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Results from the Long-Term Interaction and Modeling of SRL-131 Glass with Aqueous Solutions

D. M. Strachan
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R. O. Lokken

November 1985

Prepared for the U.S. Department of Energy
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ABSTRACT

Leaching studies on SRL-131 simulated defense waste glass have been carried out for a duration of two years. This glass contained nonradioactive elements and depleted uranium to simulate the waste content. The leachants used in this study were deionized water, a sodium bicarbonate/silicic acid solution (silicate water), a synthetic groundwater, and a high ionic strength K-Mg-Na-Cl brine. Two temperatures were used; 40°C and 90°C. The long-term results were in fair agreement with modeling calculations performed using the PHREEQE geochemical code. The leachability of SRL-131 glass from results up to two years followed the trend: deionized water > silicate water > synthetic groundwater > salt brine at 40°C and deionized water $\approx$ synthetic groundwater > silicate water > salt brine at 90°C. Solid state analyses are reported along with an Appendix containing a complete data set.

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INTRODUCTION

During the various processing activities in the production of plutonium for the U.S. national defense programs, waste byproducts were generated. These wastes, which have been generated over about the past 40 years at sites such as the Savannah River Plant in South Carolina and Hanford in Washington, have been stored in underground tanks. Plans for the final disposal of the Savannah River Plant (SRP) waste have now been documented (DOE 1982) and call for the decontaminated soluble fraction of the waste to be mixed with cementitious materials and disposed of in near-surface trenches (Langton 1984). The radionuclide fraction of the soluble waste and the insoluble fraction of the waste will be converted to glass and sent to a geologic repository. In order for the repository to accept the glass, certain performance criteria must be met. Although not fully defined, it is certain that these criteria will include some specification on the rate of release of nuclides from the glass waste form when contacted by water.

To defensibly predict whether glass or any other waste form can meet anticipated radionuclide release criteria, leaching tests are needed which are carried out for times as long as possible and are coupled with modeling calculations. Modeling calculations must be based upon a physical and chemical understanding of glass-water interactions, and not merely a mathematical fit to early-time leaching data. Geochemical models can be used to predict what solution concentrations ought to be, based upon alteration product formation, their related solubilities, and groundwater complexities. These calculations can then be tested against results obtained from long-term experiments. Unfortunately, the number of reported leaching experiments decreases rapidly with increased test length. Very few tests extend beyond one year. In this study, leaching experiments for a Savannah River Laboratory glass (SRL-131) were carried out to two years in four different leachants. The results were then compared to calculations using the PHREEQE geochemical code (Parkhurst, Thorstenson, and Plummer 1980).

Since the test began, the glass formulation for SRP waste has been changed from SRL-131 to SRL-165 (Soper et al 1983). Results from the long-term testing

of SRL-131 glass will, however, still be useful in documenting the long-term performance of SRL-165. The SRL-165 glass formulation is also subject to change as adjustments are made to the overall process that will be used to treat the waste and to produce the glass.

EXPERIMENTAL METHODS

Materials

Samples of SRL-131 glass were produced at Savannah River Laboratory by melting the nonradioactive constituent oxides, carbonates, and nitrates in a laboratory-scale ceramic melter. Depleted uranium was included in the composition. After melting at 1150°C, the molten glass was poured into 0.25L stainless steel beakers. These were subsequently annealed at an unspecified temperature and time before cooling to room temperature. The as-received samples were cut into specimens of approximately 400mm² surface area (approximately 13mm x 11mm x 2mm), washed in an ultrasonic bath, dried, and weighed. The washes included one in acetone, one in ethanol and one in deionized water.

Randomly selected specimens were analyzed by crushing the specimen into a fine powder and fusing a portion with Na₂O₂ and another portion with KOH. The fusates were then dissolved in 6 M HCL and diluted to a known volume. The resulting solutions were analyzed using an Inductively Coupled Plasma Spectrometer (ICP; a Model 3560, ARL, Palo Alto, CA, or a Model Mark 8, Jarrel- Ash, Cambridge, MA). The results from these analyses are shown in Table 1. Cesium was analyzed using Atomic Absorption Spectrometry.

Leach Test

Four synthetic leachants were used in this experiment: deionized water, a silicic acid/sodium bicarbonate water, a nearly saturated salt brine, and a synthetic groundwater. The first three leachants were those recommended by the Materials Characterization Center (MCC 1981). The synthetic groundwater composition was that specified by Jones (1982). The composition of these leachants, except for the deionized water (Millipore Corp.), are shown in Table 2.

TABLE 1. Composition of SRL-131 Glass

	<u>Wt% Oxide</u>		<u>Wt% Oxide</u>
Al ₂ O ₃	3.05	MgO	1.24
B ₂ O ₃	9.84	MnO ₂	4.17
BaO	0.01	Na ₂ O	14.77
CaO	1.04	Nd ₂ O ₃	0.45
CeO ₂	0.24	NiO	1.54
Cr ₂ O ₃	0.18	P ₂ O ₅	0.10
Cs ₂ O	0.30	SiO ₂	38.60
CuO	0.02	SrO	0.14
Fe ₂ O ₃	14.28	TiO ₂	0.75
K ₂ O	0.12	UO ₂	1.62
La ₂ O ₃	0.33	ZrO ₂	0.31
Li ₂ O	3.89		
		<u>TOTAL</u>	<u>97.00</u>

TABLE 2. Leachant Composition (mg/L)⁽¹⁾

	<u>Silicate Water</u>	<u>Synthetic Groundwater</u>	<u>Salt Brine</u>
B (0.01)	0.04	-	17 (0.1)
Ca (0.01)	-	2.4	302 (0.1)
Fe (0.005)	-	-	0.3 (0.05)
K (0.3)	-	3.58	26800 (300)
Li (0.004)	-	-	35.2 (0.04)
Mg (0.06)	-	-	30800 (60)
Na (0.01)	47.9	364	34400 (10)
Si (0.02)	28.9	30.4	(0.2)
Sr (0.002)	-	0.004	10 (0.02)

(1) The numbers in parentheses are the detection limits in low ionic strength solutions (left) and the salt brine (right). All concentrations shown in this table are from analyses.

Although the MCC-1 Static Leach Test Method is described in detail elsewhere (MCC 1981), it is briefly described here. The specimens described above were placed in Teflon PFA jars containing a Teflon PFA specimen support and a volume of leachant equal to 10.0 times the specimen surface area. A tight-fitting lid was screwed on and the whole assembly was weighed. These jars were then placed in mechanical convection ovens (Blue M. Co, WI) at either 40°C or 90°C. Table 3 shows the test matrix that was used. Each jar/leachant/specimen assembly represented one data point. At the specified time a jar/leachant/specimen was removed from the oven and weighed. The specimen was removed, washed, air dried, and weighed. The solution, now labeled the leachate, was allowed to cool to room temperature in the resealed jar. After cooling, the pH of an aliquot was measured using a calomel combination electrode (Orion Corp., MA).

Periodically, jar/leachant/specimen assemblies were removed from the oven and weighed. Over the two-year time period, none of the assemblies lost more than 10% of the water.

During the first six months of the test and after removal of the specimens, the leachates were acidified using concentrated acids to 1 vol% HNO₃ for the nonbrine leachants and 1 vol% HCL for the brine leachants, returned to a 90°C oven for about 16 hours, and then analyzed. For test durations longer than six months, the leachants were filtered through 2 nm filters, acidified

TABLE 3. Test Matrix for the 2-yr Leach Test at 40°C and 90°C

<u>Leachant/Test Duration (d)</u>	<u>Number of Specimens per Leachate</u>										<u>Total # of Tests</u>
<u>Leachant</u>	3	7	14	28	56	91	182	364	546	728	
Deionized Water	1	1	1	3	2	3	2	3	3	3	22
Silicate Water				3	2	3	2	3			13
Salt Brine				3	2	3	2	3	3(a)	3(a)	19
Synthetic Groundwater				3	2	3	2	3	3(b)	3(b)	<u>19</u>
											73

(a) Leached only at 40°C.

(b) Leached only at 90°C.

and analyzed. The jars were filled with a 1% acid solution, returned to the 90°C oven for about 16 hours, cooled, and the resulting solution analyzed.

Solid State Analyses

Selected specimens were submitted for solid state analyses. In general, these were done by carbon coating the air-dried specimen and examining the as-leached surface using a SEM (JEOL, MA). These were then mounted in a thermoset resin, cut, and polished. Both SEM and Electron Microprobe (EMP; JEOL, MA) were used to analyze the specimens in cross section. Energy dispersive x-ray analyses were used in the SEM and wavelength dispersive energy analyses were used in the EMP to determine elemental profiles.

Solubility Calculations

In order to better understand the glass/water interactions, calculations similar to those performed by Grambow and Strachan (1984) were done using a modified version of the PHREEQE geochemical code (Parkhurst, Thorstenson, and Plummer 1980). The code had been modified to facilitate graphics and efficient processing of data.

RESULTS AND DISCUSSION

This section is divided into sections by leachant type, with data presented in the following order: deionized water, silicate water, salt brine, and synthetic groundwater. In each subsection both temperatures are discussed. Because the data sets are quite large, much of the data have been compiled in the appendix. An effort has been made to make this data set as complete as possible. Not all of the data from the solid state analyses could be included, however.

Selected photomicrographs of the as-leached specimens are shown in the following sections. These photomicrographs may, at first glance, be confusing. In each photomicrograph, the as-leached surface is shown on the left and the cross section on the right.

Deionized Water Results

The results from the leach tests in deionized water are summarized in Figures 1 to 6. The complete set of analytical data are tabulated in

FIGURE 1. Normalized Mass Loss ($\text{g}\cdot\text{m}^{-3}$) Results from the Leaching of SRL-131 Glass in 40°C Deionized Water

FIGURE 2. Normalized Mass Loss ($\text{g}\cdot\text{m}^{-3}$) Results from the Leaching of SRL-131 Glass in 40°C Deionized Water

FIGURE 3. Normalized Mass Loss ($\text{g}\cdot\text{m}^{-3}$) Results from the Leaching of SRL-131 Glass in 90°C Deionized Water

FIGURE 4. Normalized Mass Loss ($\text{g}\cdot\text{m}^{-3}$) Results from the Leaching of SRL-131 Glass in 90°C Deionized Water

40°C DEIONIZED WATER

FIGURE 5. Leachate pH values from SRL-131 Glass in 40°C Deionized Water

FIGURE 6. Leachate pH values from SRL-131 Glass in 90°C Deionized Water

Appendix A, Tables A.1 through A.4. Figures 1 to 4 and Tables A.3 and A.4 are compilation of the normalized elemental mass losses. Tables A.1 and A.2 and Figures A.1 to A.4 are the raw analytical data in mg/L. Figures 1, 2, and 5, and Tables A.1 and A.3 give 40°C data, while the remainder of the plots and tables are for the 90°C data. Figures 5 and 6 are the results from the pH measurements.

At 40°C after two years of leaching in deionized water, the extent of reaction between glass and water was small when compared with the results of tests at 90°C. Photomicrographs of the surface of the leached glass (Figure 7) after 728d of contact with water at 40°C still reveal the sharp edges that resulted from the cutting of the specimen. The surface is, however, relatively more enriched in Fe than the original glass. Cross sectional analyses of these specimens were not done because of the relative thinness of the gel layer, as seen in the photomicrographs from specimens of shorter time periods.

Examination of the photomicrographs of the as-leached surface from the 90°C test indicates that extensive reaction has taken place (Figure 8). There is no remaining evidence of the fracture topography that resulted from the cutting of the specimens. Although the gel layer remained intact and quite resistant to spalling while wet or moist, it readily flaked off after air drying. So much of the gel layer flaked off that it was difficult to find an area to obtain good photomicrographs. At 546d the surface (Figure 8) was characterized by large (20 to 30 μm) blotchy areas that were high in Mn, Fe, and Si with traces of Ca, Mg, and Ni. These areas were also present at 728d (Figure 8). Just below the gel layer, the glass surface appeared somewhat mottled at 546d but evenly textured at 728d. These differences were most likely due to differences in the initial specimen and not due to leaching. Cross sectional analyses showed that the 546d specimen had a gel layer of 32 μm to 35 μm in thickness and the 728d, 38 μm to 40 μm . In general, the surface of the gel layer was about 5 times more concentrated in Mn than the original concentration in the glass. This concentration decreased between the gel layer surface and the unaltered glass. The Mn concentration reached a minimum in the gel layer just adjacent to the unaltered glass.

FIGURE 7. Photomicrographs from Specimens Leached in Deionized Water at 40°C: as-leached surface, cross section

FIGURE 8. Photomicrographs from Specimens Leached in Deionized Water at 90°C: as-leached surface, cross section (NOTE: the 546d cross section is rotated by 90 degrees)

Also in the gel layer just adjacent to the unaltered glass of the specimen leached for 728d at 90°C was a layer of dense crystallites approximately 1 μ m in diameter (Figure 8). These crystallites were determined to be very rich in U. However, because of the small size, even a good qualitative analysis could not be achieved. A diffuse U rich layer was also found in the 365d leached specimens but the crystallites were not observed. This is a rather important finding since the gel layer was about 10 μ m thicker in the 728d specimen. This would indicate that as the gel layer grew from 26 μ m at 365d to 35 μ m at 728d, the U tended to migrate with and toward the glass/gel layer interface and the uranium concentrated enough to crystallize.

The rate of reaction of glass with water at 40°C after 728d of leaching did not decrease with time, unlike results obtained at 90°C. In general, this appears to have been due to very slow leaching kinetics, and therefore, a slow approach to saturation of critical components in solution such as silica. Approach to saturation with respect to silica has been found to moderate the rate of glass reaction (Pederson, Buckwalter, McVay, and Riddle 1983). Solution data generally indicated a smooth rise in concentration of the soluble species, such as B, Na, and Li, throughout the 728d reaction period. Figure 5 shows that the pH rose rapidly to about 9.2 then fell to a final value of about 8.6. There appeared to be a slight halt in the uniform rise at about 182d. This maybe due to an error in the measurement of the pH for one of the specimens (Appendix A, Table A1, spec. 820-287 and 288). This halt was followed by a nearly linear rise in the normalized mass loss of B, Li, and Na, while the pH remained nearly constant. Solubility controls for elements such as Fe, Ca, Cs, Si, etc. were indicated by the solution analyses (Figures 1 and 2), although slow kinetics relative to matrix dissolution may also be an explanation.

At 90°C steady increases in the solution concentrations of the more soluble elements, such as B, Li, and Na, were noted for the first 365d, followed by a leveling off in the rate of increase between 365d and 728d (Figure 3). The behavior of the other elements in solution indicated that new solid phases were controlling the concentrations or that the concentrations were a result of slow kinetics (Figures 5 and 6). The pH rose rapidly to 10.1, then, over the remaining reaction time, decreased slightly to about 9.9 (Figure 6).

Additional understanding of the reaction between the glass and deionized water can be obtained by calculating what the solution chemistry ought to have been based on uniform reaction of the glass with water followed by solubility controls for elements that form alteration products. The results of such a calculation for the 40°C data is shown in Figure 9. This plot was constructed using the PHREEQE geochemical code (Parkhurst, Thorstenson, and Plummer 1980). In this plot data for the ordinate were calculated by dividing the theoretical concentration of any given element by the mass fraction of that element in the glass. Data for the x-axis were calculated in a similar manner but are expressed as the amount of glass dissolved in solution with the assumption that all of the glass that reacts dissolves. This quantity gives a parameter which is equivalent to the reaction progress parameter discussed by Aagaard and Helgeson (1982) and applied to glass dissolution by Grambow (1983a). Any element for which solubility controls do not exist at the concentrations of interest here, such as boron, are calculated to leach congruently and the data for both axes are equal. In these plots the curves represent the calculated data and the data points come from the experiments. For this plot (Figure 9) the solid alteration phases that best fit the data were $\text{Fe}(\text{OH})_3$, $\text{Nd}(\text{OH})_3$, rhodochrosite (MnCO_3), analcime ($\text{NaAlSi}_2\text{O}_6 \cdot \text{H}_2\text{O}$), sepiolite [$\text{Mg}_2\text{Si}_3\text{O}_6(\text{OH})_4$], calcite (CaCO_3), and amorphous SiO_2 . It should be noted that these phases were used because they best fit the solution data, but no experimental evidence for these phases could be found. Rhodochrosite does not appear to be a good solid to have been used for Mn since the leach data, except for one data point, appear to be undersaturated with respect to this solid. However, other Mn containing minerals were not available in the version of PHREEQE that was used for the calculations. No Mn solids were identified by the MCC (1984) for specimens leached at 70°C. The Ca data are also undersaturated with respect to calcite, but it has been suggested that this is due to sorption and not to a solubility control (Strachan, Krupka, and Grambow 1984). Leonhardite [$\text{Ca}_2\text{Al}_4\text{Si}_8\text{O}_{24} \cdot 7\text{H}_2\text{O}$] was also used as a control for Ca in one of the calculations, but the calculated Ca data were more than two orders of magnitude below the observed values. Aluminum appears to be controlled by analcime. This phase has frequently been

FIGURE 9. Calculated and Observed Data From SRL-131 Glass in Deionized Water at 40°C

reported on the surfaces of reacted glasses and has been reported by the MCC (1984) for SRL-131 glass leached at 70°C. Alcalcime is predicted to begin precipitating at 182d.

Strong evidence that alteration phases were controlling some of the concentrations of some of the elements in solution at 90°C is evident by comparing the normalized elemental mass losses for all elements with that of B. Some of the data are plotted in Figure 10 where the theoretical curves are again obtained using the PHREEQE code. For this plot the solid alteration phases that best fit the data were $\text{Fe}(\text{OH})_3$, $\text{Nd}(\text{OH})_3$, rhodochrosite (MnCO_3), alcalcime ($\text{NaAlSi}_2\text{O}_6 \cdot \text{H}_2\text{O}$), sepiolite [$\text{Mg}_2\text{Si}_3\text{O}_6(\text{OH})_4$], hydroxyapatite [$\text{Ca}_5(\text{PO}_4)_3\text{OH}$], leonhardite [$\text{Ca}_2\text{Al}_4\text{Si}_8\text{O}_{24} \cdot 7\text{H}_2\text{O}$], gibbsite [$\text{Al}(\text{OH})_3$], and amorphous SiO_2 . It should be noted again that these phases were used because they best fit the solution data, but no experimental evidence for these phases could be found. Attempts to obtain x-ray diffraction from the air-dried gel layer yielded only diffuse scatter. If any diffraction did occur it was below the background radiation. Most of these phases were reported by the MCC (1984). The differences are anhydrite [CaSO_4], tobermorite [$\text{Ca}_5(\text{OH})_2\text{Si}_6\text{O}_{16} \cdot 8\text{H}_2\text{O}$], and montmorillonite type clays [$\text{Na}_n(\text{Al,Mg})_2\text{Si}_4\text{O}_{10}(\text{OH})_2 \cdot x\text{H}_2\text{O}$] for Al, Mg, Si, and Ca instead of hydroxyapatite and leonhardite, because these phases were not in the data base used. No Mn phases were reported. However, the fit between the data and the theoretical curves is good. Aluminum appeared initially to be controlled by leonhardite and then by alcalcime and leonhardite. Manganese increased steadily and appeared to remain slightly undersaturated with respect to rhodochrosite. Hydroxyapatite was used to explain the large undersaturation with respect to calcite and because the P data indicate a solubility control for phosphorous. Calcium however, is probably controlled by sorption rather than by a crystalline phase, as noted by Strachan, Krupka, and Grambow (1984). The very large degree of Ca oversaturation relative to that calculated using leonhardite strongly suggests that this phase is inappropriate for Ca control. Iron appears to be adequately predicted using $\text{Fe}(\text{OH})_3$. Dissolved silica was slightly undersaturated with respect to alcalcime and the glass/water reaction did not progress far enough after 728d for amorphous silica saturation. The pH at 90°C is predicted to increase steadily throughout the reaction period, but the pH values at 25°C were not calculated.

FIGURE 10. Calculated and Observed Data From SRL-131 Glass in Deionized Water at 90°C

The use of rhodochrosite as a solid phase for Mn is worthy of some discussion since the solid state analyses found "crystals" containing high concentrations of Mn and significant concentrations of Fe and Si. Rhodochrosite is a phase with Mn in the reduced Mn(II) state. Since the experiments were performed under oxidizing and alkaline conditions, the presence of a reduced phase seems unlikely and most of the Mn ought to be present as Mn(III) (Cotton and Wilkinson 1980). However, if one considers that the Fe in the glass is predominantly in the Fe(II) state (MCC 1984), that the redox reactions may be kinetically slow, and that the pH in the gel layer may be different from that measured in the bulk solution (Bunker, Arnold, Beauchamp, and Day 1983), then the reduced phase may be possible. Evidence for the possibility of slightly reducing conditions was found by the MCC (1984) using x-ray photoelectron spectroscopy of the alteration layer of SRL-131 glass leached at 90°C. Small changes in the redox or in the pH can have dramatic effects on the solubility of Mn. For instance, a relatively small decrease in the $pe + pH$ from 20.6 to 16.6, say by having a near-neutral pH in the gel layer, increases the solubility of MnO_2 by 10^8 (Lindsay 1979). Such strong effects make it difficult to select the exact phase; other problems, such as solid solution, notwithstanding. Other Mn containing phases were also considered, such as hausmannite (Mn_3O_4) and manganite ($MnOOH$), but these phases would yield concentrations that are too low by orders of magnitude (Lindsay 1979). Most silicate phases are formed with Mn(II) and not the more oxidized states of Mn. The silicate phases are also much more soluble than rhodochrosite. Thus, the solution concentrations of Mn and the solubility of the various Mn phases suggest that the Mn was present in a lower oxidation state than Mn(IV), probably a mixture of Mn(III) and Mn(II), and that $MnCO_3$ approximates the Mn behavior.

Silicate Water Results

Data on the solutions from the leach tests in silicate water are shown in Tables A.5 through A.8, Figures A.5 through A.9, and in Figures 11 through 15. In keeping with the pattern set for the deionized water results, Tables A.5 and A.6 and Figures A.5 through A.9 summarize the analytical data in mg/L, while Tables A.7 and A.8 and Figures 11 through 13 summarize the normalized elemental mass losses. Tables A.5 and A.7, Figures A.5 through A.9, and Figures 11, 12,

FIGURE 11. Normalized Mass Loss ($\text{g}\cdot\text{m}^{-3}$) Results from the Leaching of SRL-131 Glass in 40°C Silicate Water

FIGURE 12. Normalized Mass Loss ($\text{g}\cdot\text{m}^{-3}$) Results from the Leaching of SRL-131 Glass in 40°C Silicate Water

FIGURE 13. Normalized Mass Loss ($\text{g}\cdot\text{m}^{-3}$) Results from the Leaching of SRL-131 Glass in 90°C Silicate Water

and 14 are for the 40°C data while the remainder are for the 90°C data. The pH data are summarized in Figures 14 and 15. In both cases the experiments were only carried out for 365d.

Although the starting pH of the silicate water was higher than that of the deionized water, the pH after a brief period was the same in both leachates at both temperatures (Figures 14 and 15). Differences in the leachability between the two leachates can be ascribed to the increase in the dissolved silica, which was 59.4 mg SiO₂/L (27.7 mg Si/L). In general, it has been shown (Pederson, Buckwalter, McVay, and Riddle 1983) that increasing the dissolved silica concentration in the water lowers the rate at which borosilicate waste glasses are attacked by water, although there may be other factors that change this trend (see the discussion of the synthetic groundwater results shown below). Thus, the leachability of SRL-131 glass was lower in the silicate water than it was in the deionized water leachant. Solubility/sorption controls are indicated in the leach data (Figures 11 through 13) where the B, Li, and Na data are compared with the remainder of the data. For both the 40 and 90°C data, the normalized elemental mass losses for B, Li, and Na were greater than those of the less soluble elements.

To highlight the effect of solubility controls at 40°C on the solution concentrations, a plot was constructed using the PHREEQE code and the data from Table A.6 (Figure 16). This plot was constructed using the minerals Fe(OH)₃, Nd(OH)₃, rhodochrosite (MnCO₃), analcime (NaAlSi₂O₆·H₂O), sepiolite [Mg₂Si₃O₆(OH)₄], calcite, gibbsite [Al(OH)₃], and amorphous SiO₂. One noticeable difference between this plot and that for deionized water is that the Si concentration extends to the left of the congruent leaching line. This is because Si was present in the leachant. This concentration could be subtracted, but the information that would be lost is the variation of the Si just prior to saturation with respect to amorphous SiO₂. The agreement between the data and the calculated values is good. In the case of Ca, the data suggest that the departure from congruent dissolution was due to sorption, as discussed above for the deionized water leachant. There is good agreement between the calculated and observed Mg concentrations based on sepiolite. In general, there did not appear to have been any solubility controls for Mg in

FIGURE 14. Leachate pH values from SRL-131 Glass in 40°C Silicate Water

FIGURE 15. Leachate pH values from SRL-131 Glass in 90°C Silicate Water

FIGURE 16. Calculated and Observed Data From SRL-131 Glass in Silicate Water at 40°C

glass/water experiments of two years duration at 40°C. Analytical error is probably the reason that the last two Mg data points are above the congruent dissolution line. Sepiolite was predicted to begin precipitating at about the same time the experiment ended. Since U data were not in the data base, these calculations could not be done. The Mn data are also in good agreement with the calculations. Aluminum was undersaturated with respect to gibbsite, which was the only solubility control for Al until a short period of reaction progress when both gibbsite and analcime controlled the Al. After that short period, analcime solely controlled the solution concentration of Al.

At 90°C, solubility/sorption controls for Al, Ca, Cs, Si, Sr, and U are evident from the normalized elemental mass loss plot (Figure 13). These data are corroborated by the solid state analysis and the PHREEQE calculations. The pH of the leachate rose from the leachant pH of 7.5 to about 9.7 after 28d (Figure 15), and remained fairly constant until the experiment was terminated after 365d.

Calculations using the PHREEQE code were made using the solid phases $\text{Nd}(\text{OH})_3$, $\text{Fe}(\text{OH})_3$, sepiolite, rhodochrosite, leonhardite, analcime, and amorphous SiO_2 . These phases led to the data shown in Figure 17. In general, there is good agreement between the observed and calculated data, although the Mg data appear to be quite oversaturated with respect to sepiolite. However, only at two time periods was Mg observed in excess of the analytical detection limits. Similar comments as were made earlier for the Ca data in deionized water at 90°C apply here as well. The calculated pH curve is somewhat more complex than those shown earlier. As the solid phases, such as leonhardite and analcime, precipitate, hydronium ions are generated. This causes inflections in the pH curve with increasing reaction progress. These data have not been recalculated to 25°C for comparison with the observed pH values.

Solid state analyses indicated a gel layer about 10 μm in thickness after 365d of leaching at 90°C, and about 3 μm after similar times at 40°C (Figures 18 and 19). This layer was enriched in those elements for which solubility/sorption was indicated by the solution analyses. The Mn concentration increased between the gel/glass interface while the Ca and U concentrations reached maxima within the gel layer then decreased toward the surface. In the

FIGURE 17. Calculated and Observed Data From SRL-131 Glass in Silicate Water at 90°C

FIGURE 18. Photomicrographs from Specimens Leached in Silicate Water at 40°C: as-leached surface, cross section

FIGURE 19. Photomicrographs from Specimens Leached in Silicate Water at 90°C: as-leached surface, cross section

case of Ca, the concentration reached a maximum near the middle of the gel layer. Uranium was at its maximum concentration near the gel/glass interface, similar to the uranium concentration profile on the specimens from the deionized water experiment. These observations are, however, qualitative since the density of the gel layer is lower than that of the glass and, in general, not known. Therefore, one has to be cautious when interpreting the solid state analyses in gel layers.

Salt Brine Results

Results from the leaching of SRL-131 glass in the standard MCC salt brine (MCC 1981) are tabulated in Tables A.9 through A.12 and plotted in Figures 20 through 24 and in Figures A.10 through A.13. Tables A.11 and A.12 and Figures 20 through 22 are the normalized elemental mass loss data, while the remainder of the tables and plots are the analytical data in mg/L or are pH values. Tables A.9 and A.11 and Figures 20, 21, and 23 are for the 40°C data while the remainder are for the 90°C data. Experiments in salt brine at 90°C were terminated after 365d but continued to 728d at 40°C. The rationale behind the decision to continue the experiment at 40°C but not at 90°C was that the lower temperature represented a more realistic temperature for a salt repository after breach of the canister plus overpack (ONWI, 1983). Figures 23 and 24 show the pH as a function of time. Two curves are drawn in each figure; one is the pH measured at room temperature and the other is the corrected pH. A Gran titration was performed to determine the pH error arising from the liquid junction potential in high ionic strength solutions (Pederson 1985). In this method, a series of standard acid additions are made to a known volume of salt brine, beyond the buffering capacity of any of the salt brine components. Where buffering is non-existent, a linear relation exists between the quantity of acid added per liter of solution and the hydrogen ion concentration, as measured using a pH electrode. The logarithm of the slope of that line gives the error in pH contributed by some offset voltage at the liquid junction. For the MCC salt brine, the pH correction is $+0.98 \pm 0.01$ pH units, i.e. a measured pH of 7.00 is actually 7.98.

From Figures 20 and 22, it is immediately obvious that the leachability of SRL-131 glass in the MCC salt brine is very low; lower, in fact, than in any of

FIGURE 20. Normalized Mass Loss ($\text{g}\cdot\text{m}^{-3}$) Results from the Leaching of SRL-131 Glass in 40°C Salt Brine

FIGURE 21. Normalized Mass Loss ($\text{g}\cdot\text{m}^{-3}$) Results from the Leaching of SRL-131 Glass in 40°C Salt Brine

FIGURE 22. Normalized Mass Loss ($\text{g}\cdot\text{m}^{-3}$) Results from the Leaching of SRL-131 Glass in 90°C Salt Brine

FIGURE 23. Leachate pH values from SRL-131 Glass in 40°C Salt Brine

FIGURE 24. Leachate pH values from SRL-131 Glass in 90°C Salt Brine

the other leachants. At shorter leach times a similar effect, although not as dramatic, was observed for PNL 76-68 glass (Strachan 1983). One of the main differences between PNL 76-68 glass and SRL-131 glass is that, at 90°C after 365d of contact with salt brine, the normalized boron mass loss for PNL 76-68 glass was nearly equal to that in the other leachants, whereas the normalized boron mass loss for SRL-131 glass was substantially lower.

Glass reaction rates in NaCl-rich saturated salt brines have been reported to be considerably lower than in deionized water (Braithwaite 1980; Shade, Pederson, and McVay 1983), particularly after long reaction times. However, saturation concentrations for silica are also lower in solutions of high ionic strength than in deionized water, consistent with a lowering of the activity of water by solvation ions (Marshall 1980). Further, saturation with respect to silica is known to reduce the rate of glass reaction (Pederson, Buckwalter, McVay, and Riddle 1983). Therefore, it follows that the reaction of glass will proceed more slowly in salt brines than in deionized water because of a more rapid approach to saturation with respect to silica and/or a more rapid increase in the rate at which the silanol groups condense (Grambow 1983b) for the same amount of glass reaction. In addition, Grambow and Strachan (1984) have correlated the rate of leaching of nuclear waste glasses to the driving force, eg. chemical potential difference between silica in the glass and that in the gel layer. When glasses were leached in a dilute solution of $MgCl_2$, they found that the rate of glass reaction was ultimately dependent upon the precipitation rate of sepiolite. Since the rate of precipitation as well as dissolution is temperature dependent, the same model may be applicable to the reaction of SRL-131 glass in MCC salt brine at 40°C.

Figure 25 traces the development of the surface composition and structure from 28d to 728d at 40°C. Remnants of the original fracture surface that resulted from cutting the specimen are evidence of the slow reaction rate. After 728d of contact with MCC salt brine the surface was covered with a protruding plate-like material. After 728d of leaching the layer was about $1\mu m$ thick, which makes analyses of the surface difficult to obtain without a significant contribution from the unreacted glass below the surface. However, the surface appears to be enriched in Fe and Mg. This would be consistent with the

FIGURE 25. Photomicrographs from Specimens Leached in Salt Brine at 40°C: as-leached surface, cross section

results from the other leachants, which showed the ease with which Mg tends to precipitate. In cross section the altered layer was too thin to obtain any composition information.

Figure 26 traces the development of the surface composition and structure of the specimens reacted at 90°C for up to 365d. For these specimens a much thicker gel layer developed - about 3 μ m after 365d. The absence of the cracks that resulted from the sawing, previously noted in the specimens leached at 40°C in deionized water (see Figure 7), is puzzling. If the normalized B data for the 365d salt brine leachate are divided by the density of the glass (2.75g/cm³), a leach depth of 5.8 μ m is calculated or nearly double the observed leach depth, but less than the depth of the cracks observed in the deionized water specimen. If the 5.8 μ m depth is correct, then the observed depth was the result of the removal of a substantial amount of material and/or the gel layer resulting from the reaction with salt brine was very dense - much more dense than the gel layers obtained by reaction with the other leachants. Evidence for highly dense gels has been reported elsewhere (Grambow and Strachan 1984).

Photomicrographs of the specimens reacted at 90°C from the 28d and 91d tests show the development of segregated clumps of apparently amorphous material (Figure 26). This material at 28d was very enriched in Mg and appeared to be a Mg silicate, perhaps sepiolite. At 91d these clumps of material were still present but the composition appeared to have shifted toward a more silica rich Mg silicate. This, however, may be a natural result of the increased ionic strength of the solution and its effect on the solubility of silica (Marshall and Warakomski 1980, Chen and Marshall 1982) or a tendency for this amorphous material to have a variable composition that is SiO₂-rich. After 365d of contact with the MCC salt brine these clumps of material were no longer visible as distinct entities but as small specks found throughout the gelsurface. No evidence of these Mg silicate clumps was found in the cross sections of the 365d specimen. Instead, a rather uniform layer was found that was enriched in Mg, Fe, Si, and other insoluble elements. Although not well resolved, there appeared to be an increasing amount of Cl⁻ in the magnesium-rich silicates. This may indicate that the magnesium oxychloride reported by

FIGURE 26. Photomicrographs from Specimens Leached in Salt Brine at 90°C as-leached surface, cross section

the MCC (1984) was also present. Areas of magnesium oxychloride such as those reported by the MCC (1984) were not found, however.

Apparent crystal formation followed by the formation of a gel, which either replaces the crystalline material or fills in the voids, has been observed in the reaction of basalt glass with sea water (Crovisier et al 1983a, 1983b). When basalt glass reacted with sea water, an amorphous gel layer was formed, upon which hydrotalcite $[\text{Mg}_6\text{Al}_2\text{CO}_3(\text{OH})_{16}\text{H}_2\text{O}]$ grew. After a period of time, the hydrotalcite crystals were covered by an amorphous Si-Mg-Al gel followed in sequence by the growth of saponite, an ill-defined magnesium-alumino-silicate clay-like material, on the surface of the hydrotalcite, and serpentine $[\text{Mg}_6\text{Si}_4\text{O}_{10}(\text{OH})_8]$ between the hydrotalcite and the hydrated glass surface. This complex sequence of crystallization is difficult to decipher without the aid of a good transmission electron microscopic study.

Because of the high ionic strength of the MCC salt brine, no attempt was made to calculate the solution concentrations as a function of glass dissolution using the PHREEQE code.

Synthetic Groundwater Results

Results from the reaction of SRL-131 glass in a synthetic groundwater are summarized in Figures 27 through 32, Figures A.14 through A.17, and Tables A.13 through A.16. Figures 27 through 30 and Tables A.14 and A.16 are the normalized elemental mass loss data and the remainder of the figures and tables are the analytical data in mg/L or pH. The 40°C data are summarized in Figures 27 and 28 and Tables A.13 and A.15. Because the repository temperature is predicted to be greater than 40°C (DOE 1982b) and to decrease the cost of the test, experiments using synthetic groundwater as the leachant were continued from 365d to 728d at 90°C only.

The leachability of this glass in synthetic groundwater was about equal to that in deionized water. At 90°C the normalized releases of B (Figure 29) were about the same as in deionized water except that the rate of increase slowed earlier than in deionized water. Many elements show signs of solubility/sorption controls. These solubility/sorption controls can be seen by

FIGURE 27. Normalized Mass Loss ($\text{g} \cdot \text{m}^{-3}$) Results from the Leaching of SRL-131 Glass in 40°C Synthetic Groundwater

FIGURE 28. Normalized Mass Loss ($\text{g} \cdot \text{m}^{-3}$) Results from the Leaching of SRL-131 Glass in 40°C Synthetic Groundwater

FIGURE 29. Normalized Mass Loss ($\text{g} \cdot \text{m}^{-3}$) Results from the Leaching of SRL-131 Glass in 90°C Synthetic Groundwater

FIGURE 30. Normalized Mass Loss ($\text{g} \cdot \text{m}^{-3}$) Results from the Leaching of SRL-131 Glass in 90°C Synthetic Groundwater

FIGURE 31. Leachate pH values from SRL-131 Glass in 40°C Synthetic Groundwater

FIGURE 32. Leachate pH values from SRL-131 Glass in 90°C Synthetic Groundwater

comparing the data plotted in Figures 29 and 30. Cesium showed higher normalized elemental mass losses than those observed in the deionized water tests (see Figures 3 and 29) whereas the Si losses were lower. As expected from the solution analyses, very little reaction of the glass with synthetic groundwater at 40°C was evident (Figure 33). Calcium in the synthetic groundwater reacted quite rapidly with the glass at 90°C and decreased to near detection limits. It is uncertain if this is due to sorption or to precipitation, although calcium in the starting solution calculates to be saturated with respect to calcite (CaCO_3) and fluorite (CaF_2). No anion analyses were performed so precipitation of fluorite cannot be confirmed. Strontium behaved in a fashion similar to Ca. Uranium remained at concentrations of less than 1mg/L even under these oxidizing conditions.

As expected from the solution analyses, very little reaction of the glass with synthetic groundwater at 40°C was evident (Figure 33). The alteration layer was not detectable in the specimens examined. The light areas shown in Figure 33 are due to charging and not to any physical differences in the specimen composition or morphology.

Solid state results from the specimens leached in synthetic groundwater at 90°C indicate that the surfaces were generally enriched in Mg, Si, Ca, Mn, Fe, and Ni. At 365d, 546d, and 728d at 90°C the specimens appeared to have small areas with very high enrichments of Mg and Si (Figure 33). This result would point to a Mg silicate as a solubility control for both Si and Mg. Both the glass and the synthetic groundwater contained Mg, 1.24% and 0.1 mg/L, respectively. In cross section, the gel layer appeared less complex than that observed for the deionized water specimens. The layer was generally uniform with respect to the concentrations of many elements. Electron microprobe studies of the 728d specimen in cross section indicated that, from the unleached glass to a distance one-half of the layer thickness, the gel layer contained as much Na as the glass. In addition, there was a thin layer, perhaps 1 to 2 μm thick, that is enriched in Na over the rest of the gel layer. These results are consistent with the PHREEQE calculations which show that the solution was nearly saturated with respect to analcime. Specimens leached for 28d showed very high surface enrichments of Ca. This is in agreement with the

FIGURE 33. Photomicrographs from Specimens Leached in Synthetic Groundwater at 40°C: as-leached surface, cross section

solution analyses which showed a rapid decrease in the Ca concentration originally present. Also in agreement with these observations is the fact that the original solution calculates to be oversaturated with respect to the Ca minerals calcite, fluorite (CaF_2), and leonhardite. As the glass continues to react, the surface analyses show a decreasing concentration of Ca on the surface. This may be due to the relative enrichment of the other elements or to a general spreading out of the Ca throughout the gel layer. Some areas of localized high concentrations of Ca were noted, however.

Calculations using PHREEQE indicate that the initial solution at 40°C was oversaturated with respect to calcite, fluorite (CaF_2), and leonhardite, but because there was no decrease in the observed Ca concentration, neither phase was included in the calculation which led to Figure 33. The reason the Ca concentration remained constant is probably due to the fact that there was insufficient glass reaction at 40°C and, hence, insufficient sorption/nucleation sites for any significant reaction to occur. At 90°C (see below) sufficient reaction took place that the Ca concentration was significantly reduced.

Calculations for the 90°C data were done using the PHREEQE code and included solubility control from the solids $\text{Fe}(\text{OH})_3$, $\text{Nd}(\text{OH})_3$, rhodochrosite, leonhardite, hydroxyapatite, sepiolite, calcite, analcime, and amorphous SiO_2 . The results of this calculation are shown in Figure 36. Calcium was first controlled by calcite, then by calcite and leonhardite, followed by the dissolution of calcite in favor of hydroxyapatite and leonhardite. Leonhardite controlled Al up to a reaction progress of about 1000g/m^3 after which leonhardite dissolved in favor of analcime which became the only control for Al. Silicon was controlled by sepiolite during the early reaction of the glass with synthetic groundwater. From about 365d to 728d analcime was calculated to be the solubility control for Si. There is good fit between the calculated and observed data for Si, Al, Mn, and Fe. The Mg data appeared to be quite oversaturated with respect to sepiolite, although the data from the last 365d of the reaction period seemed to be approaching the calculated solution concentrations. The Ca data seem to be scattered about the calculated solution concentrations.

FIGURE 34. Photomicrographs from Specimens Leached in Synthetic Ground-water at 90°C: as-leached surface, cross section

FIGURE 35. Calculated and Observed Data From SRL-131 Glass in Synthetic Groundwater at 40°C

FIGURE 36. Calculated and Observed Data From SRL-131 Glass in Synthetic Groundwater at 90°C

COMPARISON OF RESULTS FROM ALL LEACHANTS

Comparison of the leach results at 90°C from the three non-salt brine leachants leads to some interesting observations about the effect of the Si concentration on the leachability of borosilicate glasses. The order of decreasing leachability would appear to be, from the two-year results, deionized water $\approx$ synthetic groundwater > silicate water. Based on the Si concentrations in the original leachants one might have predicted that the leachability of SRL-131 glass would be nearly equal in both silicate water and synthetic groundwater. Although the pH of the starting leachants was quite different, the final pH values were within 0.5 units of each other. This difference in pH does not seem to affect the "solubility" of silica in these systems since the Si concentrations were equal within experimental error. Although the modeling results are only qualitative indicators of the behavior of the glass in these leachants, there are differences. Using the same phases in the PHREEQE calculations for the three leachants leads to different behavior of the various dissolved constituents. Iron, for instance, is predicted to have a lower solubility in the silicate water than in the other two leachants at the pH and reaction progress values of interest. It has been suggested by Grambow and Strachan (1984) and Strachan, Krupka, and Grambow (1984) that iron in the gel layer plays an important role in the kinetics of waste glass dissolution. Because of the sorption sites that are provided by the amorphous iron hydroxide/hydrated oxide, the increased solubility of the iron phase may lead to an decrease in the sorption sites for constituents such as silicic acid. It has been shown that increasing the solubility of Fe and other normally insoluble elements by the addition of a strong complexant allows Si to leach congruently with the remainder of the glass constituents even though the Si is not complexed (MCC 1982). Thus, it would appear that the behavior of the glass in various leachants may well be linked to the formation of solid phases which differ depending upon the chemistry of the leachant.

Solid state analyses revealed the complexity of the glass/water reaction. Examination of the photomicrographs show a complex gel layer developed over the relatively short time period of 2 y. The specimens leached in deionized water had multiple layers and areas within those layers with feather-like morphology

which appeared to be crystalline in the photomicrographs, but were x-ray amorphous. Large (10 μ m) areas, highly enriched in Mn with significant concentrations of Fe and Si, clearly indicated that well crystallized material should form if the experiments were carried out longer. Development of highly enriched areas of Mg silicates on the specimens leached in synthetic groundwater as well as in the salt brine point to the development of a Mg phase that is quite stable under a wide range of solution conditions. In the case of the synthetic groundwater only trace quantities of Mg were present in the leachant whereas Mg is a major constituent in the salt brine.

The development of the U-rich area in the specimens leached in deionized water at 90°C points to the complexity of the mechanism by which these solids precipitate and, perhaps, the complexity of the gel layer chemistry. The U-rich layer appeared to have migrated with and toward the glass/gel layer interface, becoming more concentrated, and developing apparent crystallinity. These solids need to be investigated using a higher resolution microscope such as a transmission electron microscope in an attempt to determine the mechanisms by which these solids form. Uranium in the deionized water leachant might be controlled by the solid phase that formed near the glass/gel layer interface.

Uranium in the leachates remained below 1 mg/L for the first 365d of the leach test in all leachants. Unfortunately, the U analyses were not performed on the leachates taken after 365d. The solubility of U(VI) is expected to increase with increasing pH in carbonate-free solutions at 25°C (Krupka et al 1984) but the behavior at elevated temperatures has not been fully investigated. The presence of carbonate in the leachates used in the work reported here undoubtedly increased the solubility of the U-bearing solid, but the effect on the solubility of the complex leachant/leachate used in this work cannot be estimated. However, the solubility of schoepite (UO₃·2H₂O) in the range of pH values for the leachates of this study is in the range 0.4 mg U/L to 20 mg U/L (Krupka et al 1984). While the two ranges overlap, there is no evidence to conclude that the solid that controls the solution concentration of U in these leach experiments is schoepite. In the case of the salt brine leachant solid phases which might control the U concentration are alkali or alkaline-earth uranates. A sodium uranate may also be possible in the other leachants because of the relatively high Na concentrations.

SUMMARY AND CONCLUSIONS

Leaching studies of SRL-131 simulated defense nuclear waste glass have been carried out to two years duration, in leachants expected to be relevant to geologic sites being considered for a high-level nuclear waste repository. The long-term leaching results were in agreement with modeling calculations using the PHREEQE geochemical code. Validation of modeling calculations using experimental data corresponding to leaching times as long as possible is the most defensible means of predicting release characteristics over repository-relevant times.

The leachability of SRL-131 glass, from results up to two years, followed the trend: deionized water $\approx$ synthetic groundwater > silicate water > salt brine. The relative saturation fraction of silicic acid in the leachant apparently does play an important role in determining the glass reactivity, although other factors must also be considered. That salt brines gave the lowest leach rates is consistent with a known decreased solubility of SiO_2 -bearing solids in solutions of high ionic strength. For the same reasons that the SiO_2 solubility is reduced in high ionic strength solutions, the rate at which the silanol groups condense (Grambow 1983b) may increase at high ionic strengths. This interpretation is also consistent with the work of Weres, Yee, and Tsao. Deionized water obviously contained no measurable silicic acid initially, and thus, required the greatest extent of glass reaction to saturate the leachant. On the other hand, synthetic groundwater yielded a higher reaction rate than might be expected on the basis of the silicic acid solution concentration alone, demonstrating the limitation of any model based solely on that factor. Modeling calculations yielded different solid phases as a function of reaction progress and leachant composition. Although the actual presence of all the calculated solid phases could not be verified experimentally, the high degree of agreement between calculated and experimental solution concentrations implies that the complete glass-water-alteration product system must be considered to understand the behavior of the glass in the various leachants. Leaching of the glass may depend critically on such reactions as the kinetics of alteration product formation, especially for those alteration products containing SiO_2 . In turn, the rate at which the alteration phases form is also a function of the leachant chemistry.

Temperature appears to have two effects. The kinetic effect slows the rate of reaction by one to two orders of magnitude when the temperature is lowered from 90°C to 40°C. However, a complicating effect is that of predicted changes in the chemistry of the solids/solution system. Although there are insufficient data to make the PHREEQE calculations quantitative, there are qualitative indications that the chemistry of the leachate and the solubility of the solids change significantly with temperature, which will certainly cause differences in the dissolution behavior of the glass. While PHREEQE or some other geochemical code can be used to forecast some of the changes in the chemistry of the glass/water reaction, these codes do not address the important issue of the mechanism and the kinetics of the glass/water reaction.

Illustrative of the complex interplay of kinetics and thermodynamics are the U data from the deionized water experiments at 90°C. The data suggest that, during the early stages of the glass/water reaction, the kinetics of dissolution cause the U to precipitate as an amorphous material spread throughout the alteration layer. However, as the kinetics of dissolution slowed, the U began to precipitate at a location in the alteration layer of minimum solubility, near the glass/layer interface. The minimum in the U solubility within the alteration layer was probably a function of the redox potential of the area and the local chemistry. Other elements, such as Fe, Mn, etc., might be expected to show similar behavior as a function of time. The long-term behavior of dissolved constituents in the solutions that contact nuclear waste forms will, in general, depend on the complex chemistry and kinetics of the waste package/water interactions. These results point to the need for repository-relevant tests of very long duration.

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APPENDIX A

TABLE A.1. Concentrations (mg/L) of Elements Leached from SRL-131 Glass
in Deionized Water at 40°C

SAMPLE ID	82D-217	82D-219	82D-221	82D-223	82D-224	82D-225	82D-247S	82D-247F	82D-248	82D-263	82D-264	82D-265
TIME, d	3	7	14	28	28	28	56	56	56	91	91	91
Al	0.020	0.132	0.287	0.406	0.450	0.459	0.010	0.406	0.588	0.619	0.63	0.660
B	0.078	0.276	0.553	0.985	1.02	1.09	0.013	1.42	1.57	1.74	1.78	1.89
Ca	0.032	0.061	0.119	0.142	1.49	0.143	0.006	0.074	0.165	0.182	0.159	0.185
Cr	--	0.004	0.002	0.001	0.003	--	0.001	0.002	0.001	0.001	--	--
Cs	0.010	0.032	0.069	0.120	0.123	0.129	--	0.166	0.216	0.210	0.215	0.220
Cu	0.005	0.003	0.003	0.005	0.005	0.006	0.009	0.002	0.005	0.003	0.001	--
Fe	0.002	0.010	0.016	0.022	0.023	0.021	0.029	0.003	0.033	0.034	0.031	0.029
K	--	--	--	--	--	--	--	--	--	--	--	--
La	--	--	--	--	--	--	0.003	--	--	0.003	--	--
Li	0.043	0.168	0.311	0.592	0.618	0.654	0.007	0.816	0.959	1.11	1.12	1.17
Mg	0.007	0.047	0.141	0.197	0.195	0.219	0.041	0.105	0.309	0.255	0.240	0.257
Mn	0.041	0.051	0.018	0.028	0.025	0.029	0.052	0.001	0.049	0.061	0.051	0.037
Mo	0.001	--	0.002	--	--	0.002	0.002	0.001	0.001	--	--	--
Na	0.299	1.02	2.02	3.26	3.37	3.68	--	4.69	5.61	5.98	6.04	6.26
Nd	--	--	0.001	--	--	--	--	--	--	--	--	--
Ni	0.014	0.010	0.006	0.014	0.011	0.017	0.025	0.002	0.020	0.030	0.023	0.020
P	--	--	--	0.060	0.054	0.055	--	0.025	--	0.053	0.051	0.020
Si	0.490	1.61	3.04	5.15	5.39	5.61	0.084	7.14	7.93	8.68	8.81	9.27
Sr	0.003	0.009	0.016	0.020	0.021	0.019	0.002	0.009	0.022	0.017	0.016	0.017
Ti	--	--	0.002	--	--	--	--	--	--	--	--	--
U	0.015	0.017	0.021	0.034	0.035	0.033	0.005	0.046	0.083	0.092	0.083	0.102
Zn	0.003	0.002	0.005	0.002	0.003	0.004	0.005	0.050	0.001	0.003	0.003	0.003
Zr	0.002	--	0.003	0.003	--	--	0.001	0.001	--	--	--	--
pH	7.44	8.59	8.82	9.13	9.14	9.19	9.33	9.33	8.77	8.68	9.18	9.27

S = results from acid stripping the leach container

F = results from solutions filtered through an 18A⁰ filter. Note Ca data are usually high in these solutions and should be disregarded.

TABLE A.1. (contd)

SAMPLE ID	82D-287	82D-288	82D-303	82D-304	82D-305	82D-327	82D-328	82D-329	82D-339	82D-340	82D-341
TIME, d	182	182	364	364	364	546	546	546	728	728	728
Al	0.544	0.360	0.310	0.390	0.390	0.212	0.121	0.187	0.114	0.097	0.103
B	2.20	1.59	2.93	2.80	2.94	3.56	3.78	3.58	4.73	3.90	4.44
Ca	0.211	0.223	0.110	0.130	0.100	0.157	0.185	0.171	0.174	0.219	0.191
Cr	0.002	0.001	--	--	--	0.003	--	0.001	--	--	--
Cs	0.250	0.180	0.310	0.315	0.325	0.190	0.190	0.220	--	--	--
Cu	0.011	0.010	--	--	--	--	--	--	--	--	--
Fe	0.006	0.002	0.070	0.094	0.076	0.025	0.002	0.039	0.0003	0.007	0.002
K	--	--	--	--	--	0.158	--	0.105	0.133	0.067	0.093
La	--	--	--	--	--	--	--	--	--	--	--
Li	1.42	1.03	1.70	1.70	1.70	2.02	2.22	2.07	2.83	2.37	2.83
Mg	0.311	0.318	0.280	0.310	0.260	0.102	0.085	0.136	0.234	0.275	0.275
Mn	0.008	0.058	0.220	0.230	0.190	--	--	--	0.014	0.024	0.017
Mo	0.007	0.001	--	--	--	0.009	0.006	0.011	0.017	0.002	--
Na	7.96	5.90	10.7	10.2	10.7	11.9	12.8	12.1	15.7	13.5	15.5
Nd	--	--	--	--	--	0.004	--	--	--	--	--
Ni	0.002	0.012	0.064	0.071	0.068	0.003	--	--	--	--	--
P	0.058	0.044	--	--	--	--	--	0.016	0.010	0.004	0.012
Si	10.1	7.70	12.2	11.8	12.2	13.1	13.8	13.1	15.5	13.5	15.5
Sr	0.019	0.030	0.012	0.012	0.011	0.005	0.004	0.005	0.007	0.009	0.008
Ti	--	--	--	--	--	0.001	--	0.001	--	--	--
U	0.800	0.400	0.210	0.200	0.205	--	--	--	--	--	--
Zn	0.009	0.011	--	--	--	0.301	0.382	0.535	0.493	0.617	0.317
Zr	0.033	0.007	--	--	--	0.006	--	--	0.0005	--	--
pH	8.71	7.80	8.54	8.67	8.81	8.77	8.70	8.32	8.69	8.50	8.69

S = results from acid stripping the leach container

F = results from solutions filtered through an 18A filter. Note Ca data are usually high in these solutions and should be disregarded.

TABLE A.2. Normalized Elemental Mass Loss (g/m^2) for SRL-131 Glass in Deionized Water at 40°C

SAMPLE ID	82D-217	82D-219	82D-221	82D-223	82D-224	82D-225	82D-247F	82D-248	82D-263	82D-264	82D-265	82D-287
Time, d	3	7	14	28	28	28	56	56	91	91	91	182
Al	0.12	0.82	1.78	2.52	2.79	2.84	2.52	3.64	3.83	3.9	4.09	3.37
B	0.25	0.89	1.8	3.21	3.32	3.55	4.63	5.12	5.68	5.81	6.17	7.18
Ca	0.43	0.82	1.6	1.91	20	1.92	1	2.22	2.39	2.08	2.43	2.78
Cr	--	--	--	--	--	--	--	--	0.048	--	--	0.14
Ce	0.35	1.13	2.44	4.24	4.35	4.56	5.87	7.63	7.42	7.6	7.77	8.83
Cu	--	--	--	--	--	0.21	--	--	1.04	0.21	--	4.38
Fe	--	0.008	0.014	0.02	0.021	0.019	0.001	0.031	0.033	0.03	0.028	0.005
K	--	--	--	--	--	--	--	--	--	--	--	--
La	--	--	--	--	--	--	--	--	0.11	--	--	--
Li	0.22	0.92	1.71	3.27	3.42	3.62	4.51	5.31	6.16	6.21	6.49	7.88
Mg	0.094	0.63	1.89	2.63	2.61	2.93	1.4	4.13	3.29	3.09	3.32	4.04
Mn	0.15	0.19	0.063	0.1	0.089	0.1	--	0.18	0.23	0.19	0.14	0.03
Mo	--	--	--	--	--	--	--	--	--	--	--	--
Na	0.27	0.93	1.84	2.97	3.07	3.36	4.28	5.12	5.45	5.51	5.71	7.26
Nd	--	--	0.026	--	--	--	--	--	--	--	--	--
Ni	0.11	0.074	0.041	0.11	0.083	0.13	0.0083	0.16	0.25	0.19	0.17	0.017
P	--	--	--	3.21	1.83	2.06	--	--	5.73	5.28	--	6.88
Si	0.27	0.89	1.68	2.85	2.98	3.1	3.95	4.39	4.8	4.87	5.12	5.58
Sr	0.25	0.76	1.35	1.69	1.77	1.6	0.76	1.86	1.44	1.35	1.44	1.6
Ti	--	--	0.044	--	--	--	--	--	--	--	--	--
U	0.1	0.12	0.15	0.24	0.24	0.23	0.32	0.58	0.64	0.58	0.71	5.6
Zn	--	--	--	--	--	--	--	--	--	--	--	--
Zr	0.087	--	0.13	0.13	--	--	0.044	--	--	--	--	1.44

S = results from acid stripping the leach container

F = results from solutions filtered through an 18 μ filter. Note Ca data are usually high in these solutions and should be disregarded.

TABLE A.2. (contd)

SAMPLE ID	82D-288	82D-303	82D-304	82D-305	82D-327	82D-328	82D-329	82D-339	82D-340	82D-341
Time, d	182	364	364	364	546	546	546	728	728	728
Al	2.23	1.92	2.42	2.42	1.27	0.7	1.08	0.71	0.6	0.64
B	5.19	9.57	9.14	9.6	11.6	12.3	11.5	15.2	12.5	14.3
Ca	2.94	1.48	1.75	1.35	1.22	1.6	1.41	2.18	2.79	2.41
Cr	0.048	--	--	--	0.26	--	0.13	--	--	--
Cs	6.36	11	11.1	11.5	6.71	6.71	7.77	--	--	--
Cu	3.96	--	--	--	--	--	--	--	--	--
Fe	0.001	0.057	0.081	0.063	--	--	0.0085	--	0.0043	--
K	--	--	--	--	11.9	--	6.61	11.4	4.68	7.35
La	--	--	--	--	--	--	--	--	--	--
Li	5.72	9.43	9.43	9.43	11.2	12.3	11.5	15.7	13.1	15.7
Mg	4.13	3.74	4.15	3.48	1.36	1.13	1.81	2.95	3.5	3.5
Mn	0.22	0.83	0.87	0.72	--	--	--	0.049	0.085	0.058
Mo	--	--	--	--	--	--	--	--	--	--
Na	5.38	9.77	9.31	9.77	10.6	11.4	10.8	14.2	12.3	14.1
Nd	--	--	--	--	0.11	--	--	--	--	--
Ni	0.099	0.53	0.59	0.56	0.025	--	--	--	--	--
P	3.67	--	--	--	--	--	--	2.36	0.87	2.66
Si	4.25	6.73	6.51	6.73	7.24	7.65	7.25	8.54	7.47	8.55
Sr	2.53	1.01	1.01	0.93	0.38	0.35	0.42	--	--	--
Ti	--	--	--	--	--	--	--	--	--	--
U	2.8	1.47	1.4	1.44	--	--	--	--	--	--
Zn	--	--	--	--	--	--	--	--	--	--
Zr	0.31	--	--	--	0.27	--	--	--	--	--

S = results from acid stripping the leach container

F = results from solutions filtered through an 18A filter. Note Ca data are usually high in these solutions and should be disregarded.

TABLE A.3. Concentrations (mg/L) of Elements Leached from SRL-131 Glass in Deionized Water at 90°C

	82D-218	82D-220	82D-222	82D-235	82D-236	82D-237	82D-255F	82D-255S	82D-256	82D-275	82D-276	82D-277
TIME, d	3	7	14	28	28	28	56	56	56	91	91	91
Al	1.48	1.88	2.04	2.27	2.26	2.22	2.52	--	2.65	2.60	2.64	2.50
B	4.14	6.23	7.97	10.3	10.2	9.92	15.2	0.030	15.7	19.7	19.9	21.1
Ca	0.061	0.024	0.031	--	0.012	0.011	--	--	0.014	0.013	--	0.013
Cr	--	--	--	--	--	--	--	--	--	--	--	--
Cs	0.431	0.682	0.880	1.04	1.02	1.00	1.03	--	1.14	1.09	1.05	1.06
Cu	0.020	0.005	--	--	0.004	--	--	0.006	--	--	0.004	0.006
Fe	0.039	0.017	0.028	0.044	0.042	0.101	0.012	0.015	0.176	0.064	0.111	0.128
K	--	--	--	--	--	--	--	--	--	--	--	--
La	--	--	--	--	--	0.008	--	--	0.036	--	--	--
Li	2.54	3.88	4.91	6.23	6.19	5.94	9.10	0.020	9.49	12.8	13.1	13.300
Mg	--	--	--	--	--	--	--	--	0.129	--	--	--
Mn	0.014	0.023	0.030	0.039	0.052	0.057	0.002	0.033	0.075	0.048	0.046	0.073
Mo	0.018	--	--	--	--	--	--	--	0.012	--	--	--
Na	15.2	21.0	30.0	34.3	34.1	32.9	51.4	--	54.5	63.4	64.3	64.5
Nd	--	--	--	--	--	--	--	--	--	--	--	--
Ni	--	--	--	--	--	--	--	--	0.023	--	0.024	0.020
P	--	--	--	--	--	--	--	--	--	--	--	--
Si	20.2	29.3	36.4	44.8	44.6	42.5	60.7	0.145	62.2	71.8	71.7	73.0
Sr	0.018	0.002	--	--	--	--	--	--	0.016	--	--	--
Ti	0.007	0.002	0.002	--	--	0.007	--	--	0.012	0.003	0.003	0.014
U	0.163	0.152	0.222	0.113	0.236	0.236	0.233	0.008	0.382	0.567	0.355	0.507
Zn	--	--	--	--	--	--	0.061	--	--	--	--	--
Zr	0.033	--	--	--	--	--	--	--	0.014	--	--	0.015
pH	10.0	10.11	10.19	10.13	10.13	10.04	9.92	9.92	10.15	10.24	10.24	10.08

S = results from acid stripping the leach container

F = results from solutions filtered through an 18⁰ filter. Note Ca data are usually high in these solutions and should be disregarded.

TABLE A.3. (contd)

	82D-295	82D-295F	82D-295S	82D-296	82D-296S	82D-315	82D-315F	82D-315S	82D-316	82D-316F	82D-316S	82D-317
TIME, d	182	182	182	182	182	364	364	364	364	364	364	364
Al	2.48	2.55	--	2.41	0.032	2.30	2.30	--	2.20	2.20	--	2.10
B	28.4	28.4	0.442	27.6	0.536	38.5	38.1	--	41.6	41.5	--	40.4
Ca	0.019	0.138	--	0.017	--	--	0.130	--	--	0.170	--	--
Cr	0.024	0.021	--	0.026	--	0.053	0.048	--	0.059	0.058	--	0.053
Cs	0.960	1.00	0.011	1.10	0.017	1.10	1.10	--	1.10	1.10	--	1.10
Cu	0.009	--	--	0.009	--	--	--	--	--	--	--	--
Fe	0.115	0.025	0.010	0.109	0.008	0.097	0.027	0.021	0.100	0.028	0.015	0.057
K	--	--	--	--	--	0.350	0.400	--	0.400	0.380	--	0.350
La	--	--	--	--	--	--	--	--	--	--	--	--
Li	16.7	19.5	0.237	16.2	0.281	20.4	20.0	--	21.8	21.7	--	21.2
Mg	--	--	--	--	--	--	--	--	--	--	--	--
Mn	0.045	--	0.009	0.027	0.010	0.044	--	0.017	0.043	--	0.010	0.032
Mo	--	--	--	--	--	--	--	--	--	--	--	--
Na	85.3	94.6	1.35	84.6	1.63	123	121	--	131	130	--	127
Nd	--	--	--	--	--	--	--	--	--	--	--	--
Ni	--	--	--	0.022	--	0.028	--	--	0.020	--	--	0.023
P	--	--	--	--	--	--	--	--	--	--	--	--
Si	91.7	94.1	1.44	90.7	1.81	124	123	0.110	131	130	0.100	129
Sr	--	--	0.003	--	--	--	--	--	--	--	--	--
Ti	--	--	--	--	--	--	--	--	--	--	--	--
U	2.62	--	--	0.540	--	0.714	0.461	0.001	0.750	0.545	0.001	0.650
Zn	--	0.611	--	--	--	0.012	0.750	--	--	0.830	--	--
Zr	0.013	--	--	--	--	--	--	--	--	--	--	--
pH	10.27	10.27	10.27	10.21	10.21	9.98	9.98	9.98	10.0	10.0	10.0	9.99

S = results from acid stripping the leach container

F = results from solutions filtered through an 18 μ filter. Note Ca data are usually high in these solutions and should be disregarded.

TABLE A.3. (contd)

	82D-317F	82D-317S	82D-333	82D-334	82D-335	82D-345	82D-346	82D-347
TIME, d	364	364	546	546	546	728	728	728
Al	2.10	--	2.32	2.30	2.60	2.52	2.00	2.29
B	40.3	--	35.9	33.3	35.7	35.2	41.1	38.9
Ca	0.160	--	0.242	0.253	0.256	0.182	0.212	0.193
Cr	0.055	--	0.042	0.044	0.050	0.057	0.065	0.059
Cs	1.00	--	0.700	0.520	0.680	1.04	1.10	1.10
Cu	--	--	--	--	--	--	--	--
Fe	0.065	0.020	0.014	0.077	0.041	0.017	0.002	0.012
K	0.430	--	0.263	0.263	0.290	0.346	0.386	0.373
La	--	--	--	--	--	0.0006	--	--
Li	21.0	--	19.6	17.9	19.1	19.8	23.1	21.6
Mg	--	--	--	--	--	0.031	--	0.021
Mn	--	0.022	--	--	--	0.002	0.0005	0.0005
Mo	--	--	0.013	0.019	0.009	0.009	0.018	0.021
Na	125	--	106	100	108	113	128	123
Nd	--	--	--	--	--	--	--	--
Ni	--	--	--	--	--	--	--	--
P	--	--	0.449	0.399	0.449	0.395	0.411	0.865
Si	128	0.120	113	105	110	107	120	115
Sr	--	--	0.0002	--	0.002	0.002	0.001	0.001
Ti	--	--	--	--	0.011	0.005	--	--
U	0.434	0.002	--	--	--	--	--	--
Zn	1.00	--	1.73	1.88	1.23	0.925	1.14	0.909
Zr	--	--	0.002	--	0.018	0.015	--	0.003
pH	9.99	9.99	9.97	10.01	10.01	9.83	9.89	9.86

S = results from acid stripping the leach container

F = results from solutions filtered through an 18A⁰ filter. Note Ca data are usually high in these solutions and should be disregarded.

TABLE A.4. Normalized Elemental Mass Loss (g/m²) for SRL-131 Glass
in Deionized Water at 90°C

	82D-218	82D-220	82D-222	82D-235	82D-236	82D-237	82D-255F	82D-256	82D-275	82D-276	82D-277	82D-295F
Time, days	3	7	14	28	28	28	56	56	91	91	91	182
Al	9.17	11.6	12.6	14.1	14	13.8	15.6	16.4	16.1	16.4	15.5	15.8
B	13.5	20.3	26	33.6	33.3	32.4	49.6	51.3	64.3	65	68.9	92.7
Ca	0.82	0.32	0.42	--	0.1	0.087	--	0.13	0.02	--	0.02	0.1
Cr	--	--	--	--	--	--	--	--	--	--	--	1.72
Cs	15.2	24.1	31.1	36.8	36	35.3	36.4	40.3	38.5	37.1	37.5	35.3
Cu	6.05	--	--	--	--	--	--	--	--	1.46	2.29	--
Fe	0.037	0.015	0.026	0.041	0.039	0.098	0.0095	0.17	0.057	0.1	0.12	0.018
K	--	--	--	--	--	--	--	--	--	--	--	--
La	--	--	--	--	--	0.28	--	1.28	--	--	--	--
Li	14.1	21.5	27.2	34.6	34.3	33	50.5	52.7	71	72.7	73.8	108
Mg	--	--	--	--	--	--	--	1.72	--	--	--	--
Mn	0.047	0.082	0.11	0.14	0.19	0.21	0.0038	0.28	0.18	0.17	0.28	--
Mo	--	--	--	--	--	--	--	--	--	--	--	--
Na	13.9	19.2	27.4	31.3	31.1	30	46.9	49.7	57.9	58.7	58.9	86.3
Nd	--	--	--	--	--	--	--	--	--	--	--	--
Ni	--	--	--	--	--	--	--	0.19	--	0.19	0.16	--
P	--	--	--	--	--	--	--	--	--	--	--	--
Si	11.2	16.2	20.2	24.8	24.7	23.5	33.6	34.4	39.7	39.7	40.4	52.1
Sr	1.52	0.17	--	--	--	--	--	1.35	--	--	--	--
Ti	0.16	0.044	0.044	--	--	0.16	--	0.27	0.067	0.067	0.31	--
U	1.14	1.07	1.56	0.79	1.66	1.66	1.63	2.67	3.97	2.49	3.55	--
Zn	--	--	--	--	--	--	--	--	--	--	--	--
Zr	1.44	--	--	--	--	--	--	0.61	--	--	0.65	--

S = results from acid stripping the leach container

F = results from solutions filtered through an 18A filter. Note Ca data
are usually high in these solutions and should be disregarded.

TABLE A.4. (contd)

	82D-296	82D-315F	82D-316F	82D-317F	82D-333	82D-334	82D-335	82D-345	82D-346	82D-347
Time, days	182	364	364	364	546	546	546	728	728	728
Al	14.9	14.2	13.6	13	14.3	14.3	16.1	15.6	12.4	14.1
B	90.1	124	136	132	117	109	116	115	134	127
Ca	0.074	--	--	--	2.37	2.52	2.56	2.42	2.82	2.57
Cr	2.2	4.58	5.54	5.25	4.02	4.15	4.8	5.46	6.22	5.62
Cs	38.9	38.9	38.9	35.3	24.7	18.4	24	36.8	38.9	38.9
Cu	3.55	--	--	--	--	--	--	--	--	--
Fe	0.1	0.021	0.022	0.059	0.0046	0.067	0.032	0.017	0.0017	0.012
K	--	40.2	38.1	43.2	26.4	26.4	29.1	34.1	38.1	36.8
La	--	--	--	--	--	--	--	0.021	--	--
Li	89.9	111	120	117	109	99.2	106	110	128	120
Mg	--	--	--	--	--	--	--	0.38	--	0.24
Mn	0.1	--	--	--	--	--	--	0.0017	--	--
Mo	--	--	--	--	--	--	--	--	--	--
Na	77.2	110	119	114	96.4	90.9	97.9	103	117	111
Nd	--	--	--	--	--	--	--	--	--	--
Ni	0.17	--	--	--	--	--	--	--	--	--
P	--	--	--	--	47.7	36.4	47.7	35.9	39.5	144
Si	50.2	68.1	72	70.9	62.6	58.2	61.2	59.7	66.4	63.8
Sr	--	--	--	--	0.017	--	0.13	--	--	--
Ti	--	--	--	--	--	--	--	0.12	--	--
U	3.78	3.23	3.82	3.04	--	--	--	--	--	--
Zn	--	--	--	--	--	--	--	--	--	--
Zr	--	--	--	--	0.1	--	0.8	0.64	--	0.12

S = results from acid stripping the leach container

F = results from solutions filtered through an 18A filter. Note Ca data are usually high in these solutions and should be disregarded.

FIGURE A.1. Concentrations (mg/L) in the Leachates from SRL-131 Glass in Deionized Water at 40°C

FIGURE A.2. Concentrations (mg/L) in the Leachates from SRL-131 Glass in Deionized Water at 40°C

FIGURE A.3. Concentrations (mg/L) in the Leachates from SRL-131 Glass in Deionized Water at 90°C

FIGURE A.4. Concentrations (mg/L) in the Leachates from SRL-131 Glass in Deionized Water at 90°C

TABLE A.5. Concentrations (mg/L) of Elements Leached from SRL-131 Glass
in Silicate Water at 40°C

SAMPLE ID	82D-226	82D-227	82D-228	82D-249	82D-250	82D-266	82D-267	82D-268	82D-289	82D-290	82D-306	82D-307	82D-308
TIME, d	28	28	28	56	56	91	91	91	182	182	364	364	364
Al	--	--	--	0.030	0.038	0.003	0.043	0.019	--	--	0.040	0.030	0.050
B	0.199	0.203	0.211	0.246	0.228	0.352	0.371	0.320	0.341	0.396	0.410	0.570	0.580
Ca	0.046	0.040	0.041	0.054	0.048	0.067	0.094	0.062	0.049	0.069	0.058	0.066	0.060
Cr	0.002	0.002	0.002	0.003	0.006	--	0.038	0.008	0.005	0.005	--	--	--
Cs	0.020	0.020	0.020	0.024	0.019	0.050	0.040	0.040	0.037	0.040	0.045	0.058	0.055
Cu	0.004	--	--	0.260	0.269	0.003	0.002	0.002	0.007	0.003	--	--	--
Fe	0.008	0.033	0.010	0.030	0.035	0.020	0.023	0.024	0.005	0.006	0.040	0.038	0.029
K	--	--	--	--	--	0.198	0.468	0.270	--	--	0.200	0.200	0.300
La	--	--	--	0.005	0.003	--	--	--	--	--	--	--	--
Li	0.048	0.046	0.081	0.119	0.076	0.244	0.321	0.243	0.252	0.281	0.270	0.370	0.360
Mg	0.050	0.035	0.051	0.075	0.057	0.361	0.395	0.422	0.082	0.090	0.220	0.240	0.250
Mn	0.041	0.034	0.034	0.038	0.032	0.045	0.088	0.057	0.036	0.042	0.040	0.044	0.043
Mo	--	--	--	0.003	0.003	--	--	--	0.005	--	--	--	--
Na	50.3	51.4	49.4	40.3	40.1	48.3	48.0	50.8	54.3	55.8	53.2	53.8	54.1
Nd	--	--	--	0.010	--	--	--	--	--	--	--	--	--
Ni	0.012	0.010	0.009	0.014	0.010	0.014	0.015	0.014	0.008	0.007	0.020	0.030	0.020
P	0.011	--	0.044	0.011	--	--	0.064	0.047	--	--	--	--	--
Si	28.2	28.5	27.9	24.6	24.5	27.6	27.4	27.9	28.2	28.3	28.5	28.8	29.1
Sr	0.003	0.003	0.003	0.005	0.004	0.005	0.004	0.004	0.005	0.005	--	--	--
Ti	--	--	--	0.002	--	--	--	--	--	--	--	--	--
U	0.050	0.056	0.059	0.033	0.048	0.085	0.088	0.081	0.400	2.30	0.094	0.149	0.163
Zn	0.001	--	--	0.001	0.003	0.007	0.004	0.004	0.014	0.012	--	--	--
Zr	0.004	0.002	0.003	0.014	0.014	0.006	0.006	0.006	0.041	0.016	--	--	--
pH	8.67	8.77	8.74	7.52	7.85	8.50	8.60	8.42	8.66	8.67	8.56	8.56	8.57

S = results from acid stripping the leach container

F = results from solutions filtered through an 18A filter. Note Ca data
are usually high in these solutions and should be disregarded.

TABLE A.7. Concentrations (mg/L) of Elements Leached from SRL-131 Glass
in Silicate Water at 90°C

SAMPLE ID	82D-226	82D-227	82D-228	82D-249	82D-250	82D-266	82D-267	82D-268	82D-289	82D-290	82D-306	82D-307	82D-308
Time, d	28	28	28	56	56	91	91	91	182	182	364	364	364
Al	--	--	--	0.19	0.24	0.019	0.27	0.12	--	--	--	--	--
B	0.47	0.49	0.51	0.63	0.57	1.09	1.16	0.99	1.06	1.24	1.31	1.83	1.86
Ca	0.33	0.25	0.26	0.44	0.36	0.57	0.93	0.5	0.32	0.59	0.44	0.55	0.47
Cr	0.19	0.19	0.19	0.29	0.57	--	3.58	0.72	0.43	0.43	--	--	--
Cs	0.71	0.71	0.71	0.85	0.67	1.77	1.41	1.41	1.31	1.41	1.59	2.05	1.94
Cu	--	--	--	106	110	--	--	--	--	--	--	--	--
Fe	0.004	0.029	0.006	0.026	0.031	--	--	--	--	--	--	--	--
K	--	--	--	--	--	8.68	35.8	15.9	--	--	--	--	5.02
La	--	--	--	0.18	0.11	--	--	--	--	--	--	--	--
Li	0.26	0.24	0.44	0.65	0.41	1.35	1.78	1.35	1.4	1.56	1.5	2.05	2
Mg	0.66	0.46	0.68	1	0.76	2.9	3.36	3.72	--	--	0.6	0.87	1
Mn	0.14	0.11	0.11	0.13	0.1	0.17	0.33	0.22	0.14	0.16	0.15	0.17	0.16
Mo	--	--	--	--	--	--	--	--	--	--	--	--	--
Na	--	0.27	--	--	--	0.82	0.55	3.1	6.3	7.67	1.92	2.46	2.74
Nd	--	--	--	0.26	--	--	--	--	--	--	--	--	--
Ni	0.099	0.083	0.074	0.12	0.083	0.062	0.07	0.062	0.012	0.0041	--	0.083	--
P	0.8	--	8.37	0.8	--	--	2.64	--	--	--	--	--	--
Si	--	0.19	--	--	--	0.3	0.19	0.47	0.64	0.69	0.53	0.69	0.86
Sr	0.25	0.25	0.25	0.42	0.34	--	--	--	--	--	--	--	--
Ti	--	--	--	0.044	--	--	--	--	--	--	--	--	--
U	0.35	0.39	0.42	0.23	0.33	0.6	0.61	0.57	2.8	16.1	0.66	1.04	1.14
Zn	--	--	--	--	--	--	--	--	--	--	--	--	--
Zr	--	--	--	--	--	--	--	--	0.78	--	--	--	--

S = results from acid stripping the leach container

F = results from solutions filtered through an 18A filter. Note Ca data are usually high in these solutions and should be disregarded.

TABLE A.6. Normalized Elemental Mass Loss (g/m^2) for SRL-131 Glass
in Silicate Water at 40°C

	82D-238	82D-239	82D-240	82D-257	82D-258	82D-278	82D-279	82D-280	82D-297	82D-297F	82D-297S	82D-298
TIME, d	28	28	28	56	56	91	91	91	182	182	182	182
Al	0.859	0.885	0.857	0.789	0.847	0.773	0.799	0.789	0.844	0.852	--	0.787
B	6.19	6.17	6.43	7.66	8.07	10.5	10.3	10.6	13.9	13.3	0.099	13.7
Ca	0.011	--	0.053	0.022	0.019	--	--	--	0.026	0.012	--	0.027
Cr	--	--	--	--	--	--	--	--	0.025	0.022	--	0.023
Cs	0.600	0.590	0.620	0.660	0.620	0.760	0.740	0.750	0.940	0.910	--	0.940
Cu	--	--	--	0.200	0.207	0.046	0.016	0.008	0.044	--	--	--
Fe	0.032	0.042	0.028	0.047	0.060	0.091	0.072	0.072	0.040	0.008	0.030	0.026
K	--	--	--	--	--	0.464	--	--	--	--	--	--
La	--	--	--	--	--	--	--	--	--	--	--	--
Li	4.15	4.20	4.27	4.66	4.84	7.30	7.20	7.15	8.74	9.08	0.035	8.90
Mg	--	--	--	0.127	0.179	0.809	0.284	0.366	0.144	--	--	0.120
Mn	0.066	0.076	0.062	0.089	0.102	0.124	0.131	0.117	0.079	--	0.041	0.077
Mo	--	--	--	--	--	0.035	0.011	--	--	--	--	--
Na	78.0	79.4	78.9	64.5	65.3	79.7	79.4	77.3	91.1	99.7	0.514	94.5
Nd	--	--	--	--	--	--	--	--	--	--	--	--
Ni	--	0.029	--	0.032	0.042	0.090	0.073	0.072	0.020	--	--	0.025
P	--	--	--	--	--	--	--	--	--	--	--	--
Si	51.3	51.4	51.9	48.2	49.9	57.8	57.5	57.8	68.3	68.5	0.474	67.4
Sr	--	--	--	0.002	0.004	0.033	0.010	0.003	--	--	--	--
Ti	--	--	--	--	--	0.028	0.003	--	--	--	--	--
U	0.708	0.763	0.596	0.997	0.900	0.735	0.818	0.490	1.30	--	--	3.20
Zn	--	--	--	--	--	0.042	--	--	--	0.529	--	--
Zr	--	--	--	--	--	0.040	0.011	--	0.009	--	--	--
pH	9.70	9.70	9.72	9.71	9.83	9.76	9.73	9.70	9.77	9.77	9.77	9.870

S = results from acid stripping the leach container

F = results from solutions filtered through an 18 μ filter. Note Ca data
are usually high in these solutions and should be disregarded.

TABLE A.6. (contd)

	82D-298F	82D-298S	82D-318	82D-318F	82D-318S	82D-319	82D-319F	82D-319S	82D-320	82D-320F	82D-320S
TIME, d	182	182	364	364	364	364	364	364	364	364	364
Al	0.786	0.034	1.20	1.20	0.070	1.30	1.10	--	1.20	1.00	0.070
B	12.8	0.089	18.5	17.6	--	18.8	18.3	--	26.1	25.7	--
Ca	0.035	--	--	0.080	--	--	0.060	--	--	0.070	--
Cr	0.021	--	0.042	0.036	--	0.046	0.038	--	0.056	0.048	--
Cs	0.890	--	0.730	0.680	--	0.720	0.660	--	0.860	0.750	--
Cu	--	--	--	--	--	--	--	--	--	--	--
Fe	0.009	0.030	0.091	0.019	0.072	0.180	0.018	0.031	0.100	0.021	0.035
K	0.333	--	0.350	0.400	--	0.400	0.380	--	0.540	0.460	--
La	--	--	--	--	--	--	--	--	--	--	--
Li	8.39	0.031	10.2	9.80	--	10.4	10.1	--	14.2	14.0	--
Mg	--	0.066	--	--	--	0.400	--	--	0.500	--	--
Mn	--	0.046	0.110	--	0.079	0.200	--	0.040	0.190	--	0.063
Mo	--	--	--	--	--	--	--	--	--	--	--
Na	92.6	0.465	118	113	0.200	118	115	0.200	139	137	0.100
Nd	--	--	--	--	--	--	--	--	--	--	--
Ni	--	--	0.048	--	0.050	0.058	--	0.030	0.051	--	0.025
P	--	--	--	--	--	--	--	--	--	--	--
Si	66.0	0.436	88.0	85.0	0.340	89.0	87.0	0.200	110	107	0.270
Sr	--	--	--	--	--	--	--	--	--	--	--
Ti	--	--	--	--	--	--	--	--	--	--	--
U	--	--	1.11	0.97	0.004	0.905	1.29	0.002	1.33	1.26	0.002
Zn	0.465	--	0.033	0.290	0.020	0.030	0.300	0.023	0.018	0.330	0.014
Zr	--	--	--	--	--	--	--	--	--	--	--
pH	9.87	9.87	9.70	9.70	9.70	9.65	9.65	9.60	9.77	9.77	9.77

S = results from acid stripping the leach container

F = results from solutions filtered through an 18A filter. Note Ca data are usually high in these solutions and should be disregarded.

TABLE A.8. Normalized Elemental Mass Loss (g/m²) for SRL-131 Glass in Silicate Water at 90°C

	82D-238	82D-239	82D-240	82D-257	82D-258	82D-278	82D-279	82D-280	82D-297F	82D-298F	82D-318F	82D-319F	82D-320F
Time, days	28	28	28	56	56	91	91	91	182	182	364	364	364
Al	5.32	5.48	5.31	4.89	5.25	4.79	4.95	4.89	5.28	4.87	7.31	6.69	6.07
B	20	20	20.8	24.8	26.2	34.2	33.6	34.6	43.4	41.7	57.4	59.7	83.9
Ca	--	--	0.42	0.0067	--	--	--	--	0.061	0.074	--	--	--
Cr	--	--	--	--	--	--	--	--	2.05	1.96	3.44	3.63	4.58
Cs	21.2	20.9	21.9	23.3	21.9	26.9	26.2	26.5	32.2	31.5	24	23.3	26.5
Cu	--	--	--	83.2	86.2	16.5	3.96	0.63	--	--	--	--	--
Fe	0.025	0.035	0.021	0.04	0.053	0.081	0.062	0.062	--	--	--	--	--
K	--	--	--	--	--	37.7	--	--	--	24.6	15.1	13	21.1
La	--	--	--	--	--	--	--	--	--	--	--	--	--
Li	23	23.3	23.7	25.9	26.9	40.5	40	39.7	50.4	46.6	54.4	56	77.7
Mg	--	--	--	1.69	2.39	8.97	1.95	3.04	--	--	--	--	--
Mn	0.24	0.28	0.22	0.33	0.38	0.47	0.5	0.44	--	--	--	--	--
Mo	--	--	--	--	--	--	--	--	--	--	--	--	--
Na	23.8	25.1	24.6	11.5	12.2	27.2	26.9	25	45.4	38.9	51.7	53.6	73.7
Nd	--	--	--	--	--	--	--	--	--	--	--	--	--
Ni	--	0.24	--	0.26	0.35	0.58	0.44	0.43	--	--	--	--	--
P	--	--	--	--	--	--	--	--	--	--	--	--	--
Si	12.5	12.6	12.9	10.8	11.8	16.5	16.3	16.5	22.4	21	30.4	31.5	42.6
Sr	--	--	--	0.17	0.34	2.79	0.84	0.25	--	--	--	--	--
Ti	--	--	--	--	--	0.57	0.011	--	--	--	--	--	--
U	4.96	5.34	4.17	6.98	6.3	5.15	5.73	3.43	--	--	6.79	9.03	8.82
Zn	--	--	--	--	--	--	--	--	--	--	--	--	--
Zr	--	--	--	--	--	1.44	0.17	--	--	--	--	--	--

S = results from acid stripping the leach container

F = results from solutions filtered through an 18Å filter. Note Ca data are usually high in these solutions and should be disregarded.

FIGURE A.5. Concentrations (mg/L) in the Leachates from SRL-131 Glass in Silicate Water at 40°C

FIGURE A.6. Concentrations (ng/L) in the Leachates from SRL-131 Glass in Silicate Water at 40°C

FIGURE A.7. Concentrations (mg/L) in the Leachates from SRL-131 Glass in Silicate Water at 40°C

FIGURE A.8. Concentrations (ng/L) in the Leachates from SRL-131 Glass in Silicate Water at 90°C

FIGURE A.9. Concentrations (mg/L) in the Leachates from SRL-131 Glass in Silicate Water at 90°C

TABLE A.9. Concentrations (mg/L) of Elements from SRL-131 Glass in Salt Brine at 40°C

SAMPLE ID	82D-230	82D-231	82D-251	82D-252	82D-269	82D-270	82D-271	82D-291	82D-291F	82D-291S	82D-292
TIME, d	28	28	56	56	91	91	91	182	182	182	182
Al	0.430	0.510	--	--	0.150	0.140	0.130	0.03	--	--	0.03
B	19.9	20	19.5	19	18.6	18.5	19.2	18.8	19	0.031	19.3
Ca	306	307	301	295	294	288	295	293	289	0.180	297
Cr	0.070	0.100	0.030	0.020	0.020	--	0.030	--	0.09	0.018	--
Cs	--	--	--	--	--	--	--	--	--	--	--
Cu	0.620	0.530	0.520	0.550	--	0.330	0.590	0.08	0.04	0.024	0.04
Fe	1.170	1.00	0.840	0.980	0.970	0.920	0.930	0.17	0.24	0.029	0.12
K	26900	27200	27000	27600	24900	25600	24800	29800	29700	11.8	28800
La	0.190	0.240	0.050	0.010	0.220	0.180	0.160	0.21	0.12	--	0.19
Li	34.5	34.8	37.2	36.5	35.0	36.9	38.2	34.0	37.0	0.051	35.9
Mg	30300	31900	32500	31900	29200	30000	29200	31200	31200	13.1	31400
Mn	0.040	--	--	--	--	--	0.010	--	0.01	0.019	--
Mo	0.040	0.060	0.020	--	0.160	0.020	0.040	0.04	--	0.003	0.06
Na	37600	38500	38200	38500	35400	36400	35300	41800	41800	16.7	39800
Nd	0.240	0.450	--	--	0.390	0.160	--	0.29	0.02	--	0.11
Ni	1.39	1.40	1.11	1.19	0.430	0.950	1.27	0.46	0.32	0.017	0.42
P	0.730	1.03	--	0.150	0.240	--	0.240	--	1.09	0.046	--
Si	1.30	1.34	0.460	0.190	0.690	0.500	0.730	--	--	0.058	--
Sr	13.6	13.6	13.8	13.6	12.8	12.7	13.2	12.2	12.8	0.007	12.7
Ti	0.040	0.070	--	--	0.060	0.020	--	0.02	--	--	--
U	0.114	0.108	0.070	0.071	0.133	0.111	0.323	--	--	--	--
Zn	0.230	0.120	0.040	0.050	0.180	0.150	0.070	0.01	1.41	0.011	0.02
Zr	0.020	0.040	--	--	0.420	0.170	0.070	0.01	--	--	--
Ph	7.76	7.91	7.83	7.95	7.65	7.76	7.73	7.66	7.66	7.66	7.80

S = results from acid stripping the leach container

F = results from solutions filtered through an 18A⁰ filter. Note Ca data are usually high in these solutions and should be disregarded.

TABLE A.9. (contd)

SAMPLE ID	82D-292F	82D-292S	82D-309	82D-310	82D-311	82D-330	82D-331	82D-332	82D-342	82D-343	82D-344
TIME, d	182	192	364	364	364	546	546	546	728	728	728
Al	--	--	--	--	--	2.43	2.61	2.43	1.10	0.838	0.045
B	19.3	0.050	19.3	19.4	19.3	20.6	20.9	20.6	20.0	20.0	2.00
Ca	290	0.815	313	314	313	240	236	244	307	303	300
Cr	--	0.006	0.043	0.029	0.157	1.44	1.44	1.34	0.210	0.160	0.009
Cs	--	--	--	--	--	--	--	--	--	--	--
Cu	--	0.028	--	--	--	--	--	--	--	--	--
Fe	--	0.038	1.19	1.13	1.21	0.683	0.864	0.576	1.35	0.102	0.092
K	28800	64.8	27000	26857	26514	24816	24759	24759	25294	25013	25080
La	0.04	--	0.052	--	--	--	--	--	0.096	0.077	0.034
Li	40.4	0.108	34.0	34.1	34.0	27.6	27.9	27.8	35.7	35.7	36.0
Mg	31400	74.3	32678	32452	31967	30265	30102	30157	30814	30305	30458
Mn	--	0.007	0.244	0.220	0.205	0.225	0.225	0.271	1.01	0.813	0.784
Mo	--	--	--	0.018	--	0.174	0.124	0.199	0.052	0.052	0.029
Na	39800	85.7	38803	38757	38261	36157	36062	35827	36546	35840	36299
Nd	--	--	0.042	0.095	0.095	--	--	--	0.514	0.422	0.020
Ni	0.31	0.020	1.52	1.45	1.45	1.03	1.03	0.989	2.12	1.64	1.55
P	0.11	0.124	0.515	0.811	0.516	11.4	10.9	11.7	0.788	0.481	0.350
Si	--	--	2.44	2.31	1.95	3.07	2.94	2.54	6.67	5.15	4.71
Sr	13.1	0.033	13.9	13.9	13.9	--	--	--	13.1	13.0	13.1
Ti	--	--	0.013	--	--	0.055	0.041	0.028	0.053	0.039	0.007
U	--	--	--	--	--	--	--	--	--	--	--
Zn	1.55	0.020	0.100	0.148	0.132	--	--	--	0.162	0.156	0.148
Zr	--	--	--	--	--	0.087	0.058	0.044	0.043	0.027	--
pH	7.80	7.80	7.75	7.85	7.90	7.20	7.16	7.24	7.14	7.14	7.14

S = results from acid stripping the leach container

F = results from solutions filtered through an 18 μ filter. Note Ca data are usually high in these solutions and should be disregarded.

TABLE A.10. Normalized Elemental Mass Loss (g/m²) for SRL-131 Glass in Salt Brine at 40°C

SAMPLE ID	82D-230	82D-231	82D-251	82D-252	82D-269	82D-270	82D-271	82D-291F	82D-292F	82D-309	82D-310	82D-311	82D-330	82D-331	82D-332	82D-342	82D-343	82D-344
Time, d	28	28	56	56	91	91	91	182	182	364	364	364	546	546	546	728	728	728
Al	1.61	2.11	--	--	0.93	0.87	0.81	--	--	--	--	--	0.0062	1.13	0.0062	5.8	4.2	1.8
B	--	0.16	--	--	--	--	0.98	0.33	1.31	1.03	1.25	0.98	2.83	3.71	2.76	2.27	2.2	2.08
Ca	--	--	--	--	33.6	--	47.1	--	--	--	4.84	--	51.1	5.38	104	17.7	--	--
Cr	6.68	9.55	2.86	1.91	1.91	--	2.86	8.59	--	--	--	4.97	3.72	3.72	--	16.2	11.5	4.3
Cu	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Fe	27.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
K	--	--	--	--	0.07	0.02	0.03	--	--	--	--	--	0.003	0.18	--	0.74	--	--
La	--	--	--	--	--	--	--	13100	24100	10800	93600	59100	--	--	--	33500	5320	12000
Li	0.53	2.31	--	--	3.55	2.13	1.42	--	--	1.85	--	--	--	--	--	3.41	2.74	1.21
Mg	--	--	13	9.16	--	--	--	--	8.32	1.88	2.76	1.88	2.09	4.03	3.22	--	--	--
Mn	--	669	8690	669	--	--	--	15400	18100	13100	10100	3640	--	--	--	3800	--	--
Mo	0.15	--	--	--	--	--	0.038	0.038	--	0.93	0.83	0.78	0.85	0.85	1.03	3.57	2.82	2.71
Na	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Nd	6.22	11.7	--	--	10.1	4.15	--	3790	1960	1560	1520	1070	--	--	--	275	--	49.3
Ni	--	--	--	--	--	--	--	0.52	--	1.09	2.46	2.46	--	--	--	13.3	10.9	5.18
P	167	216	--	34.4	55	--	55	250	25.2	--	--	--	5.5	--	--	7.94	4.06	3.34
Si	0.22	0.25	--	--	0.38	0.28	0.4	--	--	0.87	0.8	0.6	0.55	0.48	0.26	103	32.3	2.29
Sr	--	--	12.7	--	--	--	12.7	--	4.22	1.86	3.46	0.17	--	--	--	3.39	2.55	2.31
Ti	0.44	1.11	--	--	1.33	0.44	--	--	--	0.29	--	--	1.22	0.91	0.62	1.18	0.87	0.16
U	0.8	0.75	0.49	0.49	0.93	0.78	2.26	--	--	--	--	--	--	--	--	--	--	--
Zn	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Zr	--	--	--	--	18.3	7.41	3.05	--	--	--	--	--	3.79	2.53	1.92	1.87	1.18	--

S = results from acid stripping the leach container

F = results from solutions filtered through an 18 μ filter. Note Ca data are usually high in these solutions and should be disregarded.

TABLE A.11. Concentrations (mg/L) of Elements Leached from SRL-131
Glass in Salt Brine at 90°C

	82D-241	82D-242	82D-243	82D-259	82D-260	82D-281	82D-282	82D-283	82D-299	82D-299F	82D-299S	82D-300
TIME, d	28	28	28	56	56	91	91	91	182	182	182	182
A	0.42	0.96	0.39	--	--	0.39	0.35	--	0.12	--	--	0.16
B	20.5	20.3	20.5	20.8	20.9	21.2	21.8	21.1	23.8	23.4	0.06	24.0
Ca	304	303	304	307	305	302	309	300	312	303	0.59	317
Cr	--	--	--	--	--	--	--	--	--	0.03	--	--
Cs	--	--	--	--	--	--	--	--	--	--	--	--
C	0.56	0.64	0.55	0.17	0.27	0.52	0.60	0.55	0.12	0.14	0.02	0.19
Fe	1.35	1.31	1.34	0.93	0.91	1.03	1.11	1.24	0.08	--	0.04	0.10
K	27900	28500	29400	26900	27500	27100	25900	25000	32100	32100	55.9	29800
L	0.24	0.35	0.25	--	--	0.20	0.19	0.17	0.18	0.12	--	0.21
Li	34.3	33.9	34.2	39.4	39.1	38.6	40.6	39.3	39.9	41.7	0.09	39.5
Mg	31900	32400	32000	31600	32000	30300	30100	29700	33300	33300	59.4	33200
Mn	0.30	0.33	0.31	0.13	0.21	0.58	0.50	0.46	--	0.10	0.07	--
Mo	--	--	0.24	0.15	--	--	0.10	--	0.09	--	--	0.12
Na	39300	40300	40500	37100	37900	38600	36800	35700	44000	44000	73.9	41200
Nd	0.30	0.84	0.39	--	--	--	--	--	0.11	--	--	0.13
Ni	1.41	1.44	1.42	1.02	0.98	1.29	1.27	1.19	0.07	0.09	0.04	0.10
P	--	--	--	--	--	--	--	--	--	0.46	0.01	0.00
Si	3.79	4.15	3.78	4.36	4.57	6.94	7.09	6.31	1.89	1.27	--	2.05
Sr	13.5	13.4	13.5	14.4	14.4	13.5	13.9	13.5	13.5	13.6	0.03	13.7
Ti	0.06	0.09	0.08	--	--	--	--	0.01	--	--	0.01	--
U	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.03	--	--	0.00	--
Zn	--	--	--	--	--	--	--	--	0.06	1.74	0.01	0.08
Zr	--	0.09	0.73	0.29	--	--	--	--	--	--	--	--
Ph	8.20	8.32	8.14	8.12	7.90	7.53	7.76	7.67	6.61	6.61	6.61	67.0

S = results from acid stripping the leach container

F = results from solutions filtered through an 18A filter. Note Ca data are usually high in these solutions and should be disregarded.

TABLE A.11. (contd)

	82D-300F	82D-300S	82D-321	82D-321F	82D-321S	82D-322	82D-322F	82D-322S	82D-323	82D-323F	82D-323S
TIME, d	182	182	364	364	364	364	364	364	364	364	364
Al	0.02	--	--	--	0.05	--	--	0.03	--	--	0.04
B	23.2	0.04	24.6	23.5	0.07	24.5	23.6	0.05	27.4	26.6	0.09
Ca	305	0.32	335	330	0.13	337	329	0.09	333	331	0.11
Cr	0.02	--	--	--	--	--	--	--	--	--	--
Cs	--	--	--	--	--	--	--	--	--	--	--
Cu	0.18	0.01	--	--	--	--	--	--	--	--	--
Fe	0.02	0.03	1.10	0.16	0.18	1.10	0.19	0.16	1.00	--	0.22
K	29800	27.9	29400	29000	12.4	29000	28600	8.9	29000	28600	11.5
La	0.15	--	--	--	--	--	--	--	--	--	--
Li	40.6	0.04	39.9	39.5	0.02	40.0	40.2	0.01	41.4	41.2	0.02
Mg	33200	31.5	35500	35100	17.4	35200	34700	12.4	35000	34600	18.8
Mn	0.13	0.05	--	--	--	--	--	--	--	--	--
Mo	--	--	--	--	--	--	--	--	--	--	--
Na	41200	37.9	42800	42100	18.0	42400	42100	13.0	42400	41700	17.0
Nd	0.04	--	--	--	--	--	--	--	--	--	--
Ni	0.12	0.04	1.10	0.20	0.11	1.30	0.10	0.08	1.50	0.20	0.19
P	1.77	0.05	--	--	--	--	--	--	--	--	--
Si	1.33	--	11.5	0.70	1.30	12.7	0.80	1.00	21.2	5.00	3.00
Sr	13.6	0.01	15.0	14.8	--	15.0	15.0	--	15.0	15.0	--
Ti	--	--	--	--	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--	--	--	--	--
Zn	1.72	0.01	0.14	1.60	--	0.14	1.40	--	0.14	1.60	--
Zr	--	--	--	--	--	--	--	--	--	--	--
pH	67.0	6.70	7.61	7.61	7.61	7.42	7.42	7.42	6.50	6.50	6.50

S = results from acid stripping the leach container

F = results from solutions filtered through an 18A filter. Note Ca data are usually high in these solutions and should be disregarded.

TABLE A.12. Normalized Elemental Mass Loss (g/m²) for SRL-131 Glass in Salt Brine at 90°C

	82D-241	82D-242	82D-243	82D-259	82D-260	82D-281	82D-282	82D-283	82D-299F	82D-300F	82D-321F	82D-322F	82D-323F
Time, days	28	28	28	56	56	91	91	91	182	182	364	364	364
Al	2.6	5.95	2.42	--	--	2.42	2.17	--	--	0.12	--	--	--
B	0.98	0.33	0.98	1.96	2.29	5.88	7.84	5.55	13.1	12.4	10.6	10.9	20.7
Ca	--	--	--	--	--	20.2	114	--	33.6	60.5	--	--	--
Cr	--	--	--	--	--	--	--	--	--	--	--	--	--
Cs	--	--	--	--	--	--	--	--	--	--	--	--	--
Cu	14.6	48	10.4	--	--	--	--	--	--	--	--	--	--
Fe	--	--	--	--	--	--	--	--	--	--	--	--	--
K	9030	15100	24100	--	50200	65200	--	--	56700	33600	10500	64700	64700
La	4.09	8	4.44	--	--	1.6	1.24	0.53	--	--	--	--	--
Li	--	--	--	21.1	19.4	--	9.16	1.94	15.3	9.16	16.4	20.3	25.8
Mg	12000	18700	13400	8020	13400	--	--	--	38100	36800	14200	8890	7560
Mn	1.14	1.25	1.18	0.49	0.8	2.14	1.84	1.69	0.32	0.44	--	--	--
Mo	--	--	--	--	--	--	--	--	--	--	--	--	--
Na	1510	2420	2600	--	228	913	--	--	5840	3290	931	931	566
Nd	7.78	21.8	10.1	--	--	--	--	--	--	1.04	--	--	--
Ni	0.12	0.37	0.21	--	--	--	--	--	--	--	--	--	--
P	--	--	--	--	--	--	--	--	106	406	--	--	--
Si	1.42	1.62	1.41	1.74	1.85	3.59	3.68	3.25	0.45	0.49	--	--	2.14
Sr	--	--	--	50.7	50.7	--	33.8	--	8.45	8.45	--	14.8	14.8
Ti	1	1.67	1.45	--	--	--	--	--	--	--	--	--	--
U	0.089	0.1	0.066	0.16	0.16	0.23	0.18	0.18	--	--	--	--	--
Zn	--	--	--	--	--	--	--	--	--	--	--	--	--
Zr	--	--	25.9	6.75	--	--	--	--	--	--	--	--	--

S = results from acid stripping the leach container

F = results from solutions filtered through an 18A filter. Note Ca data are usually high in these solutions and should be disregarded.

FIGURE A.10. Concentrations (mg/L) in the Leachates from SRL-131 Glass in Salt Brine at 40°C

FIGURE A.11. Concentrations (mg/L) in the Leachates from SRL-131 Glass in Salt Brine at 40°C

FIGURE A.12. Concentrations (mg/L) in the Leachates from SRL-131 Glass in Salt Brine at 90°C

FIGURE A.13. Concentrations (mg/L) in the Leachates from SRL-131 Glass in Salt Brine at 90°C

TABLE A.13. Concentrations (mg/L) of Elements Leached from SRL-131 Glass in Synthetic Groundwater at 40°C

SAMPLE ID	82D-232	82D-233	82D-234	82D-253	82D-254	82D-272	82D-273	82D-274	82D-293	92D-294	82D-312	82D-313	82D-314
TIME, d	28	28	28	56	56	91	91	91	182	182	364	364	364
Al	--	0.024	0.003	--	--	0.018	--	--	--	--	0.040	0.110	0.040
B	0.041	0.032	0.031	0.049	0.050	0.072	0.072	0.073	0.095	0.092	0.170	0.170	0.180
Ca	2.79	2.79	2.76	2.69	2.68	2.55	2.57	2.57	2.65	2.59	2.61	2.63	2.63
Cr	--	--	--	--	--	0.001	--	--	0.001	0.002	--	--	--
Cs	0.010	0.010	0.010	0.007	0.009	0.013	0.012	0.012	0.010	0.011	0.022	0.022	0.022
Cu	0.006	0.003	0.005	0.009	0.008	0.006	0.005	0.005	0.004	0.005	--	--	--
Fe	0.013	0.023	0.016	0.014	0.020	0.041	0.033	0.033	0.014	0.036	0.072	0.130	0.120
K	3.09	3.28	3.33	2.32	2.34	3.53	3.47	3.53	2.05	1.96	3.30	3.40	3.40
La	--	--	--	--	--	--	--	--	--	--	--	--	--
Li	0.020	0.020	0.020	0.055	0.060	0.076	0.070	0.078	0.088	0.097	0.140	0.130	0.140
Mg	0.050	0.046	0.050	--	0.009	0.057	0.038	0.036	0.024	0.026	0.180	0.350	0.250
Mn	0.008	0.009	0.007	0.009	0.008	0.011	0.010	0.011	0.015	0.020	0.039	0.053	0.064
Mo	0.013	0.003	0.002	--	--	--	--	--	--	--	--	--	--
Na	365	362	357	352	350	375	372	376	353	350	353	358	357
Nd	--	--	--	--	--	--	--	--	--	--	--	--	--
Ni	0.014	0.006	0.010	0.003	0.004	0.013	0.012	0.011	0.001	0.006	0.029	0.037	0.035
P	--	--	--	--	0.021	0.008	0.017	--	--	--	--	--	--
Si	30.6	30.4	30.1	29.4	29.4	29.3	29.3	29.5	29.8	29.6	30.4	30.9	30.7
Sr	0.005	0.005	0.005	0.006	0.006	0.006	0.006	0.006	0.007	0.007	--	0.011	0.011
Ti	--	--	--	--	0.006	--	--	--	--	--	--	--	--
U	0.026	0.028	0.009	0.018	0.018	0.041	0.072	0.076	0.017	0.021	0.032	0.029	0.031
Zn	0.002	0.002	0.002	0.002	0.002	0.005	0.004	0.006	0.008	0.010	--	--	--
Zr	--	--	--	--	--	--	--	--	--	--	--	--	--
pH	9.67	9.63	9.64	9.55	9.52	9.52	9.57	9.56	8.99	9.36	9.04	9.01	8.97

S = results from acid stripping the leach container

F = results from solutions filtered through an 18A filter. Note Ca data are usually high in these solutions and should be disregarded.

TABLE A.14. Normalized Elemental Mass Loss (g/m^2) for SRL-131
Glass in Synthetic Groundwater at 40°C

SAMPLE ID	82D-232	82D-233	82D-234	82D-253	82D-254	82D-272	82D-273	82D-274	82D-293	82D-294	82D-312	82D-313	82D-314
Time, d	28	28	28	56	56	91	91	91	182	182	364	364	364
Al	--	0.099	--	--	--	0.096	--	--	--	--	0.25	0.68	0.25
B	0.13	0.098	0.095	0.15	0.16	0.18	0.18	0.19	0.26	0.25	0.56	0.56	0.59
Ca	0.47	0.47	0.067	--	--	--	--	--	0.13	--	--	--	--
Cr	--	--	--	--	--	--	--	--	--	--	--	--	--
Cs	0.35	0.35	0.35	0.25	0.32	0.46	0.42	0.42	0.35	0.39	0.78	0.78	0.78
Cu	0.83	--	0.12	2.09	1.67	2.09	1.67	1.67	1.25	1.67	--	--	--
Fe	0.0065	0.016	0.0095	0.0075	0.013	0.026	0.018	0.018	--	0.021	0.033	0.091	0.081
K	--	--	--	--	--	6.52	0.5	6.52	--	--	--	10	10
La	--	--	--	--	--	--	--	--	--	--	--	--	--
Li	0.064	0.064	0.064	0.26	0.29	0.34	0.3	0.35	0.4	0.45	0.78	0.72	0.78
Mg	0.17	0.11	0.17	--	--	0.24	--	--	--	--	--	2.21	0.87
Mn	0.028	0.032	0.025	0.032	0.028	0.027	0.023	0.027	0.042	0.061	0.15	0.2	0.24
Mo	--	--	--	--	--	--	--	--	--	--	--	--	--
Nb	10	7.3	2.74	--	--	178	176	179	158	155	0.46	5.02	4.11
Nd	--	--	--	--	--	--	--	--	--	--	--	--	--
Ni	0.033	0.05	0.083	0.025	0.033	0.11	0.099	0.091	0.0083	0.05	0.24	0.31	0.29
P	--	--	--	--	2.98	--	--	--	--	--	--	--	--
Si	0.75	0.64	0.47	0.083	0.083	0.25	0.25	0.36	0.53	0.42	0.19	0.47	0.36
Sr	0.084	0.084	0.084	0.17	0.17	0.25	0.25	0.25	0.34	0.34	--	0.93	0.93
Ti	--	--	--	--	0.12	--	--	--	--	--	--	--	--
U	0.18	0.2	0.063	0.13	0.13	0.28	0.5	0.53	0.12	0.14	0.22	0.21	0.22
Zn	--	--	--	--	--	--	--	--	--	--	--	--	--
Zr	--	--	--	--	--	--	--	--	--	--	--	--	--

S = results from acid stripping the leach container

F = results from solutions filtered through an 18A filter. Note Ca data are usually high in these solutions and should be disregarded.

TABLE A.15. Concentrations (mg/L) of Elements Leached from SRL-131
Glass in Synthetic Groundwater at 90°C

	82D-244	82D-245	82D-246	82D-261	82D-262	82D-284	82D-285	82D-301	82D-301F	82D-301S	82D-302F	82D-302S	82D-324	82D-324F	82D-324S	82D-325
TIME, d	28	28	28	56	56	91	91	182	182	182	182	182	364	364	364	364
Al	0.274	0.271	0.249	0.128	0.153	0.164	0.152	0.228	0.183	0.010	0.178	0.010	0.410	0.310	0.050	0.450
B	7.64	7.63	7.63	13.8	13.1	19.7	20.0	38.7	36.9	0.121	38.3	0.135	36.3	36.2	0.450	39.0
Ca	0.076	0.078	0.074	0.020	0.020	0.033	0.063	0.022	0.154	--	0.147	0.001	0.020	0.270	--	0.020
Cr	--	--	--	--	--	--	--	0.049	0.048	--	0.045	--	0.080	0.078	--	0.075
Cs	0.790	0.840	0.830	1.30	1.30	1.74	1.70	2.50	2.70	0.006	--	0.007	2.20	2.40	0.029	2.30
Cu	0.007	--	--	0.004	0.004	0.016	0.004	0.013	0.005	--	--	--	--	--	--	--
Fe	0.073	0.073	0.055	0.052	0.054	0.113	0.081	0.069	0.008	0.012	0.007	0.013	0.098	0.021	0.048	0.053
K	3.04	2.90	3.26	2.24	2.02	3.24	3.25	2.04	3.01	--	3.01	--	3.10	3.10	--	3.10
La	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Li	4.81	4.66	4.63	8.59	8.25	12.8	13.0	23.6	21.6	0.070	22.6	0.076	20.7	20.7	0.220	22.1
Mg	0.404	0.390	0.373	0.390	0.354	0.608	0.626	0.806	0.015	0.149	0.016	0.128	0.870	0.100	0.400	0.830
Mn	0.132	0.130	0.114	0.135	0.125	0.183	0.173	0.168	--	0.036	--	0.036	0.160	--	0.068	0.140
Mo	--	--	--	--	--	--	--	0.007	0.013	--	0.017	--	--	--	--	--
Na	401	390	388	404	394	441	444	482	520	1.48	527	1.75	486	485	5.20	500
Nd	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ni	0.026	--	0.024	--	--	0.027	0.021	0.013	0.006	0.005	0.001	0.003	0.035	--	0.020	0.037
P	--	--	--	--	--	--	--	0.052	0.174	--	0.059	--	--	--	--	--
Si	48.4	47.8	47.5	58	55.7	65.7	65.7	102	116	0.511	122	0.576	101	102	1.70	111
Sr	0.003	0.004	0.003	0.002	0.002	--	--	0.002	0.003	--	0.003	--	--	--	--	--
Ti	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
U	0.164	0.134	0.141	0.141	0.137	0.137	0.121	0.140	--	--	--	--	0.211	0.234	0.003	0.220
Zn	--	--	--	--	--	--	--	0.011	0.613	0.001	0.560	0.001	--	0.690	--	--
Zr	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
pH	10.0	10.01	9.99	9.59	10.15	10.31	10.28	10.48	10.48	10.48	10.47	10.47	10.05	10.05	10.05	10.05

S = results from acid stripping the leach container

F = results from solutions filtered through an 18A filter. Note Ca data are usually high in these solutions and should be disregarded.

TABLE A.15. (contd)

	82D-325F	82D-325S	82D-326	82D-326F	82D-326S	82D-336	82D-337	82D-338	82D-348	82D-349	82D-350
TIME, d	364	364	364	364	364	546	546	546	728	728	728
Al	0.350	0.070	0.410	0.370	0.070	0.424	0.439	0.454	0.452	0.460	0.464
B	38.3	0.330	37.9	37.0	0.330	38.9	36.3	37.0	40.8	40.1	41.3
Ca	0.330	--	0.620	0.350	--	0.346	0.338	0.335	0.256	0.222	0.154
Cr	0.069	--	0.081	0.080	--	0.076	0.078	0.084	0.103	0.092	0.086
Cu	2.30	0.018	2.40	2.50	0.022	1.60	1.70	1.60	2.40	2.50	2.30
Fe	--	--	--	--	--	--	--	--	--	--	--
K	0.015	0.037	0.065	0.015	0.036	0.021	0.025	0.058	0.008	0.009	0.0006
La	3.10	--	3.10	3.10	--	3.34	3.05	3.13	3.05	2.98	3.14
Li	--	--	--	--	--	--	--	0.002	--	--	--
Mg	21.8	0.160	21.5	21.0	0.160	22.5	21.2	21.2	24.0	23.9	24.7
Mn	0.100	0.300	0.760	0.100	0.400	0.017	0.017	0.051	0.036	--	0.016
Mo	--	0.057	0.150	--	0.075	--	--	--	0.0005	--	0.0002
Na	--	--	--	--	--	0.013	0.013	0.013	0.008	0.003	0.017
Nd	487	3.60	493	482	3.90	458	453	449	484	484	488
Ni	--	--	--	--	--	--	--	--	--	--	--
P	--	0.028	0.039	--	--	0.873	0.783	0.873	0.864	0.792	0.287
Si	109	1.30	103	100	1.40	110	96.6	102	99.8	96.7	107
Sr	--	--	--	--	--	0.003	0.003	0.004	0.004	0.003	0.002
Ti	--	--	--	--	--	--	--	--	--	--	--
U	0.200	0.002	0.188	0.166	0.002	--	--	--	--	--	--
Zn	0.960	--	--	1.00	--	1.21	1.39	1.06	0.714	0.747	0.774
Zr	--	--	--	--	--	--	--	0.001	0.0005	--	0.001
pH	10.05	10.05	10.07	10.07	10.07	10.08	10.08	10.07	9.93	9.94	9.95

S = results from acid stripping the leach container

F = results from solutions filtered through an 18A filter. Note Ca data are usually high in these solutions and should be disregarded.

TABLE A.16. Normalized Elemental Mass Loss (g/m^2) for SRL-131
Glass in Synthetic Groundwater at 90°C

	82D-244	82D-245	82D-246	82D-261	82D-262	82D-284	82D-285	82D-301F	82D-302F	82D-324F	82D-325F	82D-326F	82D-336	82D-337	82D-338	82D-348	82D-349	82D-350
Time, days	28	28	28	56	56	91	91	182	182	364	364	364	546	546	546	728	728	728
Al	1.7	1.68	1.54	0.79	0.95	1.02	0.94	1.13	1.1	1.7	1.95	2.08	2.44	2.53	2.63	2.8	2.91	2.87
B	25	24.9	24.9	45.1	42.8	64.3	65.3	120	125	118	125	121	127	119	121	133	131	135
Ca	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Cr	---	---	---	---	---	---	---	4.49	4.2	7.45	6.59	7.64	6.88	7.01	7.66	9.65	8.6	8.05
Cu	27.9	29.7	29.3	45.9	45.9	61.5	60.1	95.4	---	84.8	81.3	88.3	56.5	60.1	56.5	84.8	88.3	81.3
Fe	0.065	0.065	0.047	0.044	0.046	0.099	0.067	---	4.17	---	---	---	---	---	0.026	---	---	---
K	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
La	---	---	---	---	---	---	---	---	---	---	---	---	---	---	0.034	---	---	---
Li	26.7	25.8	25.7	47.6	45.7	71	72.1	120	125	115	121	117	125	118	118	133	132	137
Mg	5.06	4.87	4.65	4.39	4.87	7.75	7.99	---	---	---	---	---	---	---	---	0.45	---	0.17
Mn	0.5	0.49	0.43	0.51	0.47	0.69	0.66	---	---	---	---	---	---	---	---	0.0019	---	0.00076
Mo	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Na	37	26.9	25.1	39.7	30.6	37.4	40.2	110	116	91.3	93.1	88.5	87.5	83.3	79.2	100	100	104
Nd	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Ni	0.21	---	0.19	---	---	0.22	0.17	0.05	0.0083	---	---	---	---	---	---	---	---	---
P	---	---	---	---	---	---	---	36.1	9.75	---	---	---	184	163	184	190	173	57.3
Si	10.1	9.8	9.64	15.5	14.2	19.2	19.2	47.1	50.4	38.3	42.2	37.2	44	36.4	39.7	38.3	36.6	42.5
Sr	---	---	---	---	---	---	---	---	---	---	---	---	---	---	0.3	0.25	0.19	---
Ti	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
U	1.15	0.94	0.99	0.99	0.96	0.96	0.85	---	---	1.64	1.4	1.16	---	---	---	---	---	---
Zn	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Zr	---	---	---	---	---	---	---	---	---	---	---	---	---	---	0.026	---	---	0.031

S = results from acid stripping the leach container

F = results from solutions filtered through an 18 μ filter. Note Ca data are usually high in these solutions and should be disregarded.

FIGURE A.14. Concentrations (mg/L) in the Leachates from SRL-131 Glass in Synthetic Groundwater at 40°C

FIGURE A.15. Concentrations (mg/L) in the Leachates from SRL-131 Glass in Synthetic Groundwater at 40°C

FIGURE A.16. Concentrations (mg/L) in the Leachates from SRL-131 Glass in Synthetic Groundwater at 90°C

FIGURE A.17. Concentrations (mg/L) in the Leachates from SRL-131 Glass in Synthetic Groundwater at 90°C;

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