02	2.72E-06	2.09E-02	1.83E-08	
height (cm)	7	25,200	18,000	14,835	71	164	1.60E-02	8.87E-07	3.69E-02	1.41E-08	
2.557	24	86,400	61,200	51,231	181	345	4.07E-02	6.65E-07	7.76E-02	2.75E-08	
surface area (cm^2)	48	172,800	86,400	125,894	183	528	4.12E-02	4.77E-07	1.19E-01	3.46E-08	
75.406	72	259,200	86,400	213,818	143	671	3.22E-02	3.72E-07	1.51E-01	3.59E-08	
volume (cm^3)	96	345,600	86,400	300,849	135	806	3.04E-02	3.52E-07	1.81E-01	4.50E-08	
46.827	120	432,000	86,400	387,596	101	907	2.27E-02	2.63E-07	2.04E-01	3.25E-08	3.30E-08
V/S (cm)	456	1,641,600	1,209,600	939,462	821	1728	1.85E-01	1.53E-07	3.89E-01	2.65E-08	3.64E-08
0.621	1,128	4,060,800	2,419,200	2,716,550	740	2468	1.66E-01	6.88E-08	5.55E-01	1.56E-08	3.52E-08
weight (g) 76.97	2,160	7,776,000	3,715,200	5,768,861	523	2991	1.18E-01	3.17E-08	6.73E-01	7.01E-09	3.11E-08

Initial Cs Concentration (ug/g) 57,744

Total Cs A_0 (mg) 4444.56

Sample l/d 0.53

* $D = Gd^2/t$

G =6.11E-4 for l/d = 0.53,fraction leached = 0.204

F Leached	l/d = 0.5	l/d = 0.53	l/d = 1.0
0.2	5.59E-04	5.85E-04	9.98E-04
0.204	5.84E-04	6.11E-04	1.04E-03
0.21	6.21E-04	6.50E-04	1.11E-03

G =2.56E-3 for l/d = 0.53,fraction leached = 0.389

F Leached	l/d = 0.5	l/d = 0.53	l/d = 1.0
0.38	2.32E-03	2.43E-03	4.17E-03
0.389	2.45E-03	2.56E-03	4.40E-03
0.39	2.46E-03	2.58E-03	4.43E-03

* $D = Gd^2/t$

G =6.13E-3 for l/d = 0.53,fraction leached = 0.555

F Leached	l/d = 0.5	l/d = 0.53	l/d =1.0
0.55	5.70E-03	5.98E-03	1.03E-02
0.555	5.84E-03	6.13E-03	1.06E-02
0.56	5.98E-03	6.28E-03	1.09E-02

G =1.04E-02 for l/d = 0.53,fraction leached = 0.673

F Leached	l/d = 0.5	l/d = 0.53	l/d =1.0
0.67	9.75E-03	1.02E-02	1.79E-02
0.673	9.89E-03	1.04E-02	1.81E-02
0.68	1.02E-02	1.07E-02	1.87E-02

Table F-6 Nitrate Effective Diffusion Coefficients for Direct Grout Sample 2 Calculated as a Function of Leaching Time. This Sample Was Cured at 70°C.

DG 70 2	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt (sec)	Mean time Leach Interval T (sec)	DG 70 2 Leachate [NO_3] a_n (mg/L)	Cum NO_3 Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate $[(a_n/A_o)/(\Delta t)_n]$	Cumulative Fraction Leached ($\Sigma a_n/Ao$)	D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape * (cm^2/sec)
diameter (cm)	30 sec	30			7	7					
4.886	2	7,200	7,200	2,040	95	102	2.07E-02	2.88E-06	2.22E-02	1.96E-08	
height (cm)	7	25,200	18,000	14,835	59	161	1.29E-02	7.15E-07	3.51E-02	8.81E-09	
2.515	24	86,400	61,200	51,231	138	299	3.01E-02	4.92E-07	6.52E-02	1.44E-08	
surface area (cm^2)	48	172,800	86,400	125,894	146	445	3.18E-02	3.68E-07	9.70E-02	1.99E-08	
76.066	72	259,200	86,400	213,818	114	559	2.49E-02	2.88E-07	1.22E-01	2.06E-08	
volume (cm^3)	96	345,600	86,400	300,849	149	708	3.25E-02	3.76E-07	1.54E-01	4.95E-08	
46.282	120	432,000	86,400	387,596	79	787	1.72E-02	1.99E-07	1.72E-01	1.79E-08	
V/S (cm)	456	1,641,600	1,209,600	939,462	657	1444	1.43E-01	1.18E-07	3.15E-01	1.53E-08	2.23E-08
0.608	1,128	4,060,800	2,419,200	2,716,550	645	2089	1.41E-01	5.81E-08	4.56E-01	1.07E-08	9.02E-09
weight (g)	2,160	7,776,000	3,715,200	5,768,861	486	2575	1.06E-01	2.85E-08	5.61E-01	5.46E-09	1.87E-08
79.42											
Initial Cs Concentration (ug/g)											
57,744											
Total Cs A_0 (mg)											
4586.03											
Sample l/d											
0.51											

$* D = Gd^2/t$

G =1.53E-3 for l/d = 0.51,fraction leached = 0.315

F Leached	l/d = 0.5	l/d = 0.51	l/d = 1.0
0.31	1.46E-03	1.48E-03	2.61E-03
0.315	1.51E-03	1.53E-03	2.71E-03
0.32	1.56E-03	1.59E-03	2.81E-03

$* D = Gd^2/t$

G =3.63E-3 for l/d = 0.51,fraction leached = 0.456

F Leached	l/d = 0.5	l/d = 0.51	l/d =1.0
0.45	3.46E-03	3.52E-03	6.24E-03
0.456	3.57E-03	3.63E-03	6.44E-03
0.55	3.65E-03	3.71E-03	6.58E-03

G =6.11E-03 for l/d = 0.51,fraction leached = 0.561

F Leached	l/d = 0.5	l/d = 0.51	l/d =1.0
0.56	5.98E-03	6.08E-03	1.09E-02
0.561	6.01E-03	6.11E-03	1.10E-02
0.57	6.26E-03	6.36E-03	1.14E-02

Table F-7 Nitrate Effective Diffusion Coefficients for Direct Grout Sample1 Calculated as a Function of Leaching Time. This Sample Was Cured at 90°C.

DG 90 1	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt_n (sec)	Mean time Leach Interval T (sec)	DG 90 1 Leachate [NO_3] a_n (mg/L)	Cum NO_3 Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate $[(a_n/A_o)/(\Delta t)_n]$	Cumulative Fraction Leached $(\Sigma a_n/Ao)$	D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape* (cm^2/sec)
diameter (cm) 4.847	30 sec	30			3	3			2.31E-01		
	2	7,200	7,200	2,040	151	154	3.34E-02	4.64E-06	3.41E-02	5.24E-08	
height (cm) 2.515	7	25,200	18,000	14,835	110	264	2.44E-02	1.35E-06	5.85E-02	3.23E-08	
	24	86,400	61,200	51,231	235	499	5.20E-02	8.50E-07	1.11E-01	4.41E-08	
surface area (cm^2) 75.162	48	172,800	86,400	125,894	214	713	4.74E-02	5.49E-07	1.58E-01	4.51E-08	
	72	259,200	86,400	213,818	163	876	3.61E-02	4.18E-07	1.94E-01	4.44E-08	
volume (cm^3) 46.282	96	345,600	86,400	300,849	153	1029	3.39E-02	3.92E-07	2.28E-01	5.51E-08	3.368E-08
	120	432,000	86,400	387,596	114	1143	2.52E-02	2.92E-07	2.53E-01	3.94E-08	4.518E-08
V/S (cm) 0.616	456	1,641,600	1,209,600	939,462	919	2062	2.04E-01	1.68E-07	4.57E-01	3.17E-08	5.307E-08
	1,128	4,060,800	2,419,200	2,716,550	816	2878	1.81E-01	7.47E-08	6.37E-01	1.80E-08	5.049E-08
weight (g) 78.2	2,160	7,776,000	3,715,200	5,768,861	469	3347	1.04E-01	2.80E-08	7.41E-01	5.37E-09	4.112E-08

Initial Cs Concentration (ug/g) 57,744

Total Cs A_0 (mg) 4515.58

Sample l/d 0.52

* $D = Gd^2/t$

G =4.95E-4 for l/d = 0.52,fraction leached = 0.228

F Leached	l/d = 0.5	l/d = 0.52	l/d = 1.0
0.22	6.86E-04	6.98E-04	9.98E-04
0.228	4.71E-04	4.95E-04	1.09E-03
0.23	4.17E-04	4.45E-04	1.11E-03

G =8.31E-4 for l/d = 0.52,fraction leached = 0.253

F Leached	l/d = 0.5	l/d = 0.52	l/d = 1.0
0.25	9.05E-04	9.34E-04	1.62E-03
0.253	7.96E-04	8.31E-04	1.67E-03
0.26	5.42E-04	5.91E-04	1.77E-03

* $D = Gd^2/t$

G =3.71E-3 for l/d = 0.52,fraction leached = 0.457

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.45	3.46E-03	3.57E-03	6.24E-03
0.457	3.59E-03	3.71E-03	6.48E-03
0.46	3.65E-03	3.77E-03	6.58E-03

G =1.04E-02 for l/d = 0.52,fraction leached = 0.637

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.63	8.19E-03	8.46E-03	1.50E-02
0.637	8.45E-03	8.73E-03	1.54E-02
0.64	8.56E-03	8.84E-03	1.56E-02

G =1.36E-02 for l/d = 0.52,fraction leached = 0.741

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.74	1.31E-02	1.35E-02	2.43E-02
0.741	1.32E-02	1.36E-02	2.44E-02
0.75	1.37E-02	1.42E-02	2.54E-02

Table F-8 Nitrate Effective Diffusion Coefficients for Direct Grout Sample 2 Calculated as a Function of Leaching Time. This Sample Was Cured at 90°C.

DG 90 2	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt (sec)	Mean time Leach Interval T (sec)	DG 90 2 Leachate [NO_3] a_n (mg/L)	Cum NO_3 Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate $[(a_n/A_o)/(\Delta t)_n]$	Cumulative Fraction Leached ($\Sigma a_n/Ao$)	D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape * (cm^2/sec)
diameter (cm)	30 sec	30			4	4					
4.895	2	7,200	7,200	2,040	160	164	3.69E-02	5.13E-06	3.78E-02	6.12E-08	
height (cm)	7	25,200	18,000	14,835	138	302	3.18E-02	1.77E-06	6.97E-02	5.30E-08	
2.548	24	86,400	61,200	51,231	316	618	7.29E-02	1.19E-06	1.43E-01	8.29E-08	
surface area (cm^2)	48	172,800	86,400	125,894	297	915	6.85E-02	7.93E-07	2.11E-01	9.03E-08	8.98E-08
76.782	72	259,200	86,400	213,818	225	1140	5.19E-02	6.01E-07	2.63E-01	8.81E-08	9.64E-08
volume (cm^3)	96	345,600	86,400	300,849	205	1345	4.73E-02	5.47E-07	3.10E-01	1.03E-07	7.65E-08
46.282	120	432,000	86,400	387,596	158	1503	3.65E-02	4.22E-07	3.47E-01	7.87E-08	1.08E-07
V/S (cm)	456	1,641,600	1,209,600	939,462	1397	2900	3.22E-01	2.66E-07	6.69E-01	7.61E-08	1.52E-08
0.603	1,128	4,060,800	2,419,200	2,716,550	927	3827	2.14E-01	8.84E-08	8.83E-01	2.42E-08	1.54E-07
weight (g) 75.06	2,160	7,776,000	3,715,200	5,768,861	369	4196	8.51E-02	2.29E-08	9.68E-01	3.46E-09	1.46E-07

Initial Cs Concentration (ug/g) 57,744

Total Cs A_0 (mg) 4334.26

Sample l/d 0.52

* $D = Gd^2/t$

G =6.47E-4 for l/d = 0.52,fraction leached = 0.211

F Leached	l/d = 0.5	l/d = 0.52	l/d = 1.0
0.21	6.21E-04	6.41E-04	1.11E-03
0.211	6.28E-04	6.47E-04	1.12E-03
0.22	6.86E-04	7.08E-04	1.23E-03

G =1.04E-4 for l/d = 0.52,fraction leached = 0.263

F Leached	l/d = 0.5	l/d = 0.52	l/d = 1.0
0.26	9.86E-04	1.02E-03	1.77E-03
0.263	1.01E-03	1.04E-03	1.82E-03
0.27	1.07E-03	1.10E-03	1.92E-03

G =1.51E-3 for l/d = 0.52,fraction leached = 0.310

F Leached	l/d = 0.5	l/d = 0.52	l/d = 1.0
0.31	1.46E-03	1.51E-03	2.61E-03

* $D = Gd^2/t$

G =3.71E-3 for l/d = 0.52,fraction leached = 0.347

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.34	1.80E-03	1.86E-03	3.22E-03
0.347	1.88E-03	1.94E-03	3.37E-03
0.35	1.92E-03	1.98E-03	3.44E-03

G =1.00E-02 for l/d = 0.52,fraction leached = 0.669

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.66	9.33E-03	9.64E-03	1.71E-02
0.669	9.71E-03	1.00E-02	1.78E-02
0.67	9.75E-03	1.01E-02	1.79E-02

G =2.61E-02 for l/d = 0.52,fraction leached = 0.882

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.88	2.49E-02	2.58E-02	4.69E-02
0.882	2.52E-02	2.61E-02	4.74E-02
0.89	2.62E-02	2.71E-02	4.95E-02

G =2.61E-02 for l/d = 0.52,fraction leached = 0.968

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.96	4.22E-02	4.37E-02	8.00E-02
0.968	4.59E-02	4.75E-02	8.70E-02
0.97	4.68E-02	4.85E-02	8.87E-02

APPENDIX G

Cesium Effective Diffusion Coefficients Calculated for Reference Saltstone as a Function of Curing Temperature - Example

Table G-1 Cesium Effective Diffusion Coefficients Calculated as a Function of Leaching Time for Reference Saltstone Sample 1 Cured at Room Temperature, 24^{0}C. (The detection limit for cesium was too high to obtain meaningful results.)

Ref RT 1	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt_n (sec)	Mean time Leach Interval T (sec)	Ref RT 1 Leachate [Cs] a_n (mg/L)	Cum Cs Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate $[(a_n/A_o)/(\Delta t)_n$	Cumulative Fraction Leached $(\Sigma a_n/Ao)$	D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape* (cm^2/sec)
diameter (cm)	30 sec	30			0.075	0.075			1.91E+00		
4.865	2	7,200	7,200	2,040	0.075	0.15	1.91E+00	2.65E-04	3.81E+00	1.68E-02	
height (cm)	7	25,200	18,000	14,835	0.075	0.225	1.91E+00	1.06E-04	5.72E+00	1.95E-02	
2.521	24	86,400	61,200	51,231	0.075	0.3	1.91E+00	3.11E-05	7.62E+00	5.83E-03	
surface area (cm^2)	48	172,800	86,400	125,894	0.075	0.375	1.91E+00	2.21E-05	9.53E+00	7.18E-03	
7.575	72	259,200	86,400	213,818	0.075	0.45	1.91E+00	2.21E-05	1.14E+01	1.22E-02	
volume (cm^3)	96	345,600	86,400	300,849	0.075	0.525	1.91E+00	2.21E-05	1.33E+01	1.72E-02	
46.282	120	432,000	86,400	387,596	0.075	0.6	1.91E+00	2.21E-05	1.52E+01	2.21E-02	
V/S (cm)	456	1,641,600	1,209,600	939,462		0.6	0.00E+00	0.00E+00	1.52E+01	0.00E+00	
6.110	1,128	4,060,800	2,419,200	2,716,550		0.6	0.00E+00	0.00E+00	1.52E+01	0.00E+00	
weight (g)	2,160	7,776,000	3,715,200	5,768,861		0.6	0.00E+00	0.00E+00	1.52E+01	0.00E+00	
78.69											
Initial Cs Concentration (ug/g)											
0.5											
Total Cs A_0 (mg)											
3.93E-02											

APPENDIX H

Nitrate Effective Diffusion Coefficients Calculated for Reference Saltstone as a Function of Curing Temperature

Table H-1 Nitrate Effective Diffusion Coefficients for Reference Saltstone Sample 1 Calculated as a Function of Leaching Time. This Sample was Cured at Room Temperature, 24^{0}C.

Ref RT 1	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt_n (sec)	Mean time Leach Interval T (sec)	Ref RT 1 Leachate [NO_3] a_n (mg/L)	Cum NO_3 Leached Σa_n (mg/L)	Increment Fraction Leached (a_n/A_o)	Incremental Leach Rate $(a_n/A_o)/(\Delta t)_n$	umulative Fraction Leached (Σa_n/Ao)	D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape* (cm^2/sec)
diameter (cm) 4.835	30 sec	30			2	0.075			2.02E-05		
	2	7,200	7,200	2,040	71	71.075	1.91E-02	2.65E-06	1.91E-02	1.71E-08	
height (cm) 2.521	7	25,200	18,000	14,835	23	94.075	6.18E-03	3.43E-07	2.53E-02	2.09E-09	
	24	86,400	61,200	51,231	156	250.075	4.19E-02	6.85E-07	6.72E-02	2.87E-08	
surface area (cm^2) 74.976	48	172,800	86,400	125,894	145	395.075	3.90E-02	4.51E-07	1.06E-01	3.06E-08	
	72	259,200	86,400	213,818	106	501.075	2.85E-02	3.30E-07	1.35E-01	2.78E-08	
volume (cm^3) 46.263	96	345,600	86,400	300,849	88	589.075	2.36E-02	2.74E-07	1.58E-01	2.69E-08	
	120	432,000	86,400	387,596	82	671.075	2.20E-02	2.55E-07	1.80E-01	3.01E-08	
V/S (cm) 0.617	456	1,641,600	1,209,600	939,462	612	1283.075	1.64E-01	1.36E-07	3.45E-01	2.08E-08	2.73E-08
	1,128	4,060,800	2,419,200	2,716,550	503	1786.075	1.35E-01	5.59E-08	4.80E-01	1.01E-08	2.41E-08
weight (g) 78.69	2,160	7,776,000	3,715,200	5,768,861	486	2272.075	1.31E-01	3.52E-08	6.11E-01	8.52E-09	2.19E-08

Initial NO_3 Concentration (ug/g) 47,288

Total NO_3 A_0 (mg) 3721.09

Sample l/d 0.52

* $D = Gd^2/t$

G =1.87E-3 for l/d = 0.52, fraction leached = 0.345

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.34	1.80E-03	1.86E-03	3.22E-03
0.345	1.86E-03	1.92E-03	3.33E-03
0.35	1.92E-03	1.98E-03	3.44E-03

* $D = Gd^2/t$

G =4.18E-3 for l/d = 0.52, fraction leached = 0.480

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.48	4.05E-03	4.18E-03	7.31E-03

G =7.29E-3 for l/d = 0.52, fraction leached = 0.611

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.61	7.50E-03	7.25E-03	1.37E-03
0.611	7.53E-03	7.29E-03	1.38E-03
0.62	7.84E-03	7.58E-03	1.43E-03

Table H-2 Nitrate Effective Diffusion Coefficients for Reference Saltstone Sample 2 Calculated as a Function of Leaching Time. This Sample was Cured at Room Temperature, 24°C.

Ref RT 2	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt (sec)	Mean time Leach Interval T (sec)	Ref RT 2 Leachate [NO3] a_n (mg/L)	Cum NO_3 Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate $[(a_n/A_o)/(\Delta t)_n$	Cumulative Fraction Leached $(\Sigma a_n/Ao)$	[NO3] D_{eff} (cm²/sec)	D_{eff} Corrected for Shape * (cm²/sec)
diameter (cm)	30 sec	30			2	2			5.52E-04		
4.782	2	7,200	7,200	2,040	74	76	2.04E-02	2.83E-06	2.10E-02	1.95E-08	
height (cm)	7	25,200	18,000	14,835	80	156	2.21E-02	1.23E-06	4.30E-02	2.65E-08	
2.538	24	86,400	61,200	51,231	161	317	4.44E-02	7.26E-07	8.74E-02	3.21E-08	
surface area (cm²)	48	172,800	86,400	125,894	147	464	4.05E-02	4.69E-07	1.28E-01	3.30E-08	
74.011	72	259,200	86,400	213,818	113	577	3.12E-02	3.61E-07	1.59E-01	3.31E-08	
volume (cm³)	96	345,600	86,400	300,849	84	661	2.32E-02	2.68E-07	1.82E-01	2.57E-08	
45.560	120	432,000	86,400	387,596	81	742	2.23E-02	2.59E-07	2.05E-01	3.08E-08	3.27E-08
V/S (cm)	456	1,641,600	1,209,600	939,462	613	1355	1.69E-01	1.40E-07	3.74E-01	2.18E-08	3.28E-08
0.616	1,128	4,060,800	2,419,200	2,716,550	539	1894	1.49E-01	6.15E-08	5.22E-01	1.22E-08	2.78E-08
weight (g) 76.67	2,160	7,776,000	3,715,200	5,768,861	733	2627	2.02E-01	5.44E-08	7.25E-01	2.03E-08	5.63E-08

Initial NO_3 Concentration (ug/g) 47,288

Total NO_3 A_0 (mg) 3625.57

Sample l/d 0.53

* $D = Gd^2/t$

G =6.85E-3 for l/d = 0.53, fraction leached = 0.205

F Leached	l/d = 0.5	l/d = 0.53	l/d =1.0
0.2	5.59E-04	5.85E-04	9.98E-04
0.205	5.90E-04	6.18E-04	1.05E-03
0.21	6.21E-04	6.50E-04	1.11E-03

G =2.36E-3 for l/d = 0.53, fraction leached = 0.374

F Leached	l/d = 0.5	l/d = 0.53	l/d =1.0
0.37	2.18E-03	2.28E-03	3.92E-03
0.374	2.25E-03	2.36E-03	4.05E-03
0.38	2.32E-03	2.43E-03	4.17E-03

* $D = Gd^2/t$

G =4.93E-3 for l/d = 0.53, fraction leached = 0.522

F Leached	l/d = 0.5	l/d = 0.53	l/d =1.0
0.52	4.94E-03	4.72E-03	1.23E-03
0.522	5.02E-03	4.93E-03	3.68E-03
0.53	5.19E-03	5.44E-03	9.40E-03

G =1.91E-2 for l/d = 0.53, fraction leached = 0.725

F Leached	l/d = 0.5	l/d = 0.53	l/d =1.0
0.72	1.21E-02	1.27E-02	2.23E-02
0.725	4.63E-02	1.91E-02	2.26E-02
0.73	1.26E-01	1.20E-01	2.33E-02

Table H-3 Nitrate Effective Diffusion Coefficients for Reference Saltstone Sample 1 Calculated as a Function of Leaching Time. This Sample was Cured at 45°C.

Ref 45 1	
diameter (cm)	4.843
height (cm)	2.521
surface area (cm^2)	75.161
volume (cm^3)	46.416
V/S (cm)	0.618
weight (g)	75.58
Initial $[NO_3]$ Concentration (ug/g)	47,288
Total Cs A_o (mg)	3574.03
Sample l/d	0.52

Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt_n (sec)	Mean time Leach Interval T (sec)	Ref 45 1 Leachate $[NO_3]$ a_n (mg/L)	Cum NO_3 Leached Σa_n (mg/L)	Increment Fraction Leached (a_n/A_o)	Incremental Leach Rate $(a_n/A_o)/(\Delta t)_n$	umulative Fraction Leached $(\Sigma a_n/Ao)$	D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape* (cm^2/sec)
30 sec	30			1	0.075			1.91E+00		
2	7,200	7,200	2,040	134	134.075	2.83E-03	3.94E-07	3.75E-02	3.78E-10	
7	25,200	18,000	14,835	57	191.075	1.21E-03	6.70E-08	5.35E-02	7.97E-11	
24	86,400	61,200	51,231	117	308.075	2.47E-03	4.04E-08	8.62E-02	1.00E-10	
48	172,800	86,400	125,894	110	418.075	2.33E-03	2.69E-08	1.17E-01	1.09E-10	
72	259,200	86,400	213,818	88	506.075	1.86E-03	2.15E-08	1.42E-01	1.19E-10	
96	345,600	86,400	300,849	63	569.075	1.33E-03	1.54E-08	1.59E-01	8.57E-11	
120	432,000	86,400	387,596	63	632.075	1.33E-03	1.54E-08	1.77E-01	1.10E-10	
456	1,641,600	1,209,600	939,462	458	1090.075	9.69E-03	8.01E-09	3.05E-01	7.21E-11	8.91E-08
1,128	4,060,800	2,419,200	2,716,550	437	1527.075	9.24E-03	3.82E-09	4.27E-01	4.75E-11	1.82E-08
2,160	7,776,000	3,715,200	5,768,861	1483	3010.075	3.14E-02	8.44E-09	8.42E-01	4.92E-10	6.43E-08

* $D = Gd^2/t$

G =6.24E-3 for l/d = 0.52,fraction leached = 0.305

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.3	1.35E-03	1.10E-02	2.43E-01
0.305	1.41E-03	6.24E-03	1.22E-01
0.31	1.46E-03	1.46E-03	1.46E-03

* $D = Gd^2/t$

G =3.15E-3 for l/d = 0.52,fraction leached = 0.427

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.42	2.93E-03	3.02E-03	5.28E-03
0.427	3.05E-03	3.15E-03	5.50E-03
0.43	3.10E-03	3.20E-03	5.59E-03

G =7.69E-4 for l/d = 0.52,fraction leached = 0.842

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.84	2.04E-02	2.11E-02	3.83E-02
0.842	2.06E-02	2.13E-02	3.87E-02
0.85	2.14E-02	2.22E-02	4.02E-02

Table H-4 Nitrate Effective Diffusion Coefficients for Reference Saltstone Sample 2 Calculated as a Function of Leaching Time. This Sample was Cured at 45^{0}C.

Ref 45 2	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt (sec)	Mean time Leach Interval T (sec)	Ref 45 2 Leachate [NO3] a_n (mg/L)	Cum NO_3 Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate $[(a_n/A_o)/(\Delta t)_n$	Cumulative Fraction Leached $(\Sigma a_n/Ao)$	[NO3] D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape * (cm^2/sec)
diameter (cm)	30 sec	30			3	0.075			2.08E-05		
4.822	2	7,200	7,200	2,040	145	145.075	4.03E-02	5.60E-06	4.03E-02	7.72E-08	
height (cm)	7	25,200	18,000	14,835	54	199.075	1.50E-02	8.34E-07	5.53E-02	1.25E-08	
2.556	24	86,400	61,200	51,231	131	330.075	3.64E-02	5.95E-07	9.17E-02	2.19E-08	
surface area (cm^2)	48	172,800	86,400	125,894	126	456.075	3.50E-02	4.05E-07	1.27E-01	2.50E-08	
75.206	72	259,200	86,400	213,818	96	552.075	2.67E-02	3.09E-07	1.53E-01	2.46E-08	
volume (cm^3)	96	345,600	86,400	300,849	79	631.075	2.20E-02	2.54E-07	1.75E-01	2.35E-08	
46.654	120	432,000	86,400	387,596	78	709.075	2.17E-02	2.51E-07	1.97E-01	2.95E-08	
V/S (cm)	456	1,641,600	1,209,600	939,462	528	1237.075	1.47E-01	1.21E-07	3.44E-01	1.67E-08	2.74E-08
0.620	1,128	4,060,800	2,419,200	2,716,550	430	1667.075	1.19E-01	4.94E-08	4.63E-01	8.01E-09	2.22E-08
weight (g)	2,160	7,776,000	3,715,200	5,768,861	1318	2985.075	3.66E-01	9.86E-08	8.30E-01	6.77E-08	6.14E-08
76.1											

Initial Cs Concentration (ug/g) 47,288

Total Cs A_0 (mg) 3598.62

Sample l/d 0.53

* $D = Gd^2/t$

G =1.94E-3 for l/d = 0.53,fraction leached = 0.344

F Leached	l/d = 0.5	l/d = 0.53	l/d =1.0
0.34	1.80E-03	1.89E-03	3.22E-03
0.344	1.85E-03	1.94E-03	3.31E-03
0.35	1.92E-03	2.01E-03	3.44E-03

* $D = Gd^2/t$

G =3.89E-3 for l/d = 0.53,fraction leached = 0.463

F Leached	l/d = 0.5	l/d = 0.53	l/d =1.0
0.46	3.65E-03	3.83E-03	6.58E-03
0.463	3.71E-03	3.89E-03	6.69E-03
0.47	3.84E-03	4.03E-03	6.94E-03

G =3.07E-3 for l/d = 0.53,fraction leached = 0.830

F Leached	l/d = 0.5	l/d = 0.53	l/d =1.0
0.83	1.95E-02	2.05E-02	3.65E-02

Table H-5 Nitrate Effective Diffusion Coefficients for Reference Saltstone Sample 1 Calculated as a Function of Leaching Time. This Sample was Cured at 70°C.

Ref 70 1	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt_n (sec)	Mean time Leach Interval T (sec)	Ref 70 1 Leachate [NO_3] a_n (mg/L)	Cum NO_3 Leached Σa_n (mg/L)	Increment Fraction Leached (a_n/A_o)	Incremental Leach Rate $(a_n/A_o)/(\Delta t)_n$	umulative Fraction Leached $(\Sigma a_n/Ao)$	D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape* (cm^2/sec)
diameter (cm)	30 sec	30			2	2			5.08E+01		
4.776	2	7,200	7,200	2,040	121	123	3.33E-02	4.63E-06	3.39E-02	5.17E-08	
height (cm)	7	25,200	18,000	14,835	62	185	1.71E-02	9.49E-07	5.10E-02	1.58E-08	
2.526	24	86,400	61,200	51,231	136	321	3.75E-02	6.12E-07	8.84E-02	2.27E-08	
surface area (cm^2)	48	172,800	86,400	125,894	129	450	3.55E-02	4.11E-07	1.24E-01	2.52E-08	
73.693	72	259,200	86,400	213,818	102	552	2.81E-02	3.25E-07	1.52E-01	2.67E-08	
volume (cm^3)	96	345,600	86,400	300,849	79	631	2.18E-02	2.52E-07	1.74E-01	2.26E-08	
45.231	120	432,000	86,400	387,596	72	703	1.98E-02	2.30E-07	1.94E-01	2.42E-08	
V/S (cm)	456	1,641,600	1,209,600	939,462	539	1242	1.48E-01	1.23E-07	3.42E-01	1.67E-08	2.65E-08
0.614	1,128	4,060,800	2,419,200	2,716,550	529	1771	1.46E-01	6.02E-08	4.88E-01	1.17E-08	2.48E-08
weight (g) 76.78	2,160	7,776,000	3,715,200	5,768,861	431	2202	1.19E-01	3.20E-08	6.06E-01	6.97E-09	2.27E-08

Initial Cs Concentration (ug/g) 47,288

Total Cs A_0 (mg) 3630.77

Sample l/d 0.53

* $D = Gd^2/t$

G =1.91E-3 for l/d = 0.53, fraction leached = 0.342

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.34	1.80E-03	1.89E-03	3.22E-03
0.342	1.82E-03	1.91E-03	3.26E-03
0.35	1.92E-03	2.01E-03	3.44E-03

* $D = Gd^2/t$

G =4.42E-3 for l/d = 0.53,fraction leached = 0.488

F Leached	l/d = 0.5	l/d = 0.53	l/d =1.0
0.48	4.05E-03	4.25E-03	7.31E-03
0.488	4.22E-03	4.42E-03	7.62E-03
0.49	4.26E-03	4.47E-03	7.70E-03

G =1.21E-3 for l/d = 0.53,fraction leached = 0.606

F Leached	l/d = 0.5	l/d = 0.53	l/d =1.0
0.6	7.17E-03	7.53E-03	1.31E-02
0.606	7.37E-03	7.73E-03	1.35E-02
0.61	7.50E-03	7.87E-03	1.37E-02

Table H-6 Nitrate Effective Diffusion Coefficients for Reference Saltstone Sample 2 Calculated as a Function of Leaching Time. This Sample was Cured at R 70°C.

Ref 70 2	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt (sec)	Mean time Leach Interval T (sec)	Ref 70 2 Leachate [NO3] a_n (mg/L)	Cum NO_3 Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate $[(a_n/A_o)/(\Delta t)_n$	Cumulative Fraction Leached $(\Sigma a_n/Ao)$	[NO3] D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape * (cm^2/sec)
diameter (cm) 4.886	30 sec	30			2	0.075			2.00E-05		
	2	7,200	7,200	2,040	96	96.075	2.56E-02	3.55E-06	2.56E-02	3.10E-08	
height (cm) 2.515	7	25,200	18,000	14,835	60	156.075	1.60E-02	8.88E-07	4.16E-02	1.41E-08	
	24	86,400	61,200	51,231	134	290.075	3.57E-02	5.83E-07	7.72E-02	2.10E-08	
surface area (cm^2) 76.066	48	172,800	86,400	125,894	131	421.075	3.49E-02	4.04E-07	1.12E-01	2.47E-08	
	72	259,200	86,400	213,818	97	518.075	2.58E-02	2.99E-07	1.38E-01	2.30E-08	
volume (cm^3) 47.132	96	345,600	86,400	300,849	82	600.075	2.18E-02	2.53E-07	1.60E-01	2.32E-08	
	120	432,000	86,400	387,596	75	675.075	2.00E-02	2.31E-07	1.80E-01	2.50E-08	
V/S (cm) 0.620	456	1,641,600	1,209,600	939,462	522	1197.075	1.39E-01	1.15E-07	3.19E-01	1.50E-08	2.29E-08
	1,128	4,060,800	2,419,200	2,716,550	556	1753.075	1.48E-01	6.12E-08	4.67E-01	1.23E-08	2.26E-08
weight (g) 79.42	2,160	7,776,000	3,715,200	5,768,861	676	2429.075	1.80E-01	4.84E-08	6.47E-01	1.63E-08	2.75E-08

Initial Cs Concentration (ug/g) 47,288

Total Cs A_0 (mg) 3755.61

Sample l/d 0.51

* $D = Gd^2/t$

G =1.57E-3 for l/d = 0.51, fraction leached = 0.319

F Leached	l/d = 0.5	l/d = 0.51	l/d =1.0
0.31	1.46E-03	1.48E-03	2.61E-03
0.319	1.55E-03	1.57E-03	2.79E-03
0.32	1.56E-03	1.59E-03	2.81E-03

* D = Gd2/t

G =3.84E-3 for l/d = 0.51,fraction leached = 0.467

F Leached	l/d = 0.5	l/d = 0.51	l/d =1.0
0.46	3.65E-03	3.71E-03	6.58E-03
0.467	3.78E-03	3.84E-03	6.83E-03
0.47	3.84E-03	3.90E-03	6.94E-03

G =1.30E-3 for l/d = 0.51,fraction leached = 0.647

F Leached	l/d = 0.5	l/d = 0.51	l/d =1.0
0.64	8.56E-03	8.70E-03	1.56E-02
0.647	8.83E-03	8.97E-03	1.62E-02
0.65	8.94E-03	9.09E-03	1.64E-02

Table H-7 Nitrate Effective Diffusion Coefficients for Reference Saltstone Sample 1 Calculated as a Function of Leaching Time. This Sample was Cured at 90°C.

Ref 90 1	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt_n (sec)	Mean time Leach Interval T (sec)	Ref 90 1 Leachate [NO_3] a_n (mg/L)	Cum NO_3 Leached Σa_n (mg/L)	Increment Fraction Leached (a_n/A_o)	Incremental Leach Rate $(a_n/A_o)/(\Delta t)_n$	umulative Fraction Leached (Σa_n/Ao)	D_{eff} (cm²/sec)	D_{eff} Corrected for Shape* (cm²/sec)
diameter (cm)	30 sec	30			2	0.075			1.91E+00		
4.847	2	7,200	7,200	2,040	88	88.075	2.38E-02	3.31E-06	2.38E-02	2.66E-08	
height (cm)	7	25,200	18,000	14,835	80	168.075	2.16E-02	1.20E-06	4.55E-02	2.56E-08	
2.515	24	86,400	61,200	51,231	207	375.075	5.60E-02	9.15E-07	1.01E-01	5.13E-08	
surface area (cm²)	48	172,800	86,400	125,894	223	598.075	6.03E-02	6.98E-07	1.62E-01	7.33E-08	
75.162	72	259,200	86,400	213,818	174	772.075	4.71E-02	5.45E-07	2.09E-01	7.58E-08	5.75E-08
volume (cm³)	96	345,600	86,400	300,849	149	921.075	4.03E-02	4.66E-07	2.49E-01	7.82E-08	6.29E-08
46.382	120	432,000	86,400	387,596	120	1041.075	3.25E-02	3.76E-07	2.82E-01	6.54E-08	6.62E-08
V/S (cm)	456	1,641,600	1,209,600	939,462	889	1930.075	2.40E-01	1.99E-07	5.22E-01	4.44E-08	7.37E-08
0.617	1,128	4,060,800	2,419,200	2,716,550	837	2767.075	2.26E-01	9.36E-08	7.48E-01	4.44E-08	8.13E-08
weight (g)	2,160	7,776,000	3,715,200	5,768,861	562	3329.075	1.52E-01	4.09E-08	9.00E-01	1.15E-08	8.67E-08
78.2											
Initial Cs Concentration (ug/g) 47,288											
Total Cs A_0 (mg) 3697.92											
Sample l/d 0.52											

* $D = Gd^2/t$

G =6.34E-4 for l/d = 0.52, fraction leached = 0.209

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.2	5.59E-04	5.77E-04	9.98E-04
0.209	6.15E-04	6.34E-04	1.10E-03
0.21	6.21E-04	6.41E-04	1.11E-03

G =9.26E-4 for l/d = 0.53, fraction leached = 0.249

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.24	8.28E-04	8.54E-04	1.48E-03
0.249	8.97E-04	9.26E-04	1.61E-03
0.25	9.05E-04	9.34E-04	1.62E-03

G =1.91E-3 for l/d = 0.52, fraction leached = 0.282

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.28	1.16E-03	1.20E-03	2.08E-03
0.282	1.18E-03	1.22E-03	2.11E-03
0.29	1.26E-03	1.30E-03	2.25E-03

* $D = Gd^2/t$

G =5.15E-3 for l/d = 0.52,fraction leached = 0.522

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.52	4.94E-03	5.10E-03	8.95E-03
0.522	4.99E-03	5.15E-03	9.04E-03
0.53	5.19E-03	5.36E-03	9.40E-03

G =1.40E-2 for l/d = 0.52,fraction leached = 0.748

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.74	1.31E-02	1.35E-02	2.43E-02
0.748	1.36E-02	1.40E-02	2.52E-02
0.75	1.37E-02	1.42E-02	2.54E-02

G =2.87E-2 for l/d = 0.52,fraction leached = 0.900

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.9	2.77E-02	2.87E-02	5.23E-02

Table H-8 Nitrate Effective Diffusion Coefficients for Reference Saltstone Sample 2 Calculated as a Function of Leaching Time. This Sample was Cured at 90°C.

Ref 90 2	Cum Time t (hr)	Cum Time t (sec)	Time of Leach Interval Δt (sec)	Mean time Leach Interval T (sec)	Ref 90 2 Leachate [NO3] a_n (mg/L)	Cum NO_3 Leached Σa_n (mg/L)	Incremental Fraction Leached (a_n/A_o)	Incremental Leach Rate $[(a_n/A_o)/(\Delta t)_n$	Cumulative Fraction Leached $(\Sigma a_n/Ao)$	[NO3] D_{eff} (cm^2/sec)	D_{eff} Corrected for Shape * (cm^2/sec)
diameter (cm)	30 sec	30			3	0.075			2.11E-05		
4.895	2	7,200	7,200	2,040	83	83.075	2.34E-02	3.25E-06	2.34E-02	2.63E-08	
height (cm)	7	25,200	18,000	14,835	101	184.075	2.85E-02	1.58E-06	5.19E-02	4.54E-08	
2.548	24	86,400	61,200	51,231	284	468.075	8.00E-02	1.31E-06	1.32E-01	1.07E-07	
surface area (cm^2)	48	172,800	86,400	125,894	292	760.075	8.23E-02	9.52E-07	2.14E-01	1.40E-07	9.25E-08
76.782	72	259,200	86,400	213,818	215	975.075	6.06E-02	7.01E-07	2.75E-01	1.29E-07	1.06E-07
volume (cm^3)	96	345,600	86,400	300,849	169	1144.075	4.76E-02	5.51E-07	3.22E-01	1.12E-07	1.13E-07
47.926	120	432,000	86,400	387,596	138	1282.075	3.89E-02	4.50E-07	3.61E-01	9.60E-08	1.18E-07
V/S (cm)	456	1,641,600	1,209,600	939,462	1013	2295.075	2.85E-01	2.36E-07	6.47E-01	6.40E-08	1.33E-07
0.624	1,128	4,060,800	2,419,200	2,716,550	938	3233.075	2.64E-01	1.09E-07	9.11E-01	3.97E-08	1.81E-07
weight (g)	2,160	7,776,000	3,715,200	5,768,861	523	3756.075	1.47E-01	3.97E-08	1.06E+00	1.11E-08	
75.06											
Initial Cs Concentration (ug/g) 47,288											
Total Cs A_0 (mg) 3549.44											
Sample l/d 0.52											

* $D = Gd^2/t$

G =6.67E-4 for l/d = 0.52, fraction leached = 0.214

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.21	6.21E-04	6.41E-04	1.11E-03
0.214	6.47E-04	6.67E-04	1.16E-03
0.22	6.86E-04	7.08E-04	1.23E-03

G =1.15E-3 for l/d = 0.53, fraction leached = 0.275

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.27	1.07E-03	1.10E-03	1.92E-03
0.275	1.12E-03	1.15E-03	2.00E-03
0.28	1.16E-03	1.20E-03	2.08E-03

G =1.91E-3 for l/d = 0.52, fraction leached = 0.322

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.32	1.56E-03	1.61E-03	2.81E-03
0.322	1.58E-03	1.63E-03	2.85E-03
0.33	1.68E-03	1.73E-03	3.01E-03

* $D = Gd^2/t$

G =2.13E-3 for l/d = 0.52,fraction leached = 0.361

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.36	2.05E-03	2.12E-03	3.68E-03
0.361	2.06E-03	2.13E-03	3.70E-03
0.37	2.18E-03	2.25E-03	3.92E-03

G =9.12E-3 for l/d = 0.52,fraction leached = 0.647

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.64	8.56E-03	8.84E-03	1.56E-02
0.647	8.83E-03	9.12E-03	1.62E-02
0.65	8.94E-03	9.24E-03	1.64E-02

G =3.06E-2 for l/d = 0.52,fraction leached = 0.911

F Leached	l/d = 0.5	l/d = 0.52	l/d =1.0
0.91	2.94E-02	3.04E-02	5.55E-02
0.911	2.96E-02	3.06E-02	5.59E-02
0.92	3.12E-02	3.23E-02	5.90E-02

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Document Approval Sheet

Document No.	WSC-TR-99-00227
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Key Words (list 3)	Saltstone, Cesium, Direct Grout, Salt
Primary Author/Contact (Must be WSRC)	Christine A. Langton
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Phone No.	5-5806
Position	Sr. Fellow Scientist
User ID	T6333
Organization Code	L3230
Organization (No Abbreviations)	Waste Processing Technology
Other Authors	
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Has an invention disclosure, patent application or copyright application been submitted related to this information? ☐ Yes ☒ No If yes, date submitted ________

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Westinghouse
Savannah River Company

P.O. Box 616
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July 27, 1999

WSRC-TR-99-00227
MSD-STI-1999-1353

Ms. W. F. Perrin, Technical Information Officer
U. S. Department of Energy - Savannah River Operations Office

Dear Ms. Perrin:

REQUEST FOR APPROVAL TO RELEASE SCIENTIFIC/TECHNICAL INFORMATION

The attached document is submitted for classification and technical approvals for the purpose of external release. Please complete Part II of this letter and return the letter to the undersigned by 9/8/1999. The document has been reviewed for classification and export control by a WSRC Classification staff member and has been determined to be Unclassified.

Trish Baughman for
Kevin J. Schmidt, WSRC STI Program Manager

I. DETAILS OF REQUEST FOR RELEASE

Document Number: WSRC-TR-99-00227
Author's Name: C. A. Langton
Location: 773-43A Phone 5-5806
Department: Senior Fellow Scientist
Document Title: Direct Grout Stabilization of High Cesium Salt Waste: Cesium Leaching Studies

Presentation/Publication:
Meeting/Journal:

OSTI Reportable

Location: N/A
Meeting Date:

II. DOE-SR ACTION

Date Received by TIO 07/27/99

[X] Approved for Release
~~[X] Approved Upon Completion of Changes~~
[X] Approved with Remarks
[ ] Not Approved
[ ] Revise and Resubmit to DOE-SR

Has been corrected. AJ

Remarks: See attached comments. Also, Approved for release contingent upon any MD approval required.

W. F. Perrin
W. F. Perrin, Technical Information Officer, DOE-SR

9/19/99
Date

DOE F 241.1
(7-98) p. 1 of 2
(Formerly DOE F 1332.15)
(All other versions are obsolete)

US DEPARTMENT OF ENERGY

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c. Patent Assignee ____

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B. STI PRODUCT TITLE Direct Grout Stabilization of High Cesium Salt Waste: Cesium Leaching Studies

C. AUTHOR(s) C. A. Langton
E-mail Address(*es*):

D. STI PRODUCT IDENTIFIER
___ 1. Report Number(*s*) WSRC-TR-99-00227
___ 2. DOE Contract Number(*s*) DE-AC09-96SR18500
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E. ORIGINATING RESEARCH ORGANIZATION Savannah River Site

F. DATE OF PUBLICATION *(mm/dd/yyyy)* ....

G. LANGUAGE (*if non-English*) English

(*Grantees and Awardees: Skip to Description/Abstract section at the end of Part I*)

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J. SUBJECT CATEGORIES *(list primary one first)* 05

Keywords Saltstone, Cesium, Direct Grout, Salt Waste Treatment

K. DESCRIPTION/ABSTRACT

The direct grout alternative is a viable option for treatment/stabilization and disposal of salt waste containing Cs-137 concentrations of 1-3 Ci/gal.

The significant difference between these waste solutions is that the high cesium salt solution will contain between 1 and 3 Curies of Cs-137 per gallon compared to a negligible amount in the current salt solution. This difference will require special engineering and shielding for a direct grout processing facility and disposal units to achieve acceptable radiation exposure conditions. The higher cesium concentrations in the direct grout also require that the cesium leaching be evaluated as a function of curing temperature. ANS 16.1 leaching results and distribution ratios (approximations of distribution coefficients) as a function of temperature are presented in this report.

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DOE F 241.1 (p. 2 of 2)

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Name and/or Position K.J. Schmidt, Manager STI Program & Site Support

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