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Pacific Northwest National Laboratory
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July 2002

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

This report describes the caustic leaching test conducted on Hanford Tank T-110 sludge during FY 2002 at the Pacific Northwest National Laboratory. The data presented here can be used to develop the baseline and alternative flowsheets for pretreating Hanford tank sludge. The U.S. Department of Energy funded the work through the Efficient Separations and Processing Crosscutting Program (ESP; EM-50).

The T-110 sludge sample was first subjected to washing with dilute sodium hydroxide solution at ambient temperature. Following the dilute hydroxide washing, several aliquots of the washed solids were taken for leaching tests. The washed solids were subjected to leaching with 1, 3, or 5 M NaOH at 60, 80, or 100°C for up to 168 h. The leachates were sampled at 4, 8, 24, 72, and 168 h. The leached solids were dried to constant mass at 105°C and then analyzed.

Bismuth, Fe, Na, P, and Si are the dominant elements present in the T-110 sludge. As expected, Na is largely (> 90%) removed by dilute hydroxide washing. However, dilute hydroxide washing is ineffectual at removing Bi, Fe, or Si. For this particular sludge, the behavior of P is of major concern due to the relatively low tolerance for this element in the high-level waste (HLW) immobilization process and the high concentration of P in the waste. Only 33% of the P was removed by dilute hydroxide washing, resulting in washed solids that were 8.8 wt% P. This is presumably because the P is present as bismuth phosphate in the T-110 solids. More rigorous pretreatment (e.g., caustic leaching) will be required to remove enough P so that it is not a limiting component in the sludge solids. The minor sludge component, Cr, can also adversely affect the HLW immobilization process. The Cr in the T-110 sludge was largely insoluble in 0.01 M NaOH, with only 3% being removed by dilute hydroxide washing.

The solution obtained by washing the T-110 solids with dilute hydroxide could likely be immobilized as a Class A low-level waste (LLW), even without removing ^{137}Cs.

The work presented here indicates caustic leaching to be a very effective method for pretreating Hanford Tank T-110 sludge, primarily because this method essentially quantitatively removes P from the water-washed T-110 solids. Assuming a P_2O_5 limit of 3 wt% in the immobilized high-level waste (IHLW) glass, it is estimated that caustic leaching will result in an ~80% reduction in the IHLW mass. Unlike high-Al tanks (see for example, Lumetta et al. 2001), relatively mild leaching conditions (1 M NaOH at 60°C) should sufficiently remove P from the T-110 solids. However, more rigorous leaching conditions (or oxidative leaching) may be needed to avoid encountering the Cr limit in the glass formulation. The leaching of P from the sludge solids is rapid and largely independent of temperature and NaOH concentration. On the other hand, the leaching of Cr is much slower and is highly dependent on temperature and NaOH concentration.

Some of the caustic-leaching solutions contained significant concentrations of transuranic (TRU) elements (primarily Pu). The dissolved TRU generally increased with increasing NaOH concentration and temperature. Immobilization of these solutions could result in a waste form that exceeds the 10 nCi/g TRU limit for LLW, but they would be within the Class C limit of 100 nCi/g. This should be considered in managing these leaching solutions. As was the case with the dilute hydroxide wash solution, ^{137}Cs would likely not need to be removed to meet the Class A LLW criterion of 1 Ci/m^3.

Glossary

DOE	U.S. Department of Energy
ESP	Efficient Separations and Processing Crosscutting Program
ESW	enhanced sludge washing
GEA	gamma energy analysis
HDPE	high-density polyethylene
HLW	high-level waste
ICP-AES	inductively coupled plasma/atomic emission spectroscopy
IHLW	immobilized high-level waste
ILAW	immobilized low-activity waste
LAW	low-activity waste
LLW	low-level waste
NRC	U.S. Nuclear Regulatory Commission
PNNL	Pacific Northwest National Laboratory
PP	polypropylene
TRU	transuranic elements
UV/vis	ultraviolet/visible
WOL	Waste Oxide Loading

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1.0 Introduction

Since 1990, the primary mission at the U.S. Department of Energy's Hanford Site has changed from producing plutonium to restoring the environment. Large volumes of high-level radioactive wastes (HLW), generated during past Pu production and other operations, are stored in underground tanks onsite. The current plan for remediating the Hanford tank farms consists of waste retrieval, pretreatment, treatment (immobilization), and disposal. The tank wastes will be partitioned into high-level and low-activity fractions. The low-activity waste (LAW) will be processed to remove ^{137}Cs and ^{99}Tc (and ^{90}Sr and transuranic [TRU] elements in selected cases), and then it will be immobilized in a glass matrix and disposed of by shallow burial onsite. The HLW will be immobilized in a borosilicate glass matrix; the resulting glass canisters will then be disposed of in a geologic repository (DOE/ORP 2001). Because of the expected high cost of HLW vitrification and geologic disposal, pretreatment processes will be implemented to reduce the volume of immobilized high-level waste (IHLW).

Dilute hydroxide washing is the minimum pretreatment that would be performed on Hanford tank sludges. This method simply involves mixing the sludge with dilute (0.1 M or less) NaOH and then performing some sort of solid/liquid separation. This is meant to remove water-soluble sludge components (mainly sodium salts) from the HLW stream. Dilute hydroxide is used rather than water to maintain the ionic strength high enough that colloidal suspensions are avoided.

Caustic leaching (sometimes referred to as enhanced sludge washing or ESW) represents the baseline method for pretreating Hanford tank sludges. Caustic leaching is expected to remove a large fraction of the Al, which is present in large quantities in Hanford tank sludges. The Al will be removed by converting aluminum oxides/hydroxides to sodium aluminate. For example, boehmite and gibbsite are dissolved according to the following equations (Weber 1982).

$$AlOOH(s) + NaOH(aq) \rightarrow NaAlO_2(aq) + H_2O \quad (1.1)$$

$$Al(OH)_3(s) + NaOH(aq) \rightarrow NaAlO_2(aq) + 2H_2O \quad (1.2)$$

A significant portion of the P is also expected to be removed from the sludge by the metathesis of water-insoluble metal phosphates to insoluble hydroxides and soluble Na_3PO_4. An example of this is shown for iron(III) phosphate in the following equation.

$$FePO_4(s) + 3NaOH(aq) \rightarrow Fe(OH)_3(s) + Na_3PO_4(aq) \quad (1.3)$$

Similar metathesis reactions can also occur for insoluble sulfate salts, allowing the removal of sulfate from the HLW stream.

Based on its known amphoteric behavior (Rai et al. 1987), Cr(III) was expected to be removed by caustic leaching according to the following equation:

$$Cr(OH)_3(s) + NaOH(aq) \rightarrow Na[Cr(OH)_4](aq) \quad (1.4)$$

However, studies conducted at the Pacific Northwest National Laboratory (PNNL) have suggested that the behavior of Cr in the caustic leaching process is more complex (Lumetta et al. 1997). It is now generally recognized that oxidative mechanisms are also involved because the Cr in the leaching solutions is invariably present as primarily the CrO_4^{2-} ion.

Results of previous studies of the baseline Hanford sludge-washing and caustic-leaching process have been reported (Lumetta and Rapko 1994; Rapko et al. 1995, Lumetta et al. 1996a, 1996b, 1997, 1998; Temer and Villarreal 1995, 1996, 1997). In the initial work, each sludge sample was subjected to a standard testing condition. In FY 1998, the focus of the testing effort shifted to performing parametric tests on selected sludge samples (Lumetta et al. 1998, 2001). The purpose of the parametric tests is to provide data that process engineers can use to optimize process flowsheets for specific waste types. The parameters being considered are time, temperature, and caustic (NaOH) concentration. This report describes the results of parametric caustic-leaching tests performed on sludge from Hanford Tank T-110. This tank contains primarily waste from the second purification cycle of the bismuth phosphate process for Pu recovery. It also received waste from the final lanthanum fluoride precipitation step for purifying the Pu (Hill et al. 1995).

2.0 Experimental

This section describes composition of the T-110 sludge sample, the initial washing of its solids, the division of the washed T-110 solids, and the caustic leaching of the washed T-110 solids. Also described are the methods used to determine the hydroxide and the chromium(VI) concentrations.

2.1 Description of the T-110 Sludge Sample

The T-110 sludge sample used was a composite of segments from two different core samples (Table 2.1). The composite sample was prepared at the Hanford 222-S Laboratory and shipped to PNNL in March 2001.

Table 2.1. Description of T-110 Sludge Composite

Sample ID[a]	Core No.	Segment No.	Amount Added, g
S97T000215	180	1	10.3
S97T000255	180	2	10.0
S97T000225	180	3	10.0
S97T000227	180	4	10.1
S97T000229	180	6	10.0
S97T000258	180	7	10.2
S97T000260	180	8	10.0
S97T000126	181	1	10.3
S97T000135	181	2	10.1
S97T000138	181	3	10.0
S97T000139	181	4	9.9
S97T000167	181	5	10.0
S97T000177	181	6	9.9
S97T000161	181	7	9.9
S97T000194	181	8	10.2
		Net Mass, g:	150.9

(a) Unique identifier used at the Hanford 222-S Laboratory.

2.2 Initial Washing of the T-110 Solids

The 150-g T-110 composite sample was dry when received. The as-received solids were transferred to a 1-L high-density polyethylene (HDPE) bottle. Dilute (0.01 M) NaOH solution was added to yield a total volume of 500 mL, and then the mixture was agitated using a mechanical stirrer for ~1 h. The mixture was allowed to stand for 2 h, after which time the settled-solids layer was ~250 mL. The supernatant liquid was removed using a pipette. The settled-solids layer was mobilized by stirring and was divided equally between two 200-mL centrifuge bottles. The two portions were diluted to 200 mL with 0.01 M NaOH and then magnetically stirred for ~1 h. The wash slurries were centrifuged at ~1200 G. The wash liquor was decanted from each centrifuge bottle, and these were combined with the previous wash liquid. Dilute (0.01 M) NaOH solution was added to yield a total volume of 200 mL in each bottle, and the washing process was repeated.

After decanting the final leaching solution, the washed solids were slurried with a minimum amount of deionized water and were combined together. The mass of the slurry of washed solids was 508.2 g, and the mass of the combined washing solution was 985.8 g. The slurry of washed solids was homogenized with a mechanical stirrer, and two approximately 2-g aliquots were taken for analysis. The two aliquots were dried to constant weight at 105°C to determine the solids composition of the slurry. The slurry contained 8.3 wt% solids, which translated to a total of 42.2 g of washed solids. The two dried aliquots of washed solids were analyzed by inductively coupled plasma-atomic emission spectroscopy (ICP-AES), gamma energy analysis (GEA), and for total alpha and total beta activity (Table 2.2).

Table 2.2. Composition of the Dilute Hydroxide-Washed T-110 Solids

Component	Concentration, µg/g	Component	Concentration, µCi/g
Al	1050	Total Alpha	7.19E-01
B	[340]	$^{239+240}$Pu	6.73E-01
Ba	[62]	^{238}Pu+^{241}Am	4.49E-02
Bi	146000	$^{243+244}$Cm	1.40E-03
Ca	3580	^{242}Cm	1.72E-05
Cr	5943	^{137}Cs	1.55E-01
Fe	140000	^{241}Am (gamma)	3.83E-02
La	[80]	^{60}Co	< 6E-04
Mg	[380]		
Mn	992		
Na	76400		
P	88300		
Pb	[660]		
Si	79870		
Sr	1170		
Ti	[70]		
U	[5100]		
Zn	[270]		

(a) Experimental uncertainties are 15%, except for values given in brackets. Values given in brackets are within 10 times the detection limit, and the uncertainties for these values are greater than 15%.

2.3 Division of the Washed T-110 Solids

The slurry of washed T-110 solids was homogenized with a mechanical stirrer. Nine aliquots, nominally 30 g each, were transferred to 60-mL polypropylene (PP) bottles using a large (23-mL capacity) disposable polyethylene pipette. Table 2.3 lists the bottle labels, the mass of each aliquot, and the amount of solids in each aliquot, based on 8.4 wt% solids in the slurry.

Table 2.3. Mass of Washed T-110 Solids in Each Leaching Aliquot

Bottle ID	Mass Slurry, g	Mass Solids, g
T110-60-1	30.1	2.498
T110-60-3	30.1	2.498
T110-60-5	30.1	2.498
T110-80-1	30.2	2.507
T110-80-3	30.3	2.515
T110-80-5	30.3	2.515
T110-100-1	30.2	2.507
T110-100-3	30.2	2.507
T110-100-5	30.3	2.515

2.4 Caustic Leaching of the Washed T-110 Solids

Table 2.4 summarizes the leaching conditions for each aliquot of washed T-110 solids. The aluminum heating block was preheated to the desired temperature. Sodium hydroxide solution (10 M) was added to each aliquot of washed T-110 solids in the following amounts: 5.5 mL to yield 1 M NaOH, 15.5 mL to yield 3 M NaOH, and 25.5 mL to yield 5 M NaOH. The leaching mixtures were then diluted to 50 mL with deionized water. The ratio of ~20 mL solution per gram of washed T-110 solids was chosen so that the solutions would be under-saturated with respect to sodium phosphate.

The liquid level was marked on each reaction vessel, and each vessel was closed with a cap equipped with a tube-condenser. The leaching mixtures were mixed at temperature with a magnetic stirrer. Evaporation was minimal during the course of the experiment; occasionally, deionized water was added to bring the liquid level up to its original position. The leachates were sampled at intervals of 4, 8, 24, 72, and 168 h. The transfer pipette and the syringe filter assembly (0.45-µm nylon membrane) used in each sampling event were preheated by inserting in a boiling water bath. These were then used to filter ~1 mL of the leachate solution. A 0.5-mL aliquot of the filtered solution was immediately acidified with 15 mL of 0.3 M HNO_3. The remaining filtered solution was added back to the reaction vessel, and the leaching was continued. After 168 h, additional samples were taken for titrimetric (diluted into deionized water) analysis and Cr(VI) analysis by ultraviolet (UV) spectrophotometry (diluted into 0.1 M NaOH).

At the conclusion of the test, the reaction vessels were centrifuged for 5 min (~1200 G) immediately after removing from the heating block. The leachate was decanted and saved. The leached solids were washed thrice with 30-mL portions of 0.01 M NaOH and then were dried at 105°C. Table 2.5 gives the weights of the leached solids and the weight reductions achieved after leaching for 168 h. The mass losses are not corrected for the mass lost through filtration during sampling, so the actual mass lost through leaching is slightly less than those listed in the table.

Table 2.4. Caustic Leaching Conditions

	[NaOH], M		
Bottle ID	**Target**	**Measured**	**Temperature, °C**
T110-60-1	1	0.6	60
T110-60-3	3	2.5	60
T110-60-5	5	3.8	60
T110-80-1	1	0.6	80
T110-80-3	3	2.7	80
T110-80-5	5	4.2	80
T110-100-1	1	0.6	100
T110-100-3	3	2.5	100
T110-100-5	5	4.3	100

Table 2.5. Mass of the Leached T-110 Solids and the Mass Loss Achieved During Leaching

Bottle ID	Mass of Leached Solids, g	Mass Loss, %
T110-60-1	1.362	45
T110-60-3	1.220	51
T110-60-5	1.173	53
T110-80-1	1.359	46
T110-80-3	1.204	52
T110-80-5	1.053	58
T110-100-1	1.324	47
T110-100-3	1.140	54
T110-100-5	1.162	54

2.5 Determination of Hydroxide Concentration

The free hydroxide concentration in the T-110 caustic leaching solutions was determined by titration with standard HCl. Aliquots (0.1-mL) of the leaching solutions were diluted into 10 mL of deionized water. To these analyte solutions was added 0.1 mL of 2 M $Ca(NO_3)_2$ to precipitate any carbonate present in the samples. The resulting solutions were then titrated with 0.1 M HCl. The titration was conducted using a Mettler DL-21 automatic titrator equipped with a combination Ross® Electrode (ATI Orion, Boston, MA). The first measured equivalence point in the titration curves was assumed to be due to free hydroxide. Table 2.4 presents the measured free hydroxide concentrations.

2.6 Determination of Chromium(VI) Concentration

The CrO_4^{2-} concentration in the leaching solutions (after 1 week of leaching) was determined by ultraviolet/visible (UV/vis) spectrophotometry. A calibration curve was generated by measuring the spectra of standard CrO_4^{2-} solutions (in 0.1 M NaOH). The absorption at 372 nm was used. The leaching solutions were diluted with 0.1 M NaOH as needed, and the absorption was measured at 372 nm. The CrO_4^{2-} concentrations were calculated from the measured absorbance and the calibration curve. Table 2.6 compares the measured CrO_4^{2-} values to the total Cr concentrations determined by ICP-AES. In all cases, the Cr(VI) and total Cr concentrations were the same within experimental uncertainty. Thus, it can be concluded that all the Cr in the leaching solutions is present in the form of CrO_4^{2-}.

Table 2.6. Comparison of Measured Cr(VI) and Total Cr Concentrations

	Concentration, µg/g	
Solution	**Cr(VI)**	**Total Cr**
1 M NaOH at 60°C	26	27
3 M NaOH at 60°C	139	136
5 M NaOH at 60°C	149	145
1 M NaOH at 80°C	71	77
3 M NaOH at 80°C	215	190
5 M NaOH at 80°C	205	188
1 M NaOH at 100°C	128	116
3 M NaOH at 100°C	211	200
5 M NaOH at 100°C	199	189

3.0 Results and Discussion

This section presents the results from the dilute hydroxide washing and the caustic leaching. The behaviors of aluminum, chromium, phosphorous, and radionuclides are described. The impact of leaching on the mass of IHLW glass is discussed.

3.1 Dilute-Hydroxide Washing

Table 3.1 presents the behavior of the various non-radioactive T-110 sludge components during washing of the as-received T-110 sludge sample with 0.01 M NaOH. Bismuth, Fe, Na, P, and Si are the dominant elements present in the T-110 sludge. As expected, Na is largely removed by dilute hydroxide washing. On the other hand, dilute hydroxide washing is ineffectual at removing Bi, Fe, or Si. No detectable Bi or Fe was removed, and only 2% of the Si was found in the washing solution. For this particular sludge, the behavior of P is of major concern due to the relatively low tolerance for this element in the HLW immobilization process and the high concentration of P in the waste. Only 33% of the P was removed by dilute hydroxide washing, resulting in washed solids that were 8.8 wt% P. This is presumably because the P is present as bismuth phosphate (K_{sp} =1.3 × 10^{-23}) in the T-110 solids. More rigorous pretreatment (e.g., caustic leaching) will be required to remove enough P so that it is not a limiting component in the sludge solids. The minor sludge component, Cr, can also adversely affect the HLW immobilization process. The Cr in the T-110 sludge was largely insoluble in 0.01 M NaOH, with only 3% being removed by dilute hydroxide washing.

Table 3.1. Results of Dilute-Hydroxide Washing of the As-Received T-110 Sludge

	Initial Washing Solution		Washed Solids			
	Solution Mass, g	985.8	Solids Mass, g	42.2		
Component	**Conc. μg/g**	**Mass, μg**	**Conc. μg/g**	**Mass, μg**	**Total Mass, μg**	**Removed, %**
Ag						
Al			1048	44226	44226	(b)
As						
B	[4.4]	[4288]	[343]	[14475]	[18763]	23%
Ba			[62]	2616	2616	(b)
Be						
Bi			146000	6161200	6161200	(b)
Ca			3580	151076	151076	(b)
Cd						
Ce						
Co						
Cr	7.8	7650	5943	250795	258444	3%
Cu						
Dy						
Eu						
Fe			140000	5908000	5908000	(b)
K			N/A	N/A	N/A	N/A

Table 3.1 (Contd)

	Initial Washing Solution		Washed Solids			
	Solution Mass, g	985.8	Solids Mass, g	42.2		
Component	Conc. µg/g	Mass, µg	Conc. µg/g	Mass, µg	Total Mass, µg	Removed, %
La			[80]	[3376]	[3376]	(b)
Li						
Mg			[1400]	[59080]	[59080]	(b)
Mn			[992]	[41862]	[41862]	(b)
Mo						
Na	10900	10745111	76400	3224080	13969191	91%(c)
Nd						
Ni			N/A	N/A	N/A	N/A
P	1845	1818783	88300	3726260	5545043	33%
Pb			[660]	[27852]	[27852]	(b)
Pd						
Rh						
Ru						
Sb						
Se						
Si	[74]	[72948]	79867	3370387	3443336	2%
Sn						
Sr			1170	49374	49374	(b)
Te						
Th						
Ti			[70]	[2954]	[2954]	(b)
Tl						
U			[5100]	[215220]	[215220]	(b)
W						
Y						
Zn			[267]	[11267]	[11267]	(b)
Zr						

(a) Analyte was below detection limit if left blank. Experimental uncertainties are 15%, except for values given in brackets. Values given in brackets are within 10 times the detection limit, and the uncertainties for these values are greater than 15%.
(b) No detectable removal.
(c) Not corrected for Na added as NaOH in washing solution.

Table 3.2 presents the behavior of the radioactive components during washing of the as-received T-110 sludge sample with 0.01 M NaOH.[a] The TRU isotopes were detected at low levels in the washing solution. If this wash solution were converted to a LAW glass form with 20-wt% Na_2O, the TRU content of the resulting waste form would only be 0.04 nCi/g, which is well below the 10 nCi/g limit for Class A low-level waste (LLW). On the other hand, the washed solids contain ~700 nCi TRU/g, so they must be managed as HLW. Interestingly, only 37% of the ^{137}Cs was found in the washing liquor. Again, assuming a LAW waste form with 20 wt% Na_2O and a density of 2.7 MT/m^3, converting the washing solution to LAW glass would give a waste form containing 0.14 Ci/m^3. This also is well below the Class

(a) Analysis of the Sr-90 behavior was not done.

A LLW limit of 1 Ci/m^3, so it appears that Cs removal would not be needed before vitrifying the washing solution.

Table 3.2. Radionuclide Behavior During Dilute-Hydroxide Washing of the As-Received T-110 Sludge

	Initial Washing Solution		Washed Solids			
	Solution Mass, g: 985.79		Solids Mass, g: 42.2		Total	
Component	Conc., µCi/g	µCi	Conc., µCi/g	µCi	µCi	Removed, %
^{137}Cs	3.82E-03	3.77E+00	1.55E-01	6.54E+00	1.03E+01	37
$^{241}Am(g)$	<5E-05	<5E-02	3.83E-02	1.62E+00	1.67E+00	< 3
$^{239/240}Pu$	2.48E-06	2.44E-03	6.73E-01	2.84E+01	2.84E+01	0.01
$^{241}Am+^{238}Pu$	1.35E-07	1.33E-04	4.49E-02	1.89E+00	1.89E+00	0.01
$^{243/244}Cm$	2.69E-08	2.65E-05	1.40E-03	5.91E-02	5.91E-02	0.04
Total Alpha	2.66E-06	2.62E-03	7.19E-01	3.03E+01	3.03E+01	0.01

3.2 Caustic Leaching

Appendix A presents the concentrations of the various T-110 sludge components in the leaching solutions as a function of time, as well as the concentrations in the final washing solutions. Appendix B presents detailed results of the T-110 leaching test in terms of the concentration and mass of each component in 1) the leaching solution (after one week), 2) the post-leach washing solution, and 3) the leached solids. Appendix B also presents the concentration of each component in the water-washed solids, calculated by summing the mass of each component in the leaching and washing solutions and the residual solids and then dividing by the amount of washed solids used in the test. The concentrations determined in this manner are compared to those obtained by direct analysis of the washed solids. Mass recoveries obtained were generally within 20% for the major sludge components—Bi, Fe, P, and Si. The recoveries were especially good (near 100%) for Bi and Si. The recoveries for P were consistently ~10% high, whereas those for Fe were consistently ~15% low. Mass recoveries were also good for Cr (84 to 93%), but the recoveries for Al were generally low. However, Al is a relatively minor component in the T-110 sludge, and there was significant experimental uncertainty in the determination of this element.

Table 3.3 summarizes the removal achieved for the sludge components Al, Cr, and P by leaching the washed T-110 solids with NaOH for one week. A more detailed discussion of the behavior of these components is given in the following paragraphs.

Table 3.3. Aluminum, Chromium, and Phosphorus Removal Achieved After One Week of Leaching

		Removed, %		
T, °C	**[NaOH], M**	**Al**	**Cr**	**P**
60	0.59	27	11	99
60	2.5	42	53	100
60	3.8	59	65	100
80	0.55	53	29	99
80	2.7	67	68	100
80	4.3	83	77	99
100	0.62	50	48	99
100	2.5	75	81	99
100	4.3	77	77	99

3.2.1 Aluminum Behavior

Because of its low concentration, removing Al from the T-110 sludge is relatively unimportant. However, its behavior is of academic interest. Figures 3.1, 3.2, and 3.3 illustrate the Al dissolution at 60, 80, and 100°C, respectively; Figures 3.4, 3.5, and 3.6 illustrate the Al dissolution at 1, 3, and 5 M NaOH, respectively. In the latter plots, the data are presented in terms of both the Al concentration and the percentage of Al removed as a function of time. Scatter in the data makes interpretation difficult. This scatter is a result of the fact that the Al concentrations in the solutions are very low. It can be concluded that, as expected, Al dissolution increases with increasing NaOH concentration. The most marked gain is obtained in increasing [NaOH] from 1 to 3 M; only a modest increase is obtained by increasing [NaOH] from 3 to 5 M. For the most part, the Al concentrations are relatively constant (within experimental uncertainty) after leaching for 8 h. The data from the 3 M NaOH/60°C test suggest that the Al concentration decreases after 8 h. It is not clear if this is a real phenomenon or just due to experimental uncertainty. The sharp drop in the Al concentration after 4 h in the 3 M NaOH/100°C test is believed to be due to a dilution error in the 4-h sample.

3.2.2 Chromium Behavior

Figures 3.7, 3.8, and 3.9 illustrate the Cr dissolution at 60, 80, and 100 °C, respectively; Figures 3.10, 3.11, and 3.12 illustrate the Cr dissolution at 1, 3, and 5 M NaOH, respectively. The data are presented in terms of both the Cr concentration and the percentage of Cr removed as a function of time. At all temperatures examined, there was a marked increase in the amount of Cr in solution when [NaOH] was increased from 1 to 3 M. Increasing [NaOH] from 3 to 5 M resulted in only a modest increase in the dissolved Cr concentration. The amount of Cr removed also increased with increasing temperature. At 1 and 3 M NaOH, the increases obtained by increasing temperature were fairly regular. However, at 5 M NaOH, no significant increase was obtained in raising the temperature from 80 to 100°C.

3.2.3 Phosphorus Behavior

Figures 3.13, 3.14, and 3.15 illustrate the P dissolution at 60, 80, and 100 °C, respectively; Figures 3.16, 3.17, and 3.18 illustrate the P dissolution at 1, 3, and 5 M NaOH, respectively. The data are presented in terms of both the P concentration and the percentage of P removed as a function of time. Although there is some scatter in the data, it can be concluded that P removal from the washed T-110 solids is rapid, with near quantitative removal achieved within 4 h for all conditions examined.[(a)]

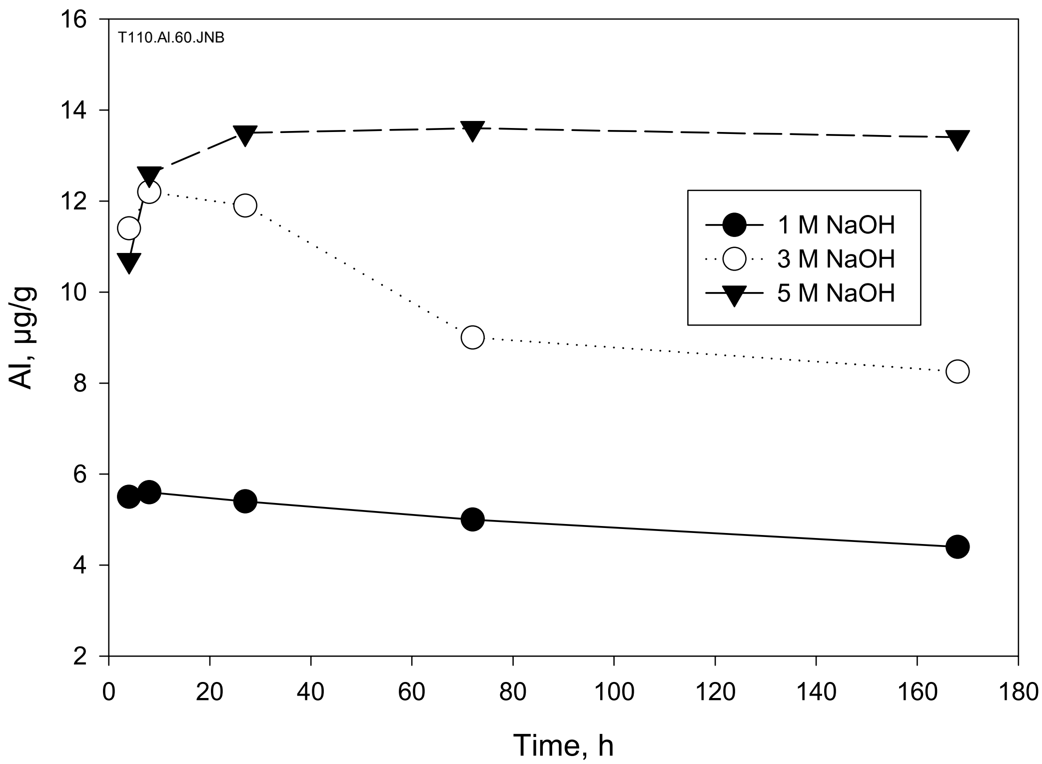

Figure 3.1. Aluminum Concentration as a Function of Time During Leaching of T-110 Solids at 60°C

(a) As with the Al concentration, the sharp drop in the P concentration after 4 h in the 3 M NaOH/100°C test is believed to be due to a dilution error in the 4-h sample. That the amount of P removed is indicated to be greater than 100% in some cases is an artifact of how the percent removal was calculated. The percent removed at time t was calculated as $(C_t)(\%R_{168})/C_{168}$, where C_t is the concentration at time t, C_{168} is the concentration at 168 h, and $\%R_{168}$ is the total percent removed after 168 h of leaching. When C_t was greater than C_{168}, the percent removed at time t is sometimes calculated to be greater than 100%. However, in such cases, C_t and C_{168} are essentially the same within experimental uncertainty.

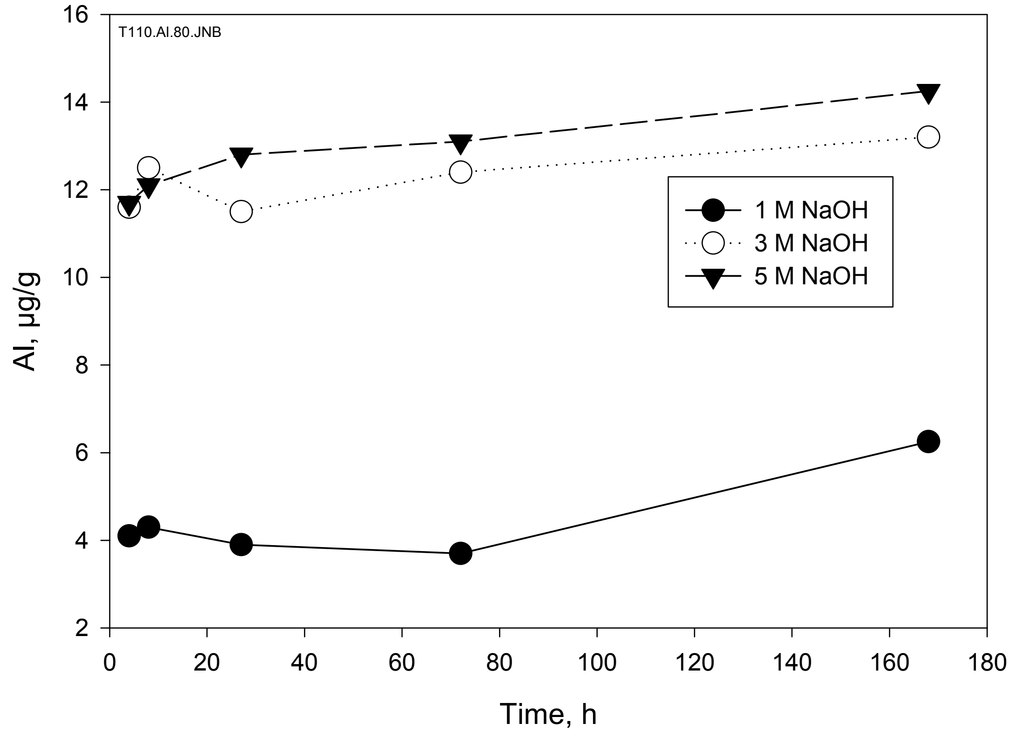

Figure 3.2. Aluminum Concentration as a Function of Time During Leaching of T-110 Solids at 80°C

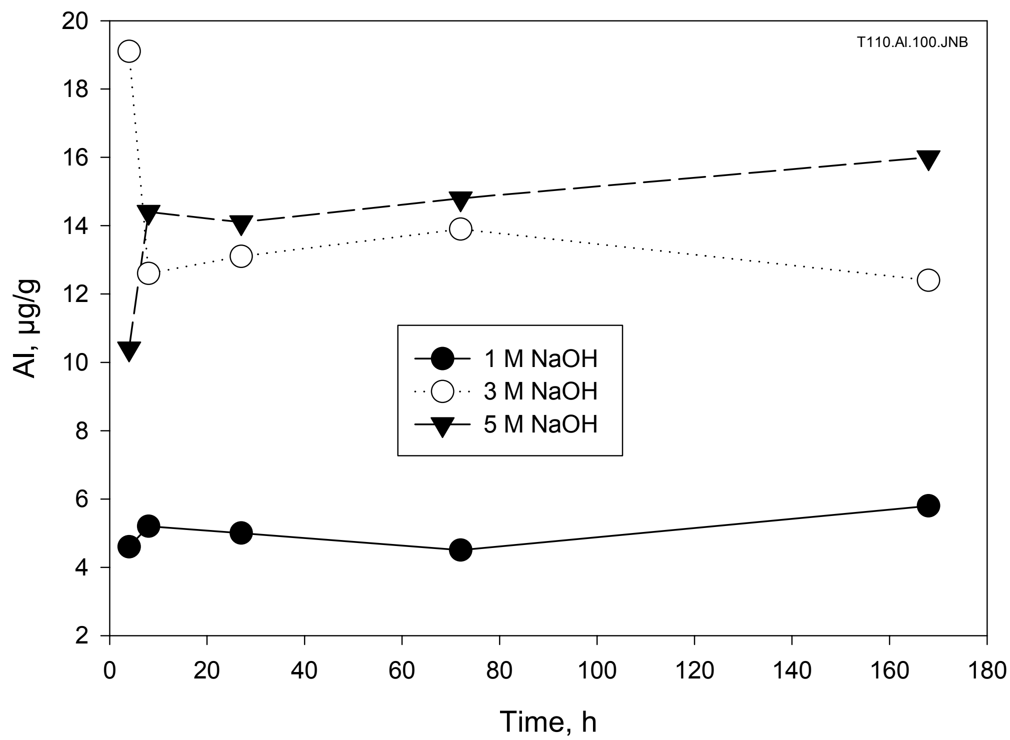

Figure 3.3. Aluminum Concentration as a Function of Time During Leaching of T-110 Solids at 100°C

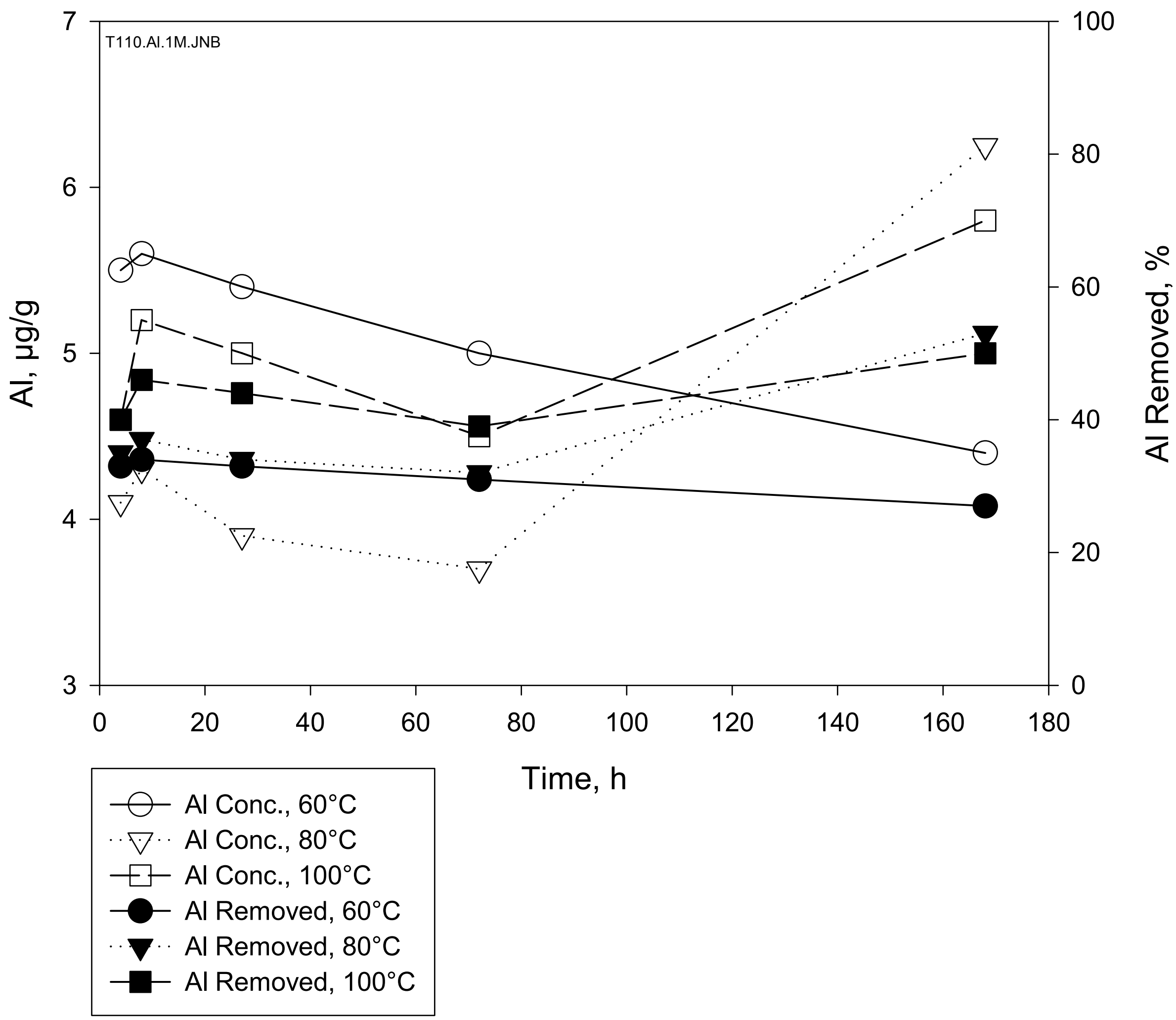

Figure 3.4. Aluminum Concentration and Removal as a Function of Time During Leaching of T-110 Solids at 1 M NaOH

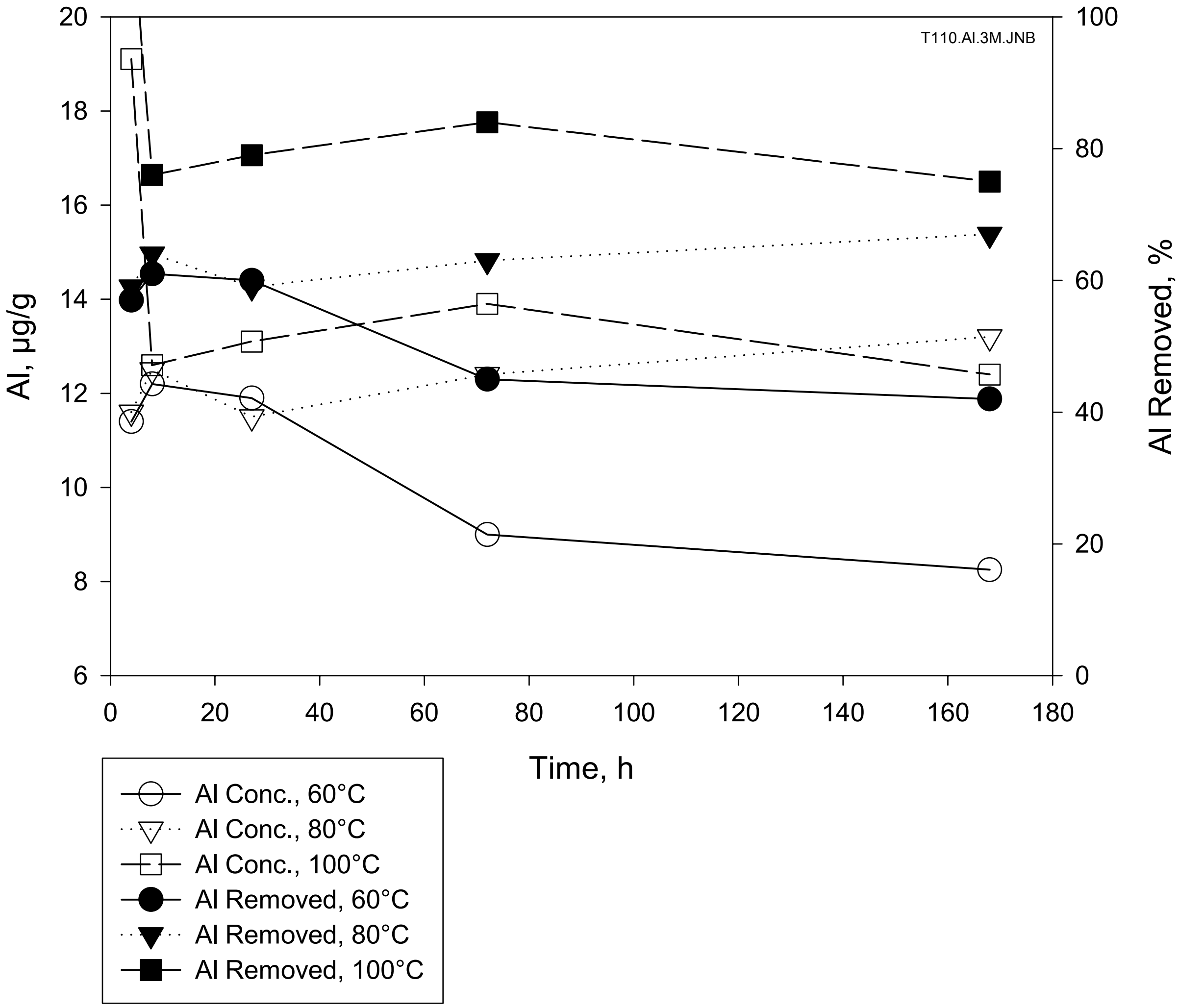

Figure 3.5. Aluminum Concentration and Removal as a Function of Time During Leaching of T-110 Solids at 3 M NaOH

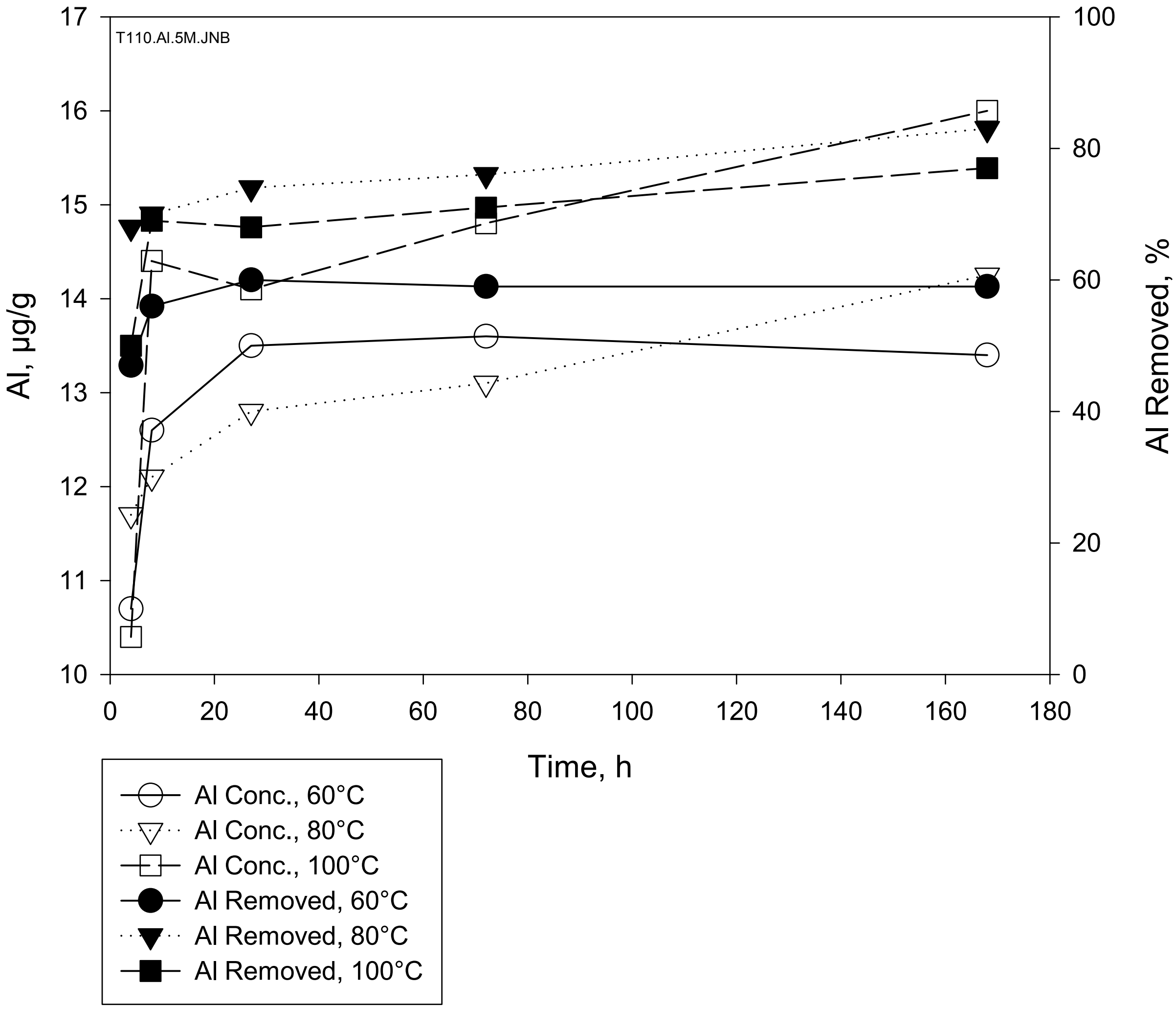

Figure 3.6. Aluminum Concentration and Removal as a Function of Time During Leaching of T-110 Solids at 5 M NaOH

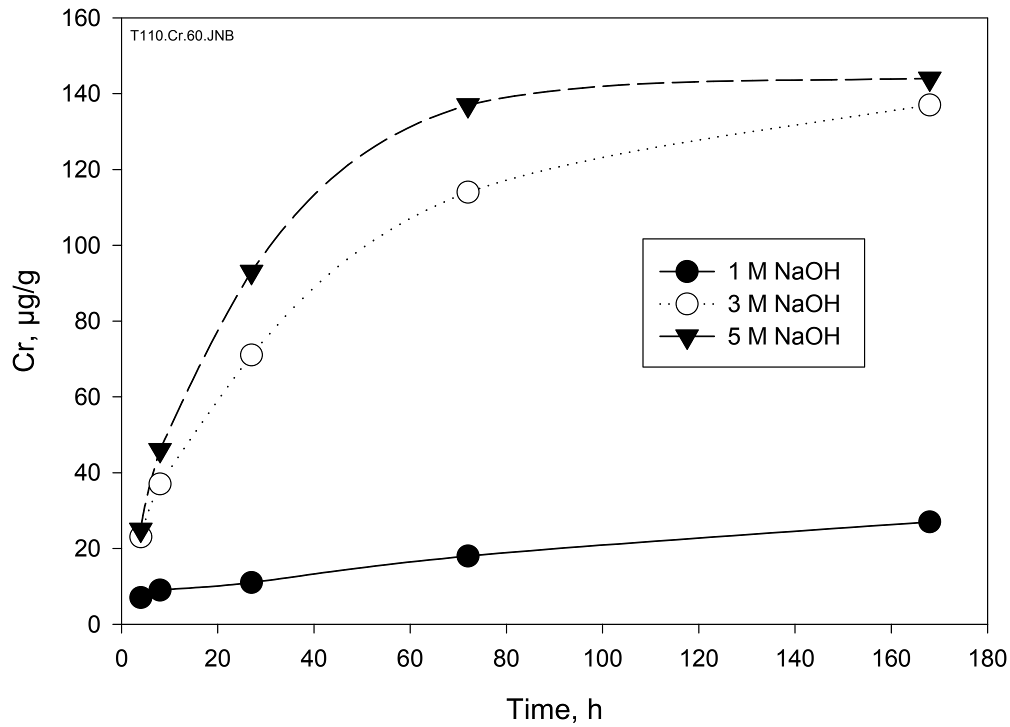

Figure 3.7. Chromium Concentration as a Function of Time During Leaching of T-110 Solids at 60°C

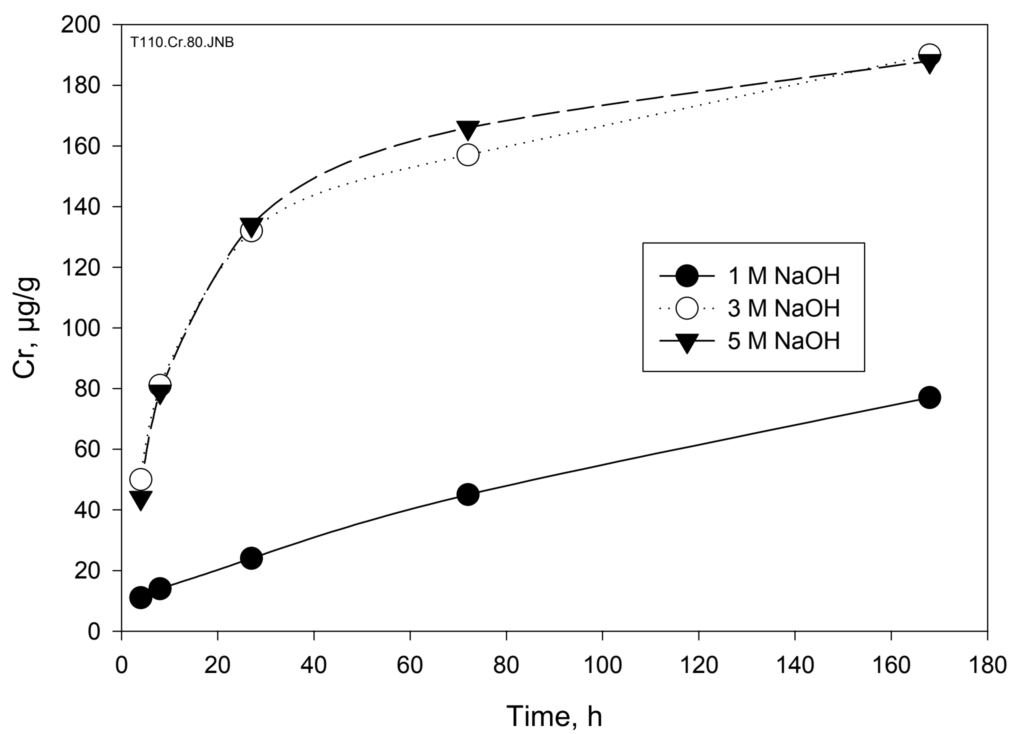

Figure 3.8. Chromium Concentration as a Function of Time During Leaching of T-110 Solids at 80°C

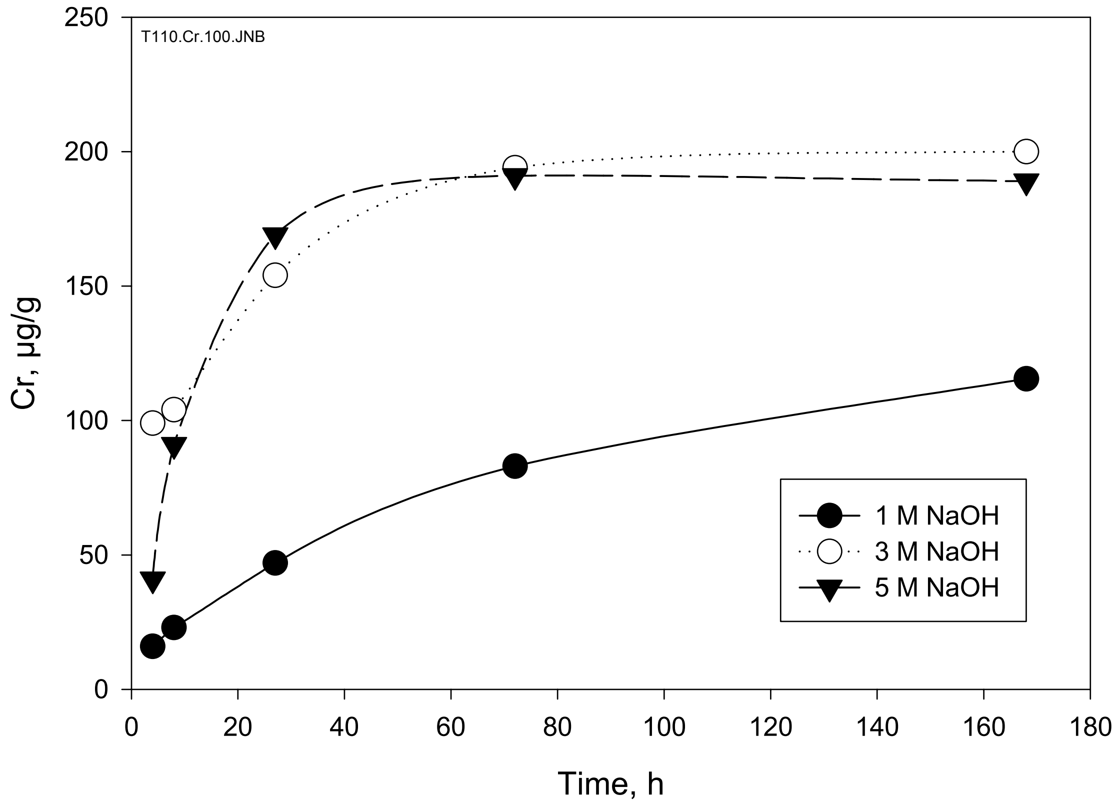

Figure 3.9. Chromium Concentration as a Function of Time During Leaching of T-110 Solids at 100°C

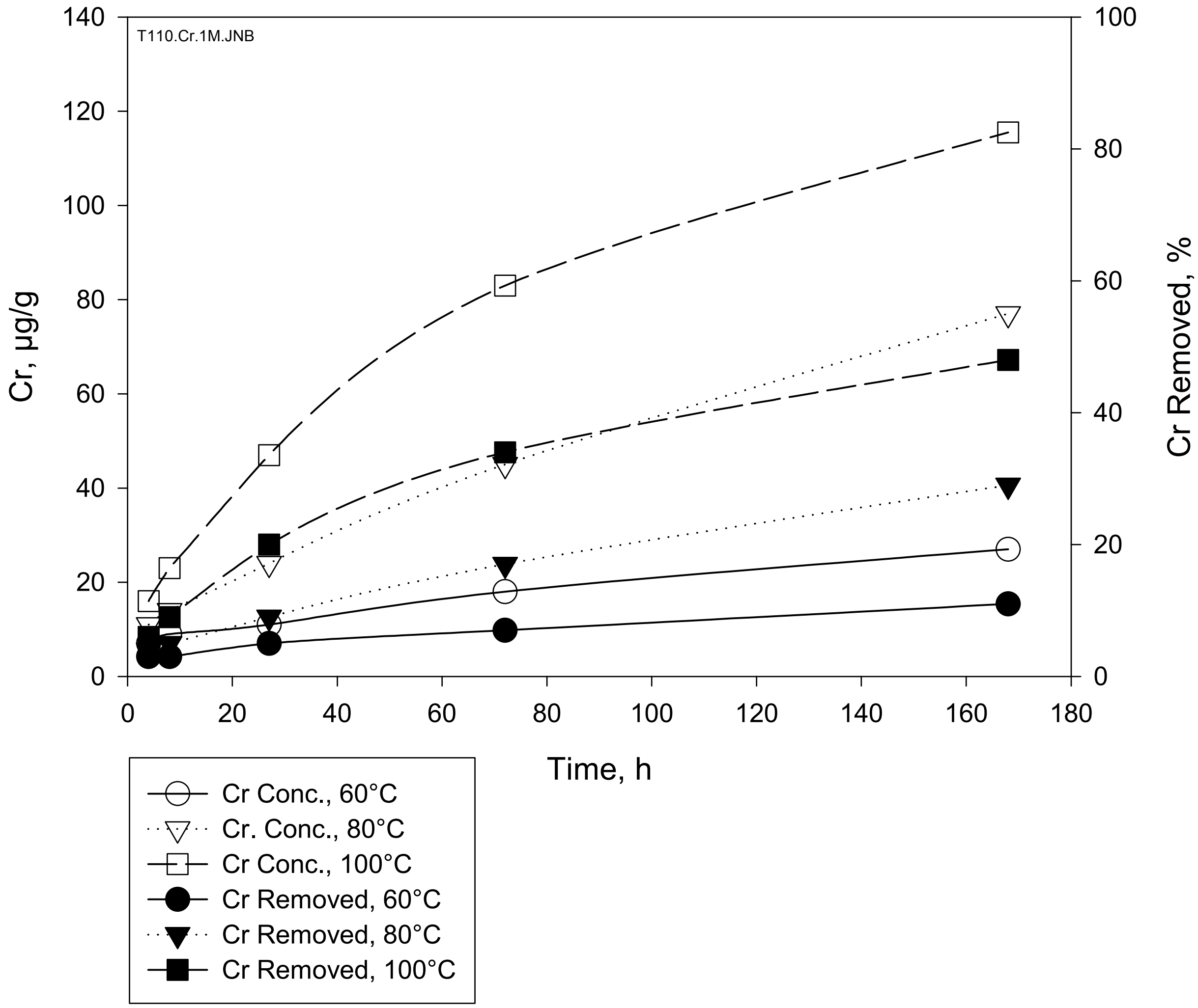

Figure 3.10. Chromium Concentration and Removal as a Function of Time During Leaching of T-110 Solids at 1 M NaOH

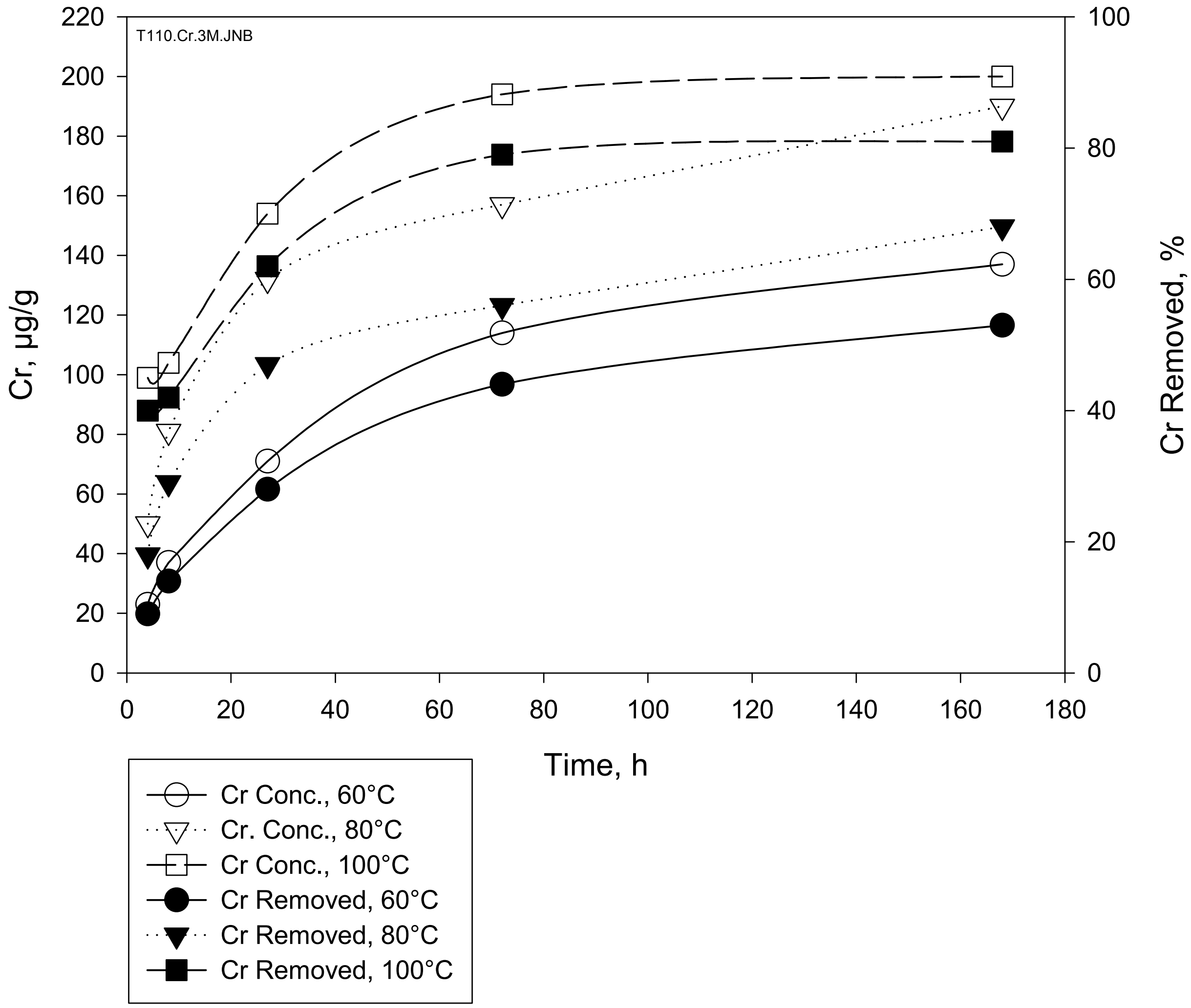

Figure 3.11. Chromium Concentration and Removal as a Function of Time During Leaching of T-110 Solids at 3 M NaOH

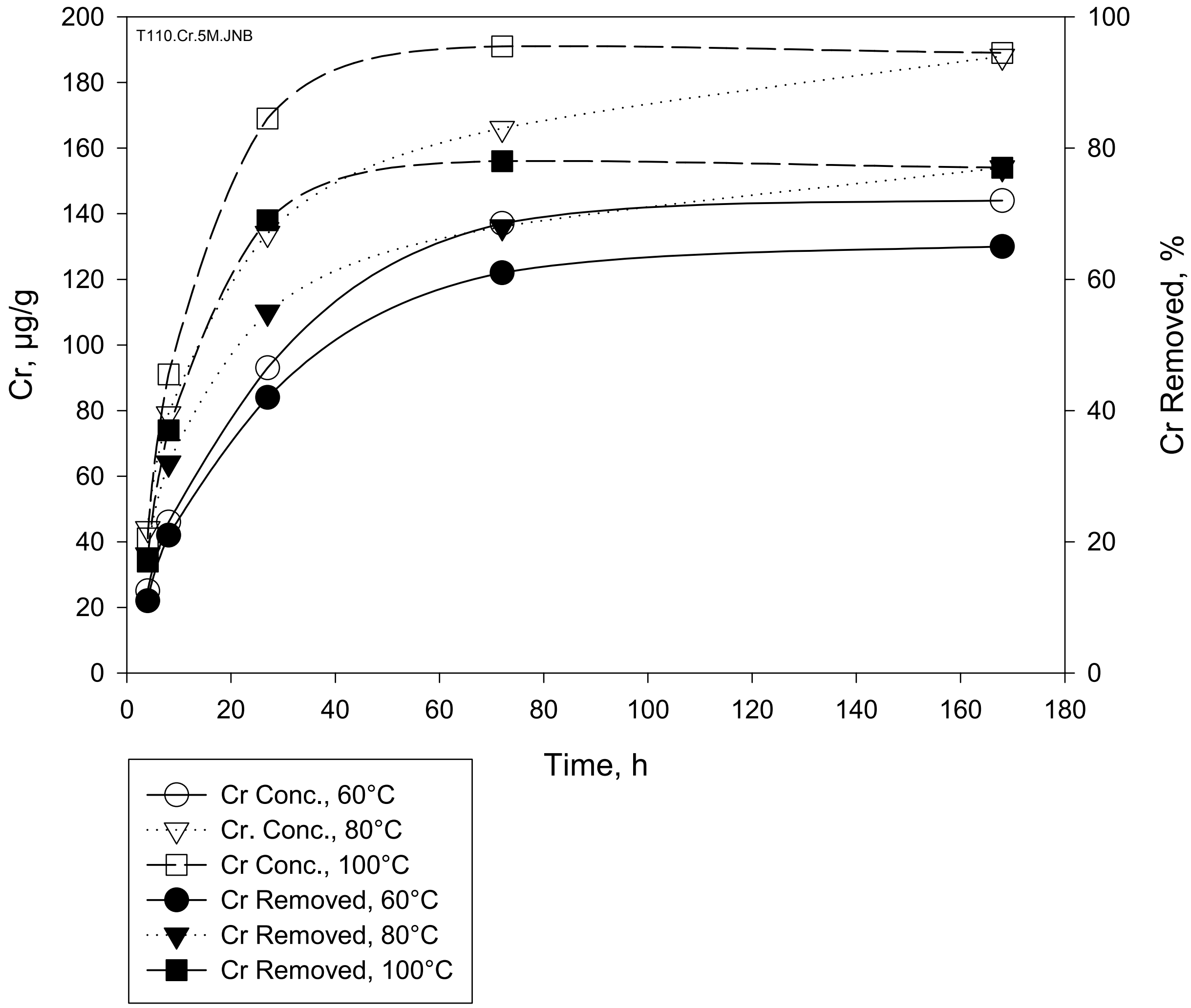

Figure 3.12. Chromium Concentration and Removal as a Function of Time During Leaching of T-110 Solids at 5 M NaOH

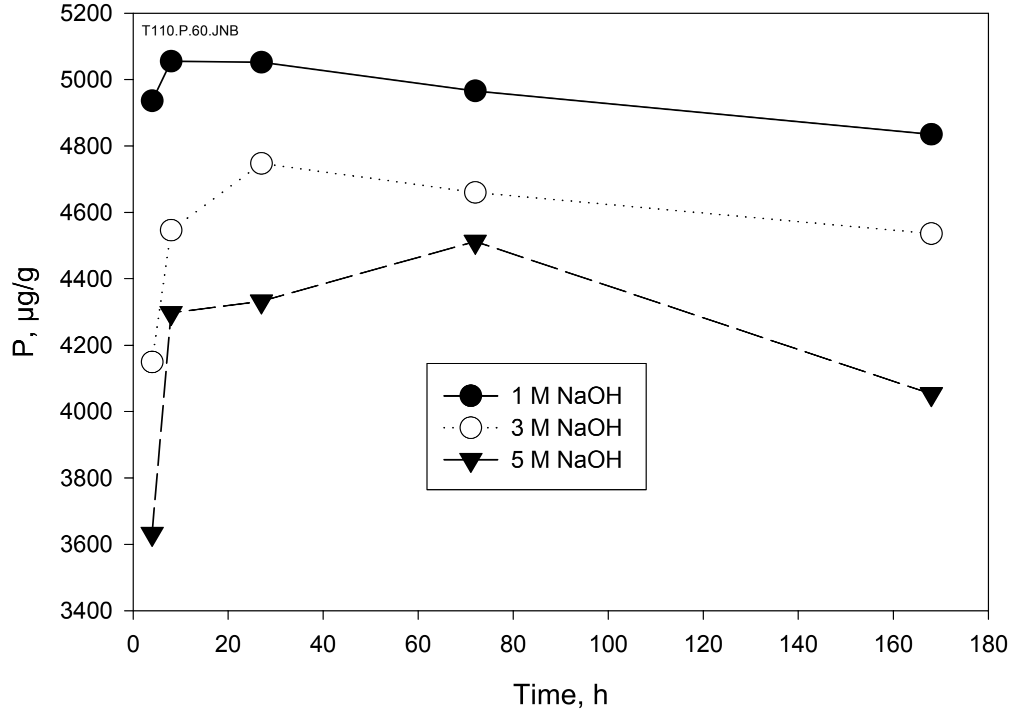

Figure 3.13. Phosphorus Concentration as a Function of Time During Leaching of T-110 Solids at 60°C

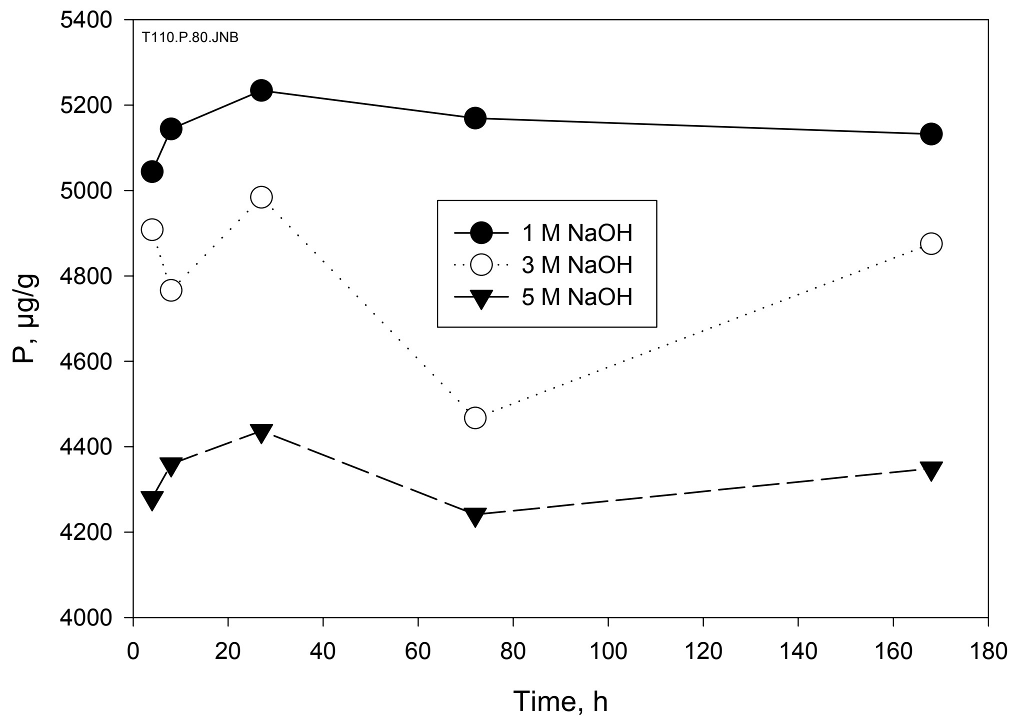

Figure 3.14. Phosphorus Concentration as a Function of Time During Leaching of T-110 Solids at 80°C

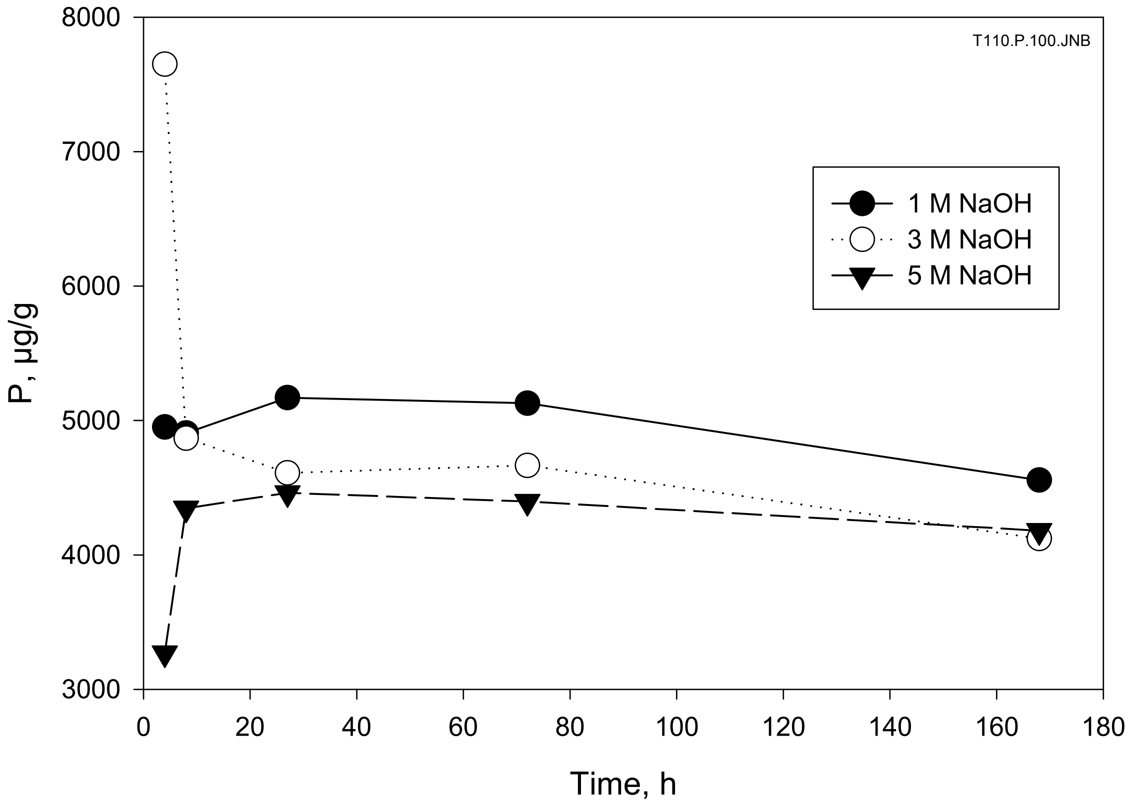

Figure 3.15. Phosphorus Concentration as a Function of Time During Leaching of T-110 Solids at 100°C

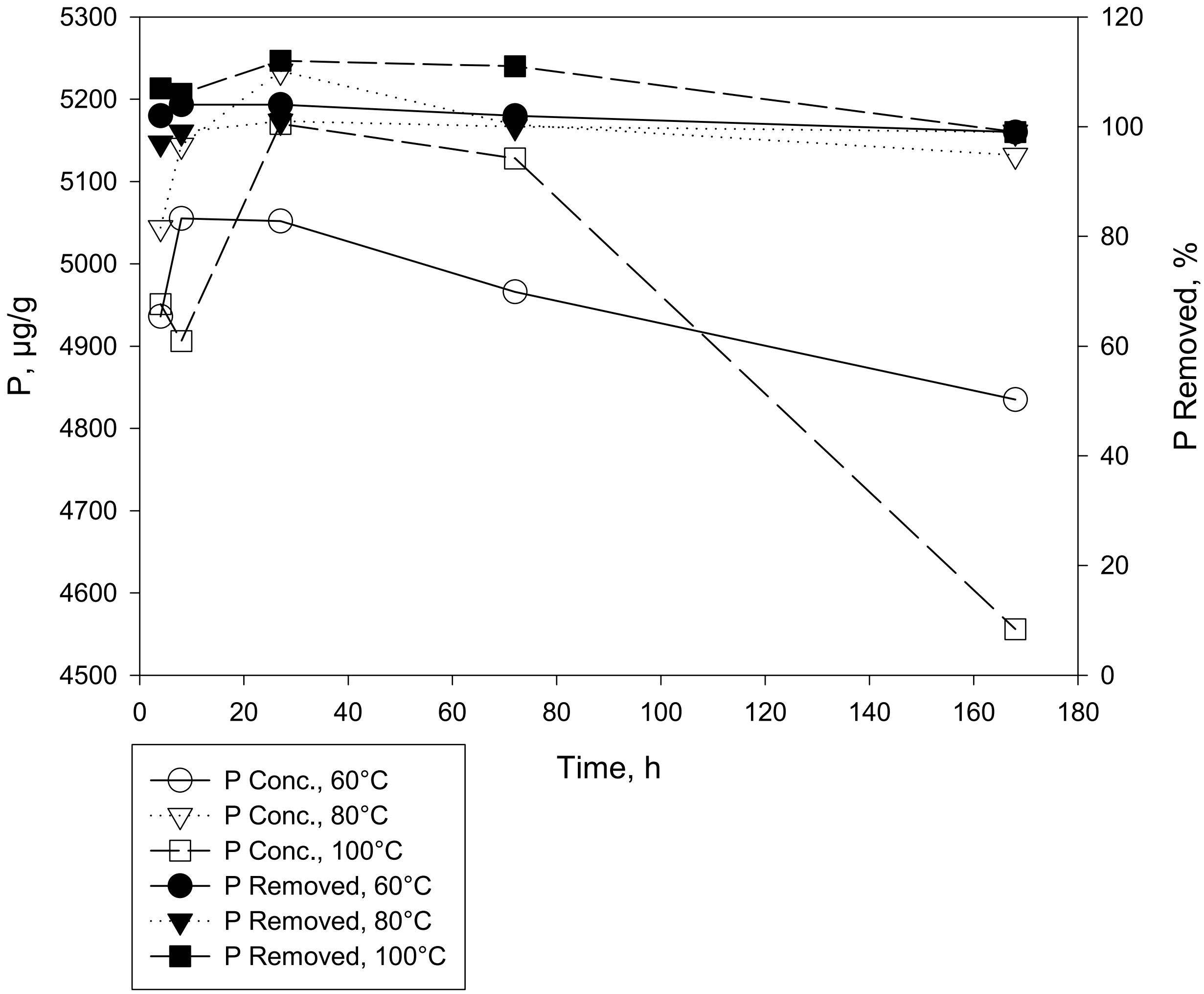

Figure 3.16. Phosphorus Concentration and Removal as a Function of Time During Leaching of T-110 Solids at 1 M NaOH

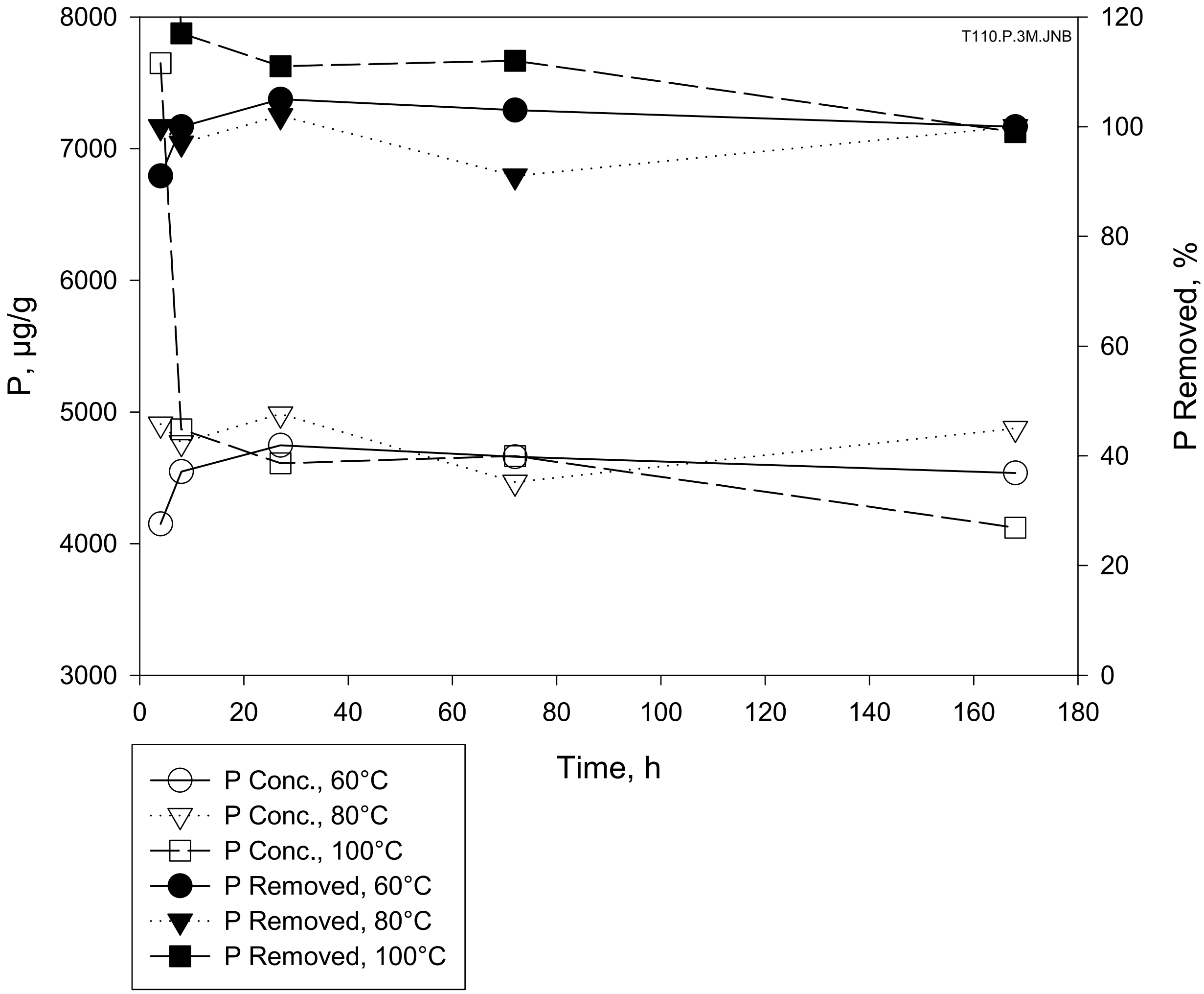

Figure 3.17. Phosphorus Concentration and Removal as a Function of Time During Leaching of T-110 Solids at 3 M NaOH

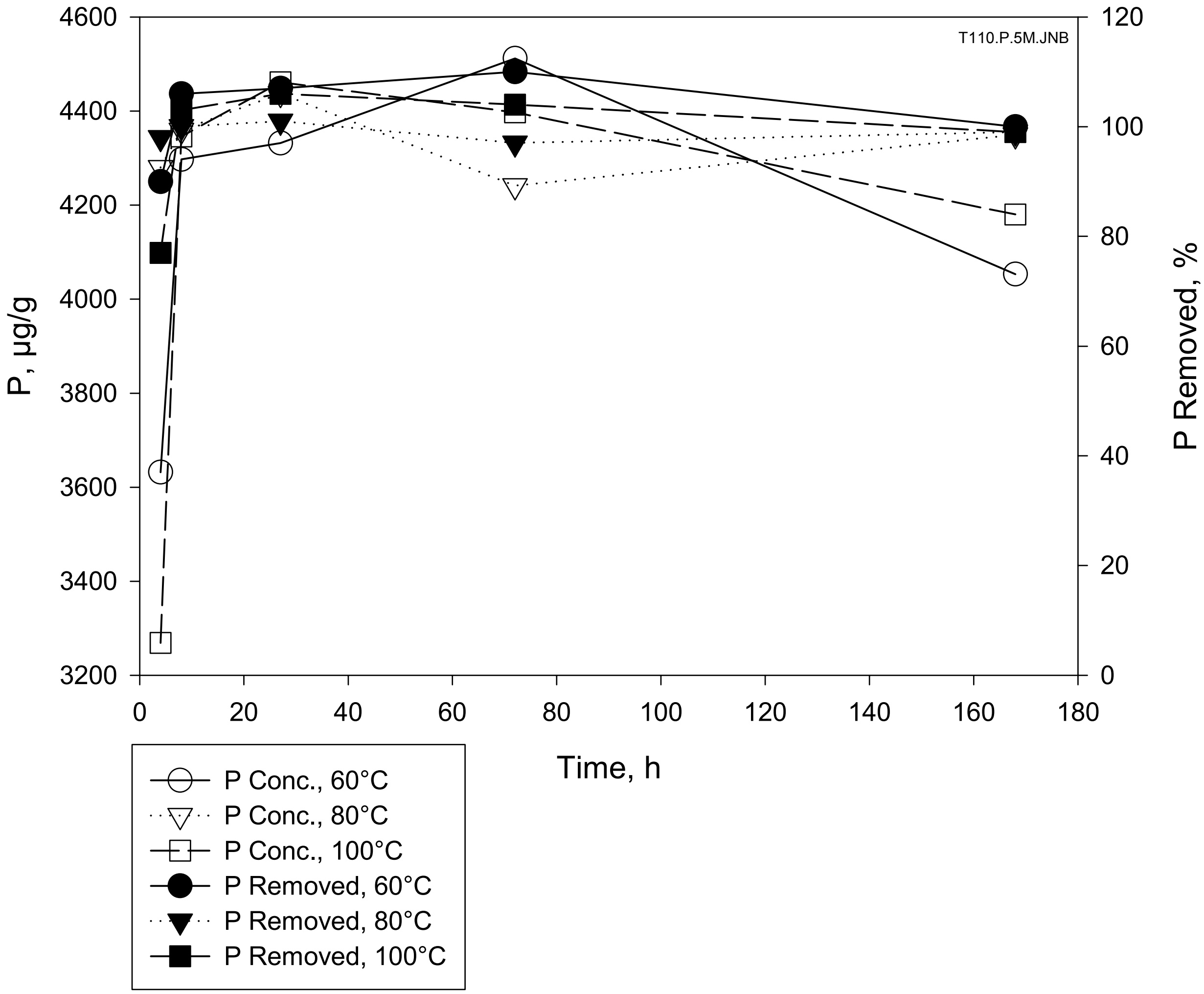

Figure 3.18. Phosphorus Concentration and Removal as a Function of Time During Leaching of T-110 Solids at 5 M NaOH

3.2.4 Radionuclide Behavior

Appendix C summarizes the behavior of the radionuclides in the T-110 caustic leaching tests. Caustic leaching liberated ^{137}Cs from the water-washed T-110 solids, with 68 to 89% of the ^{137}Cs removed from the solids. There was no apparent trend regarding the influence of NaOH concentration or temperature on ^{137}Cs removal. In contrast, the concentration of the TRU elements (which is dominated by ^{239}Pu) was dependent upon both NaOH concentration and temperature (Figure 3.19). Peretrukhin et al. (1996) investigated the solubility of TRU elements over a range of NaOH concentrations. Their data indicated that the solubility of $^{239}PuO_2{\cdot}xH_2O$ is 6×10^{-3} µCi/mL in 3 M NaOH and 2×10^{-2} µCi/mL in 5 M NaOH at 25°C. The measured TRU concentrations in the leaching solutions were less than these values, even though higher temperatures were used. However, the concentrations were on the same order of magnitude when the T-110 solids were leached with 3 or 5 M NaOH at 100°C.

The highest TRU concentration in the leachate was ~5×10^{-3} µCi/g (e.g., for leaching with 5 M NaOH at 100°C). To assess whether this would lead to an immobilized low-activity waste (ILAW) form exceeding the 10 nCi TRU/g limit for Class A LLW (10 CFR 61), we considered a 3 M NaOH leaching solution with a TRU concentration of 5×10^{-3} µCi/g as a limiting case. Assuming that the density of the leaching solution is 1.12 g/mL (i.e., the density of 3 M NaOH), and the ILAW form contains 20 wt% Na_2O, the resulting TRU concentration would be 12 nCi/g. Thus, vitrification of such a leachate would result in a glass waste form that exceeds the Class A TRU criterion. However, it would qualify as a Class C waste (< 100 nCi TRU/g).

A similar analysis can be done for ^{137}Cs. In this case, the highest concentration was ~0.01 µCi/g. Assuming that the ILAW form contains 20 wt% Na_2O and has a density of 2.7 MT/m^3, immobilization of a 3 M NaOH leachate containing 0.01 µCi/g ^{137}Cs would lead to a waste form with 0.065 Ci/m^3. This is well within the U.S. Nuclear Regulatory Commission (NRC) Class A limit of 1 Ci ^{137}Cs/m^3. Thus, no Cs removal step would be needed for this leaching solution before vitrification.

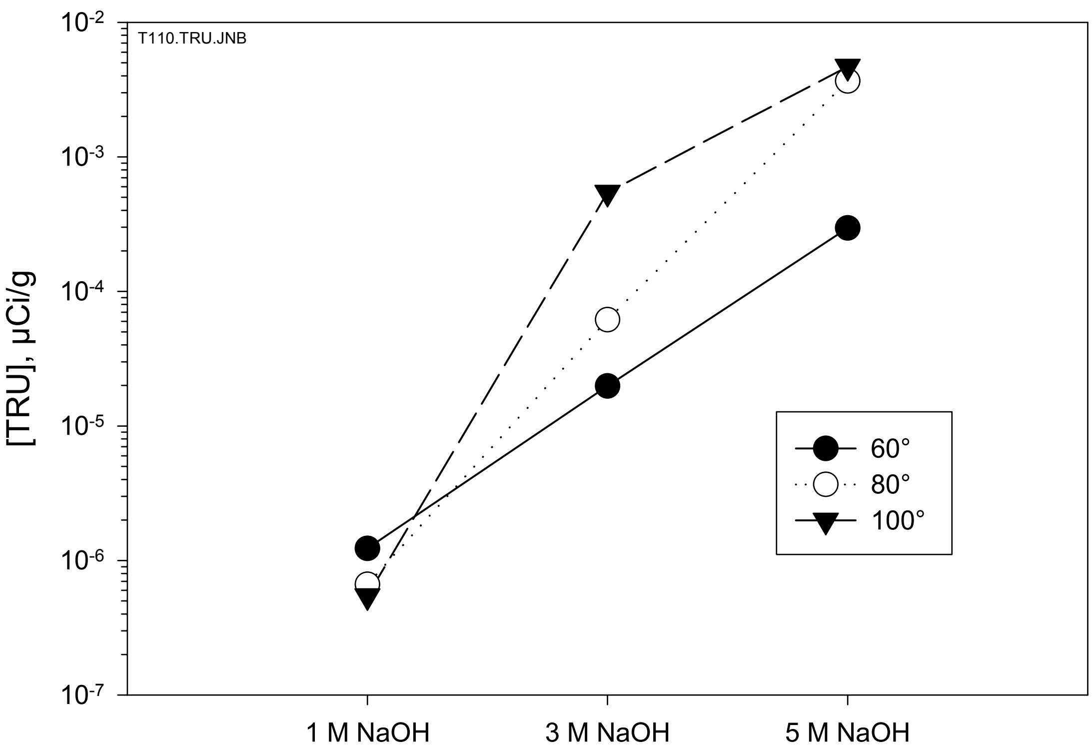

Figure 3.19. TRU Concentration In the T-110 Caustic Leaching Solutions

3.3 Impact of Leaching on Immobilized High-Level Waste Glass Mass

To illustrate the effects of caustic leaching on the production of IHLW glass, Table 3.4 shows the concentration of waste oxides in the dilute hydroxide-washed T-110 solids and in the leached T-110 solids. For the sake of discussion, the table also shows the concentrations of waste-derived components

Table 3.4. Estimated Concentrations of Waste-Derived Components in the IHLW Glass from T-110 Waste

	Washed Solids		Leached Solids (1 M NaOH/60°C/168 h)		Leached Solids (3 M NaOH/80°C/168 h)	
Component	**g oxide/g solids**	**Conc. in IHLW, wt%[a]**	**g oxide/g solids**	**Conc. in IHLW, wt%[a]**	**g oxide/g solids**	**Conc. in IHLW, wt%[a]**
Al_2O_3	0.0020	0.1	0.0015	0.06	0.0009	0.0
BaO	0.0001	0.003	0.0001	0.004	0.0001	0.004
Bi_2O_3	0.1628	6.9	0.2977	11.6	0.3323	11.6
CaO	0.0050	0.2	0.0040	0.2	0.0043	0.2
Cr_2O_3	0.0087	0.4	0.0119	0.5	0.0054	0.2
Fe_2O_3	0.2002	8.4	0.3115	12.2	0.3602	12.6
MgO	0.0023	0.1	0.0022	0.1	0.0027	0.1
MnO_2	0.0016	0.1	0.0016	0.1	0.0015	0.1
P_2O_5	0.2023	8.5	0.0030	0.1	0.0019	0.1
PbO	0.0007	0.03	0.0011	0.04	0.0011	0.04
SrO	0.0014	0.1	0.0014	0.1	0.0026	0.1
UO_3	0.0061	0.3	0.0044[b]	0.2	0.0038[c]	0.1
ZnO	0.0003	0.01	0.0004	0.02	0.0003	0.01

(a) Based on 25 wt% waste oxide loading (excluding Na_2O and SiO_2).
(b) Uranium was below the detection limit in the leached solids. For this analysis, the detection limit (3636 µg U/g) was used as the U concentration.
(c) Uranium was below the detection limit in the leached solids. For this analysis, the detection limit (3133 µg U/g) was used as the U concentration.

that would result from vitrifying these solids at 25-wt% waste oxide loading (WOL), excluding oxides of Na and Si. Two cases are presented—leaching with 1 M NaOH at 60° and leaching with 3 M NaOH at 80°C. In both cases, the results are based on the solids remaining after leaching for one week. The oxide concentrations in the washed and leached solids were determined by converting the elemental concentrations listed in Tables 2.2 (washed solids), B.1, and B.5 (leached solids) to the corresponding oxide concentrations. The oxide concentrations in the IHLW were determined according to the following formula:

$$[C_x]_{IHLW} = WOL \bullet \left(\frac{C_x}{\sum_i C_i} \right) \tag{3.1}$$

where $[C_x]_{IHLW}$ is the concentration of component x oxide (wt%) in the IHLW, C_x is the concentration of component x oxide in the washed or leached solids, and $\sum C_i$ is the sum of the concentration of all the component oxides in the washed or leached solids (excluding Na_2O and SiO_2).

Assuming upper limits of 15, 0.5, and 3.0 wt% for Al, Cr, and P oxides, respectively, in the IHLW, a 25 wt% WOL could not be achieved for the dilute-hydroxide-washed T-110 solids because of the high P content. Aluminum certainly does not pose a problem for vitrifying the washed T-110 solids. The Cr_2O_3 content of the washed solids from the sample used in this experiment is below 0.5 wt%, but is close enough to that level that Cr should probably be considered a potential limiting component for this waste.

The mass (W_{IHLW}) of IHLW glass produced from 1 g of the washed solids can be calculated as follows:

$$W_{IHLW} = 100 \bullet \frac{\sum_i C_i}{WOL} \tag{3.2}$$

Likewise, the mass of IHLW glass produced from the leached solids can be determined as follows:

$$W_{IHLW} = 100 \bullet \frac{W_L}{W_W} \bullet \frac{\sum_i C_i}{WOL} \tag{3.3}$$

where W_L is the weight of the leached solids obtained by leaching W_W grams of washed solids. In the cases considered here, W_L = 1.363 g and W_W = 2.498 g for the 1 M/60°C test, and W_L = 1.204 g and W_W = 2.515 g for the 3 M/80°C test. Setting the upper limit for P_2O_5 in the IHLW as 3.00 wt%, it can be derived from Equation 3.1 that the maximum WOL achievable for the washed T-110 solids would be 8.8 wt%. At this WOL, applying Equation 3.2 indicates that 6.7 g of IHLW would be produced per gram of washed T-110 solids.

Leaching under either condition (1 M NaOH/60°C or 3 M NaOH/80°C) would remove the P constraint for vitrifying the T-110 solids. As indicated in Table 3.4, the P_2O_5 concentration in the IHLW glass at 25wt% WOL would only be 0.1 wt% in either case. So for the purposes of this discussion, we assume that the leached T-110 solids can be immobilized at 25-wt% WOL.[a] This being the case, leaching with 1 M NaOH at 60°C for one week would result in essentially the same mass of IHLW glass as leaching with 3 M NaOH at 80°C for one week—1.4 g IHLW glass per gram of washed solids processed. So, applying caustic leaching to the washed T-110 solids can be expected to yield an approximately 80% reduction in the mass of IHLW glass produced from vitrifying this waste.

(a) In the 1 M NaOH/60°C case, the Cr_2O_3 content in the IHLW at 25 wt% WOL would be right at the 0.5 wt% limit (Table 3.4). So, as mentioned in the text above, the behavior of Cr might be an issue for the T-110 waste.

4.0 Conclusions and Recommendations

Bismuth, Fe, Na, P, and Si are the dominant elements present in the T-110 sludge. As expected, Na is largely (> 90%) removed by dilute hydroxide washing. Dilute hydroxide washing is ineffectual at removing Bi, Fe, or Si. For this particular sludge, the behavior of P is of major concern due to the relatively low tolerance for this element in the HLW immobilization process and the high concentration of P in the waste. Only 33% of the P was removed by dilute hydroxide washing, resulting in washed solids that were 8.8 wt% P. This is presumably because the P is present as bismuth phosphate in the T-110 solids. More rigorous pretreatment (e.g., caustic leaching) will be required to remove enough P so that it is not a limiting component in the sludge solids. The minor sludge component, Cr, can also adversely affect the HLW immobilization process. The Cr in the T-110 sludge was largely insoluble in 0.01 M NaOH, with only 3% being removed by dilute hydroxide washing.

The solution obtained by washing the T-110 solids with dilute hydroxide could likely be immobilized as a Class A LLW, even without removing ^{137}Cs.

The work presented here indicates caustic leaching to be a very effective method of pretreating Hanford Tank T-110 sludge, primarily because this method essentially quantitatively removes P from the water-washed T-110 solids. Assuming a P_2O_5 limit of 3 wt% in the IHLW glass, it is estimated that caustic leaching will result in an ~80% reduction in the IHLW mass. Unlike high-Al tanks (see, for example, Lumetta et al. 2001), relatively mild leaching conditions (1 M NaOH at 60°C) should sufficiently remove P from the T-110 solids. However, more rigorous leaching conditions (or oxidative leaching) may be needed to avoid encountering the Cr limit in the glass formulation. Leaching of P from the sludge solids is rapid and largely independent of temperature and NaOH concentration. On the other hand, the leaching of Cr is much slower and is highly dependent on temperature and NaOH concentration.

Some of the caustic leaching solutions contained significant concentrations of TRU elements (primarily Pu). The dissolved TRU generally increased with increasing NaOH concentration and temperature. Immobilization of these solutions could result in a waste form that exceeds the 10 nCi/g TRU limit for LLW, but they would be within the Class C limit of 100 nCi/g. This should be considered in managing these leaching solutions. As was the case with the dilute hydroxide wash solution, ^{137}Cs would likely not need to be removed to meet the Class A LLW criterion of 1 Ci/m^3.

5.0 References

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Appendix A

Solution Concentrations as a Function of Time

Appendix A: Solution Concentrations as a Function of Time

Table A.1. Component Concentrations As a Function of Time For Leaching of T-110 Solids With 1 M NaOH at 60°C

	Concentration, μg/g[(a)]						
Time, h:	4	8	24	72	168	168	Final Wash
Ag	--	--	--	--	--	--	--
Al	[5.4]	[5.6]	[5.4]	[5.0]	[5.1]	[3.6]	[2.3]
As	--	--	--	--	--	--	--
B	--	--	--	--	--	--	--
Ba	[0.3]	[0.3]	[1.1]	[0.4]	[0.3]	[0.4]	--
Be	--	--	--	--	--	--	--
Bi	[11.8]	[15.5]	[14.1]	[10.6]	[11.1]	[10.1]	--
Ca	--	--	[9.0]	[8.3]	[7.4]	--	[10.4]
Cd	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--
Cr	7	9	11	18	27	27	2
Cu	--	--	--	--	--	--	--
Dy	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Fe	8	9	8	6	6	5	2
K	[85]	[102]	[93]	[89]	[103]	[70]	--
La	--	--	--	--	--	--	--
Li	--	--	--	--	--	--	--
Mg	--	--	--	--	--	--	--
Mn	--	--	--	--	--	--	--
Mo	--	--	--	--	--	--	--
Na	25668	25999	26035	25642	24685	24908	5166
Nd	--	--	--	--	--	--	--
Ni	--	--	--	--	--	--	--
P	4934	5053	5044	4963	4800	4819	378
Pb	--	--	--	--	--	--	--
Pd	--	--	--	--	--	--	--
Rh	--	--	--	--	--	--	--
Ru	--	--	--	--	--	--	--
Sb	--	--	--	--	--	--	--
Se	--	--	--	--	--	--	--
Si	2064	2075	2034	1970	1883	1894	248
Sn	--	--	--	--	--	--	--
Sr	--	--	--	--	--	--	--
Te	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
Ti	--	--	--	--	--	--	--
Tl	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
V	--	--	--	--	--	--	--
W	--	--	--	--	--	--	--
Y	--	--	--	--	--	--	--
Zn	--	--	--	--	--	--	--
Zr	--	--	--	--	--	--	--

(a) Analyte was below detection limit if left blank. Experimental uncertainties are 15%, except for values given in brackets. Values given in brackets are within 10 times the detection limit and the uncertainties for these values are greater than 15%.

Table A.2. Component Concentrations As a Function of Time For Leaching of T-110 Solids With 3 M NaOH at 60°C

	Concentration, µg/g[(a)]						
Time, h:	4	8	24	72	168	168	Final Wash
Ag	--	--	--	--	--	--	--
Al	[11.3]	[12.1]	[11.9]	[9.0]	[8.5]	[8.0]	--
As	--	--	--	--	--	--	--
B	--	--	--	--	--	--	--
Ba	[0.4]	[0.3]	[0.7]	[0.6]	--	[0.9]	[0.5]
Be	--	--	--	--	--	--	--
Bi	42.0	[13.5]	[13.0]	[10.5]	[10.1]	[13.8]	--
Ca	[7.9]	--	--	--	--	--	[8.9]
Cd	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--
Cr	22	37	71	114	134	137	12
Cu	--	--	--	--	--	--	--
Dy	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Fe	21	26	25	19	15	16	1
K	[124]	[13]	--	--	--	--	--
La	--	--	--	--	--	--	--
Li	--	--	--	--	--	--	--
Mg	--	--	--	--	--	--	--
Mn	--	--	--	--	--	--	--
Mo	--	--	--	--	--	--	--
Na	55474	63634	68805	62246	66239	66833	6973
Nd	--	[3]	--	--	--	--	--
Ni	--	--	--	--	--	--	--
P	4111	4541	4737	4656	4460	4562	370
Pb	[4]	[5]	--	--	--	--	--
Pd	--	--	--	--	--	--	--
Rh	--	--	--	--	--	--	--
Ru	--	--	--	--	--	--	--
Sb	--	--	--	--	--	--	--
Se	--	--	--	--	--	--	--
Si	2329	2585	2726	2701	2585	2647	256
Sn	--	--	--	--	--	--	--
Sr	--	--	--	--	--	--	--
Te	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
Ti	--	--	--	--	--	--	--
Tl	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
V	--	--	--	--	--	--	--
W	--	--	--	--	--	--	--
Y	--	--	--	--	--	--	--
Zn	[5.6]	[6.3]	[6.9]	[6.4]	[5.6]	[6.6]	--
Zr	--	--	--	--	--	--	--

(a) Analyte was below detection limit if left blank. Experimental uncertainties are 15%, except for values given in brackets. Values given in brackets are within 10 times the detection limit and the uncertainties for these values are greater than 15%.

Table A.3. Component Concentrations As a Function of Time For Leaching of T-110 Solids With 5 M NaOH at 60°C

	Concentration, µg/g[(a)]						
Time, h:	4	8	24	72	168	168	Final Wash
Ag	--	--	--	--	--	--	--
Al	[10.7]	[12.6]	[13.5]	[13.4]	[15.2]	[11.3]	[5.8]
As	--	--	--	--	--	--	--
B	--	--	--	--	34	--	41
Ba	[0.3]	[0.3]	[0.5]	--	[0.7]	[0.3]	[0.9]
Be	--	--	--	--	--	--	--
Bi	12.5	[3.9]	[3.0]	[2.7]	[4.5]	[3.6]	--
Ca	--	--	--	--	[8.2]	--	[10.3]
Cd	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--
Cr	25	46	93	135	142	146	13
Cu	--	--	--	--	--	--	--
Dy	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Fe	31	43	38	30	21	24	1
K	[61]	[77]	--	--	--	--	--
La	--	--	--	--	--	--	--
Li	--	--	--	--	--	--	--
Mg	--	--	--	--	--	--	--
Mn	--	--	--	--	--	--	--
Mo	--	--	--	--	--	--	--
Na	76716	93036	99104	100784	90830	87516	9400
Nd	--	#VALUE!	--	--	--	--	--
Ni	--	--	--	--	--	--	--
P	3623	4294	4328	4454	3957	4094	341
Pb	[5.3]	[6.7]	[7.4]	[7.0]	[6.2]	[5.4]	--
Pd	--	--	--	--	--	--	--
Rh	--	--	--	--	--	--	--
Ru	--	--	--	--	--	--	--
Sb	--	--	--	--	--	--	--
Se	--	--	--	--	--	--	--
Si	2224	2665	2705	2762	2474	2546	261
Sn	--	--	--	--	--	--	--
Sr	--	--	--	--	--	--	--
Te	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
Ti	--	--	--	--	--	--	--
Tl	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
V	--	--	--	--	--	--	--
W	--	--	--	--	--	--	--
Y	--	--	--	--	--	--	--
Zn	[6.7]	[7.7]	[7.9]	[8.0]	[7.2]	[7.2]	--
Zr	--	--	--	--	--	--	--

(a) Analyte was below detection limit if left blank. Experimental uncertainties are 15%, except for values given in brackets. Values given in brackets are within 10 times the detection limit and the uncertainties for these values are greater than 15%.

Table A.4. Component Concentrations As a Function of Time For Leaching of T-110 Solids With 1 M NaOH at 80°C

	Concentration, μg/g[(a)]						
Time, h:	4	8	24	72	168	168	Final Wash
Ag	--	--	--	--	--	--	--
Al	[4.1]	[4.3]	[3.9]	[3.7]	[8.3]	[4.2]	[6.3]
As	--	--	--	--	--	--	--
B	--	--	--	--	37	--	40
Ba	[1.1]	[0.5]	[0.8]	--	[1.1]	[1.4]	[0.8]
Be	--	--	--	--	--	--	--
Bi	[18.6]	[13.4]	[12.9]	[11.9]	[16.0]	[16.8]	--
Ca	[11.9]	--	--	[7.4]	--	[7.5]	[9.3]
Cd	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--
Cr	11	14	24	45	75	79	7
Cu	--	--	--	--	--	--	--
Dy	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Fe	10	8	7	[6]	[6]	[6]	[1]
K	--	[66]	--	--	[57]	[64]	--
La	--	--	--	--	--	--	--
Li	--	--	--	--	--	--	--
Mg	--	--	--	--	--	--	--
Mn	--	--	--	--	--	--	--
Mo	--	--	--	--	--	--	--
Na	25307	25289	25719	25476	24646	25859	5866
Nd	--	--	--	--	--	--	--
Ni	--	--	--	--	--	--	--
P	5044	5144	5234	5169	4986	5278	449
Pb	--	--	--	--	--	--	--
Pd	--	--	--	--	--	--	--
Rh	--	--	--	--	--	--	--
Ru	--	--	--	--	--	--	--
Sb	--	--	--	--	--	--	--
Se	--	--	--	--	--	--	--
Si	1951	1972	1981	1948	1883	1958	286
Sn	--	--	--	--	--	--	--
Sr	--	--	--	--	--	--	--
Te	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
Ti	--	--	--	--	--	--	--
Tl	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
V	--	--	--	--	--	--	--
W	--	--	--	--	--	--	--
Y	--	--	--	--	--	--	--
Zn	--	--	--	--	--	--	--
Zr	--	--	--	--	--	--	--

(a) Analyte was below detection limit if left blank. Experimental uncertainties are 15%, except for values given in brackets. Values given in brackets are within 10 times the detection limit and the uncertainties for these values are greater than 15%.

Table A.5. Component Concentrations As a Function of Time For Leaching of T-110 Solids With 3 M NaOH at 80°C

	Concentration, μg/g[(a)]						
Time, h:	4	8	24	72	168	168	Final Wash
Ag	--	--	--	--	--	--	--
Al	[11.6]	[12.5]	[11.5]	[12.4]	[14.3]	[12.1]	[7.3]
As	--	--	--	--	--	--	--
B	--	--	--	--	29	--	38
Ba	[0.4]	[1.1]	[0.4]	[0.4]	[1.0]	[0.3]	[1.0]
Be	--	--	--	--	--	--	--
Bi	[12.4]	[12.3]	[11.8]	[11.3]	[11.1]	[8.7]	[3.0]
Ca	--	--	[7.9]	--	[7.3]	[6.9]	[12.7]
Cd	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--
Cr	50	81	132	157	191	189	17
Cu	--	--	--	--	--	--	--
Dy	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Fe	29	28	22	16	15	15	[1.5]
K	[75]	[88]	[73]	[89]	[73]	[90]	--
La	--	--	--	--	--	--	--
Li	--	--	--	--	--	--	--
Mg	--	--	--	--	--	--	--
Mn	--	--	--	--	--	--	--
Mo	--	--	--	--	--	--	--
Na	62774	58446	62691	54395	59137	57610	6275
Nd	--	--	--	--	--	--	--
Ni	--	--	--	--	--	--	--
P	4908	4766	4984	4467	4915	4835	415
Pb	[4.1]	[4.8]	[3.7]	[3.9]	[3.2]	[4.1]	--
Pd	--	--	--	--	--	--	--
Rh	--	--	--	--	--	--	--
Ru	--	--	--	--	--	--	--
Sb	--	--	--	--	--	--	--
Se	--	--	--	--	--	--	--
Si	2712	2759	2807	2515	2781	2726	298
Sn	--	--	--	--	--	--	--
Sr	--	--	--	--	--	--	--
Te	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
Ti	--	--	--	--	--	--	--
Tl	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
V	--	--	--	--	--	--	--
W	--	--	--	--	--	--	--
Y	--	--	--	--	--	--	--
Zn	[6.7]	[9.3]	[6.8]	[5.8]	[6.5]	[5.9]	--
Zr	--	--	--	--	--	--	--

(a) Analyte was below detection limit if left blank. Experimental uncertainties are 15%, except for values given in brackets. Values given in brackets are within 10 times the detection limit and the uncertainties for these values are greater than 15%.

Table A.6. Component Concentrations As a Function of Time For Leaching of T-110 Solids With 5 M NaOH at 80°C

	Concentration, μg/g[(a)]						
Time, h:	4	8	24	72	168	168	Final Wash
Ag	--	--	--	--	--	--	--
Al	[11.7]	[12.1]	[12.8]	[13.1]	[15.0]	[13.5]	[9.0]
As	--	--	--	--	--	--	--
B	--	--	--	--	28	--	67
Ba	[0.0]	[0.0]	[0.3]	--	[0.3]	[0.3]	[1.1]
Be	--	--	--	--	--	--	--
Bi	0.0	[0.0]	[0.0]	[5.1]	[5.9]	[5.5]	--
Ca	--	--	--	--	[6.7]	--	[18.4]
Cd	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--
Cr	44	79	134	166	182	194	22
Cu	--	--	--	--	--	--	--
Dy	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Fe	44	40	35	27	26	27	2
K	[53]	[53]	--	--	--	--	--
La	--	--	--	--	--	--	--
Li	--	--	--	--	--	--	--
Mg	--	--	--	--	--	--	--
Mn	--	--	--	--	--	--	--
Mo	--	--	--	--	--	--	--
Na	97507	97513	98023	90738	92560	99010	13661
Nd	--	[0]	--	--	--	--	--
Ni	--	--	--	--	--	--	--
P	4280	4359	4437	4241	4203	4496	479
Pb	[6.6]	[6.8]	[7.3]	[5.9]	[4.9]	[4.9]	--
Pd	--	--	--	--	--	--	--
Rh	--	--	--	--	--	--	--
Ru	--	--	--	--	--	--	--
Sb	--	--	--	--	--	--	--
Se	--	--	--	--	--	--	--
Si	2685	2747	2808	2622	2681	2833	398
Sn	--	--	--	--	--	--	--
Sr	--	--	--	--	--	--	--
Te	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
Ti	--	--	--	--	--	--	--
Tl	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
V	--	--	--	--	--	--	--
W	--	--	--	--	--	--	--
Y	--	--	--	--	--	--	--
Zn	[7.6]	[7.8]	[7.8]	[6.9]	[7.0]	[7.5]	--
Zr	--	--	--	--	--	--	--

(a) Analyte was below detection limit if left blank. Experimental uncertainties are 15%, except for values given in brackets. Values given in brackets are within 10 times the detection limit and the uncertainties for these values are greater than 15%.

Table A.7. Component Concentrations As a Function of Time For Leaching of T-110 Solids With 1 M NaOH at 100°C

	Concentration, µg/g[(a)]						
Time, h:	4	8	24	72	168	168	Final Wash
Ag	--	--	--	--	--	--	--
Al	[4.6]	[5.2]	[5.0]	[4.5]	[8.8]	[2.7]	[6.4]
As	--	--	--	--	--	--	--
B	--	--	--	--	38	--	45
Ba	[0.4]	[0.3]	[1.3]	[0.6]	[0.6]	--	[1.6]
Be	--	--	--	--	--	--	--
Bi	[19]	[21]	[24]	[27]	[28]	[26]	--
Ca	--	--	[9.5]	[7.5]	[7.3]	[8.1]	[11.0]
Cd	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--
Cr	16	23	47	83	115	116	10
Cu	--	--	--	--	--	--	--
Dy	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Fe	10	10	9	7	[6]	[6]	[1]
K	[66]	[79]	[66]	[64]	[68]	--	--
La	--	--	--	--	--	--	--
Li	--	--	--	--	--	--	--
Mg	--	--	--	--	--	--	--
Mn	--	--	--	--	--	--	--
Mo	--	--	--	--	--	--	--
Na	25188	24446	26779	25806	23293	24413	5735
Nd	--	--	--	--	--	--	--
Ni	--	--	--	--	--	--	--
P	4951	4906	5170	5128	4546	4566	397
Pb	--	--	--	--	--	--	--
Pd	--	--	--	--	--	--	--
Rh	--	--	--	--	--	--	--
Ru	--	--	--	--	--	--	--
Sb	--	--	--	--	--	--	--
Se	--	--	--	--	--	--	--
Si	1940	1910	2036	1979	1790	1797	280
Sn	--	--	--	--	--	--	--
Sr	--	--	--	--	--	--	--
Te	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
Ti	--	--	--	--	--	--	--
Tl	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
V	--	--	--	--	--	--	--
W	--	--	--	--	--	--	--
Y	--	--	--	--	--	--	--
Zn	--	--	[8]	--	--	--	--
Zr	--	--	--	--	--	--	--

(a) Analyte was below detection limit if left blank. Experimental uncertainties are 15%, except for values given in brackets. Values given in brackets are within 10 times the detection limit and the uncertainties for these values are greater than 15%.

Table A.8. Component Concentrations As a Function of Time For Leaching of T-110 Solids With 3 M NaOH at 100°C

	Concentration, μg/g[(a)]						
Time, h:	4	8	24	72	168	168	Final Wash
Ag	--	--	--	--	--	--	--
Al	[19.1]	[12.6]	[13.1]	[13.9]	[13.1]	[11.6]	[7.2]
As	--	--	--	--	--	--	--
B	--	--	--	--	16	--	41
Ba	[0.7]	[0.3]	[0.5]	[0.4]	[0.5]	[0.4]	[0.6]
Be	--	--	--	--	--	--	--
Bi	21.6	[10.2]	[7.6]	[7.3]	[22.2]	[21.7]	--
Ca	[11.6]	[8.6]	--	--	[7.8]	--	[11]
Cd	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--
Cr	99	104	154	194	200	200	13
Cu	--	--	--	--	--	--	--
Dy	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Fe	35	24	23	18	15	15	1
K	[121]	[97]	[107]	[113]	[91]	[90]	--
La	--	--	--	--	--	--	--
Li	--	--	--	--	--	--	--
Mg	--	--	--	--	--	--	--
Mn	--	--	--	--	--	--	--
Mo	--	--	--	--	--	--	--
Na	107265	69124	64415	66567	60129	58549	5131
Nd	--	--	--	--	--	--	--
Ni	--	--	--	--	--	--	--
P	7650	4868	4609	4665	4116	4127	256
Pb	[7]	[6]	[7]	[6]	[3]	[3]	--
Pd	--	--	--	--	--	--	--
Rh	--	--	--	--	--	--	--
Ru	--	--	--	--	--	--	--
Sb	--	--	--	--	--	--	--
Se	--	--	--	--	--	--	--
Si	4241	2717	2618	2699	1668	2466	231
Sn	--	--	--	--	--	--	--
Sr	--	--	--	--	--	--	--
Te	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
Ti	--	--	--	--	--	--	--
Tl	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
V	--	--	--	--	--	--	--
W	--	--	--	--	--	--	--
Y	--	--	--	--	--	--	--
Zn	[10.8]	[7.0]	[6.5]	[6.3]	[5.1]	[4.9]	--
Zr	--	--	--	--	--	--	--

(a) Analyte was below detection limit if left blank. Experimental uncertainties are 15%, except for values given in brackets. Values given in brackets are within 10 times the detection limit and the uncertainties for these values are greater than 15%.

Table A.9. Component Concentrations As a Function of Time For Leaching of T-110 Solids With 5 M NaOH at 100°C

	Concentration, µg/g(a)						
Time, h:	4	8	24	72	168	168	Final Wash
Ag	--	--	--	--	--	--	--
Al	[10.4]	[14.4]	[14.1]	14.8	17.9	[14.1]	[3.7]
As	--	--	--	--	--	--	--
B	--	--	--	--	40	--	[15]
Ba	[0.4]	[0.3]	--	[0.9]	[0.7]	[0.5]	[0.3]
Be	--	--	--	--	--	--	--
Bi	[2.3]	[2.9]	[2.6]	[3.4]	[6.8]	[5.7]	--
Ca	[5.6]	--	--	[7.4]	[7.6]	[8.4]	[10.1]
Cd	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--
Cr	41	91	169	191	194	184	13
Cu	--	--	--	--	--	--	--
Dy	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Fe	34	40	41	31	24	23	1
K	[75]	[122]	[88]	[99]	[101]	[104]	--
La	--	--	--	--	--	--	--
Li	--	--	--	--	--	--	--
Mg	--	--	--	--	--	--	--
Mn	--	--	--	--	--	--	--
Mo	--	--	--	--	--	--	--
Na	74272	99127	98752	98507	93781	89701	7470
Nd	--	[3]	--	--	--	--	--
Ni	--	--	--	--	--	--	--
P	3269	4346	4461	4397	4283	4077	272
Pb	[7.7]	[10.3]	[9.1]	[7.9]	[6.8]	[6.4]	--
Pd	--	--	--	--	--	--	--
Rh	--	--	--	--	--	--	--
Ru	--	--	--	--	--	--	--
Sb	--	--	--	--	--	--	--
Se	--	--	--	--	--	--	--
Si	2050	2686	2839	2835	2788	2644	231
Sn	--	--	--	--	--	--	--
Sr	--	--	--	--	--	--	--
Te	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
Ti	--	--	--	--	--	--	--
Tl	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
V	--	--	--	--	--	--	--
W	--	--	--	--	--	--	--
Y	--	--	--	--	--	--	--
Zn	[6.4]	[8.3]	[8.1]	[8.4]	[7.6]	[7.4]	--
Zr	--	--	--	--	--	--	--

(a) Analyte was below detection limit if left blank. Experimental uncertainties are 15%, except for values given in brackets. Values given in brackets are within 10 times the detection limit and the uncertainties for these values are greater than 15%.

Appendix B

Leaching Results in Terms of Percent Component Removed

Appendix B: Leaching Results in Terms of Percent Component Removed

Table B.1. Results of Leaching T-110 Sludge With 1 M NaOH At 60°C[(a)]

	Leaching Solution		*Washing Solution*		*Leached Solids*					
	Solution Mass, g:	42.308	Solution Mass, g:	91.767	Solids Mass, g:	1.363				
Component	Conc., µg/g	Mass, µg	Conc., µg/g	Mass, µg	Conc., µg/g	Mass, µg	Total Mass, µg	Removed, %	Calc. Conc. In Washed Solids, µg/g	Measured Conc. In Washed Solids, µg/g
Ag	--	--	--	--	--	--	--	--	--	--
Al	[4]	[186]	[2]	[214]	800	1090	1490	27%	597	1048
As	--	--	--	--	--	--	--	--	--	--
B	--	--	--	--	520	709	709	(b)	[284]	[343]
Ba	[0.4]	[15.5]	--	--	[88]	[120]	[135]	11%	[54]	[62]
Be	--	--	--	--	--	--	--	--	--	--
Bi	[11]	[449]	--	--	267000	363921	[364370]	0.1%	145865	146000
Ca	[7]	[314]	[10]	[954]	2870	3912	[5180]	24%	[2074]	3580
Cd	--	--	--	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--	--	--	--
Cr	27	1128	2	188	8140	11095	12410	11%	4968	5943
Cu	--	--	--	--	--	--	--	--	--	--
Dy	--	--	--	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--	--	--	--
Fe	6	233	2	150	217860	296943	297327	0.1%	119026	140000
K	[86]	[3658]	--	--	N/A	N/A	N/A	N/A	N/A	N/A
La	--	--	--	--	[130]	[177]	[177]	(b)	[71]	[80]
Li	--	--	--	--	--	--	--	--	--	--
Mg	--	--	--	--	1350	1840	1840	(b)	737	[1400]
Mn	--	--	--	--	1040	1418	1418	(b)	567	--
Mo	--	--	--	--	--	--	--	--	--	--
Na	24797	1049093	5166	474062	61410	83702	1606857	N/A	N/A	76400
Nd	--	--	--	--	--	--	--	--	--	--
Ni	--	--	--	--	N/A	N/A	N/A	N/A	N/A	N/A
P	4809	203480	378	34687	[1300]	[1772]	[239939]	99%	[96053]	88300
Pb	--	--	--	--	[1000]	[1363]	[1363]	(b)	[546]	[660]
Pd	--	--	--	--	--	--	--	--	--	--
Rh	--	--	--	--	--	--	--	--	--	--
Ru	--	--	--	--	--	--	--	--	--	--
Sb	--	--	--	--	--	--	--	--	--	--
Se	--	--	--	--	--	--	--	--	--	--
Si	1888	79895	248	22749	66800	91048	193693	53%	[77539]	79867
Sn	--	--	--	--	--	--	--	--	--	--
Sr	--	--	--	--	1880	2562	2562	(b)	1026	1170
Te	--	--	--	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--	--	--	--
Ti	--	--	--	--	[76]	[104]	[104]	(b)	[41]	[70]
Tl	--	--	--	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--	--	--	--
V	--	--	--	--	--	--	--	--	--	--
W	--	--	--	--	--	--	--	--	--	--
Y	--	--	--	--	--	--	--	--	--	--
Zn	--	--	--	--	[330]	[450]	[450]	(b)	[180]	[267]
Zr	--	--	--	--	--	--	--	--	--	--

(a) If blank, the analyte was below detection limit. Potassium and Ni were not determined in the solids because of the fusion method used to dissolve the solids for analysis. The amount of Na removed could not reasonably be calculated due to the realtively large amount of Na added as NaOH during leaching.

(b) No detectable removal.

Table B.2. Results of Leaching T-110 Sludge With 3 M NaOH At 60°C[(a)]

	Leaching Solution		*Washing Solution*		*Leached Solids*						
	Solution Mass, g:	44.928	Solution Mass, g:	92.944	Solids Mass, g:	1.220					
Component	Conc., µg/g	Mass, µg	Conc., µg/g	Mass, µg	Conc., µg/g	Mass, µg	Total Mass, µg	Removed, %	Calc. Conc. In Washed Solids, µg/g	Measured Conc. In Washed Solids, µg/g	Recovery %
Ag	--	--	--	--	--	--	--	--	--	--	--
Al	[8]	[371]	--	--	426	520	890	42%	356	1048	34%
As	--	--	--	--	--	--	--	--	--	--	--
B	[0.9]	[41]	--	--	50	61	[102]	40%	[41]	[343]	12%
Ba	--	--	[0.5]	[43]	[98]	[120]	[163]	26%	[65]	[62]	105%
Be	--	--	--	--	--	--	--	--	--	--	--
Bi	[12]	538	--	--	297000	362340	362878	0.1%	145267	146000	99%
Ca	--	--	[9]	[832]	2850	3477	[4309]	19%	[1725]	3580	48%
Cd	--	--	--	--	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--	--	--	--	--
Cr	136	6098	12	1070	5200	6344	13512	53%	5409	5943	91%
Cu	--	--	--	--	--	--	--	--	--	--	--
Dy	--	--	--	--	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--	--	--	--	--
Fe	16	[698]	[1]		239860	292629	293327	0%	117425	140000	84%
K	--	--	--	--	N/A	N/A	N/A	N/A	N/A	N/A	N/A
La	--	--	--	--	[120]	[146]	[146]	(b)	[59]	[80]	73%
Li	--	--	--	--	--	--	--	--	--	--	--
Mg	--	--	--	--	1480	1806	1806	(b)	723	[1400]	52%
Mn	--	--	--	--	830	1013	1013	(b)	405	[992]	41%
Mo	--	--	--	--	--	--	--	--	--	--	--
Na	66536	2989333	6973	648075	49910	60890	3698298	N/A	N/A	76400	N/A
Nd	--	--	--	--	--	--	--	--	--	--	--
Ni	--	--	--	--	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P	4511	[202672]	370	34411	[730]	[891]	[237974]	100%	[95266]	88300	108%
Pb	--	--	--	--	[980]	[1196]	[1196]	(b)	[479]	[660]	73%
Pd	--	--	--	--	--	--	--	--	--	--	--
Rh	--	--	--	--	--	--	--	--	--	--	--
Ru	--	--	--	--	--	--	--	--	--	--	--
Sb	--	--	--	--	--	--	--	--	--	--	--
Se	--	--	--	--	--	--	--	--	--	--	--
Si	2616	[117538]	256	23801	48900	59658	[200997]	70%	[80463]	79867	101%
Sn	--	--	--	--	--	--	--	--	--	--	--
Sr	--	--	--	--	2180	2660	2660	(b)	1065	1170	91%
Te	--	--	--	--	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--	--	--	--	--
Ti	--	--	--	--	[69]	[84]	[84]	(b)	[34]	[70]	48%
Tl	--	--	--	--	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--	--	--	[5100]	0%
V	--	--	--	--	--	--	--	--	--	--	--
W	--	--	--	--	--	--	--	--	--	--	--
Y	--	--	--	--	--	--	--	--	--	--	--
Zn	[6]	[275]	--	--	[210]	[256]	[531]	52%	[213]	[267]	80%
Zr	--	--	--	--	--	--	--	--	--	--	--

(a) If blank, the analyte was below detection limit. Potassium and Ni were not determined in the solids because of the fusion method used to dissolve the solids for analysis. The amount of Na removed could not reasonably be calculated due to the realtively large amount of Na added as NaOH during leaching.
(b) No detectable removal.

Table B.3. Results of Leaching T-110 Sludge With 5 M NaOH At 60°C[(a)]

	Leaching Solution		***Washing Solution***		***Leached Solids***						
	Solution Mass, g:	53.042	Solution Mass, g:	91.265	Solids Mass, g:	1.173					
Component	Conc., µg/g	Mass, µg	Conc., µg/g	Mass, µg	Conc., µg/g	Mass, µg	Total Mass, µg	Removed, %	Calc. Conc. In Washed Solids, µg/g	Measured Conc. In Washed Solids, µg/g	Recovery %
Ag	--	--	--	--	--	--	--	--	--	--	--
Al	[13]	[703]	[6]	[528]	[740]	[868]	[2098]	59%	840	1048	80%
As	--	--	--	--	--	--	--	--	--	--	--
B	34		41	3748	470	551	4299	87%	[1721]	[343]	502%
Ba	[0.5]	[25]	[0.9]	[78]	[120]	[141]	[244]	42%	98	[62]	157%
Be	--	--	--	--	--	--	--	--	--	--	--
Bi	[4]	[214]	--	--	298000	349554	[349768]	0.1%	140019	146000	96%
Ca	[8]	[436]	[10]	[944]	4140	4856	6236	22%	[2496]	3580	70%
Cd	--	--	--	--	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--	--	--	--	--
Cr	144	7630	13	1188	4060	4762	13581	65%	5437	5943	91%
Cu	--	--	--	--	--	--	--	--	--	--	--
Dy	--	--	--	--	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--	--	--	--	--
Fe	22	1192	1	122	244860	287221	288535	0.5%	115506	140000	83%
K	--	--	--	--	N/A	N/A	N/A	N/A	N/A	N/A	N/A
La	--	--	--	--	[160]	[188]	[188]	(b)	[75]	[80]	94%
Li	--	--	--	--	--	--	--	--	--	--	--
Mg	--	--	--	--	[1890]	[2217]	[2217]	(b)	[887]	[1400]	63%
Mn	--	--	--	--	[940]	[1103]	[1103]	(b)	441	[992]	44%
Mo	--	--	--	--	--	--	--	--	--	--	--
Na	89173	4729911	9400	857916	48410	56785	5644612	N/A	N/A	76400	N/A
Nd	--	--	--	--	--	--	--	--	--	--	--
Ni	--	--	--	--	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P	4026	213521	341	31096	[640]	[751]	[245368]	100%	[98226]	88300	111%
Pb	[6]	[308]	--	--	[980]	[1150]	[1457]	21%	[583]	[660]	88%
Pd	--	--	--	--	--	--	--	--	--	--	--
Rh	--	--	--	--	--	--	--	--	--	--	--
Ru	--	--	--	--	--	--	--	--	--	--	--
Sb	--	--	--	--	--	--	--	--	--	--	--
Se	--	--	--	--	--	--	--	--	--	--	--
Si	2510	133128	261	23822	40700	47741	204691	77%	[81942]	79867	103%
Sn	--	--	--	--	--	--	--	--	--	--	--
Sr	--	--	--	--	2200	2581	2581	(b)	1033	1170	88%
Te	--	--	--	--	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--	--	--	--	--
Ti			--	--	[83]	[97]	[97]	(b)	[39]	[70]	56%
Tl	--	--	--	--	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--	--	--	--	--
V	--	--	--	--	--	--	--	--	--	--	--
W	--	--	--	--	--	--	--	--	--	--	--
Y	--	--	--	--	--	--	--	--	--	--	--
Zn	[7]	[381]	--	--	[150]	[176]	[557]	68%	[223]	[267]	84%
Zr	--	--	0	--	--	--	--	--	--	--	--

(a) If blank, the analyte was below detection limit. Potassium and Ni were not determined in the solids because of the fusion method used to dissolve the solids for analysis.
The amount of Na removed could not reasonably be calculated due to the realtively large amount of Na added as NaOH during leaching.
(b) No detectable removal.

Table B.4. Results of Leaching T-110 Sludge With 1 M NaOH At 80°C(a)

	Leaching Solution		*Washing Solution*		*Leached Solids*						
	Solution Mass, g:	39.411	Solution Mass, g:	93.806	Solids Mass, g:	1.359					
Component	Conc., µg/g	Mass, µg	Conc., µg/g	Mass, µg	Conc., µg/g	Mass, µg	Total Mass, µg	Removed, %	Calc. Conc. In Washed Solids, µg/g	Measured Conc. In Washed Solids, µg/g	Recovery %
Ag	--	--	--	--	--	--	--	--	--	--	--
Al	[6]	[245]	[6]	[590]	540	734	1569	53%	626	1048	60%
As	--	--	--	--	--	--	--	--	--	--	--
B	37	1460	40	3706	[460]	[625]	[5791]	89%	[2310]	[343]	673%
Ba	[1.3]	[49.4]	[0.8]	[75.8]	92	125	250	50%	100	[62]	161%
Be	--	--	--	--	--	--	--	--	--	--	--
Bi	[16]	[645]	--	--	263000	357417	358062	(b)	142825	146000	98%
Ca	[8]	[297]	[9]	[870]	2870	3900	5068	23%	[2021]	3580	56%
Cd	--	--	--	--	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--	--	--	--	--
Cr	77	3045	7	629	6770	9200	12874	29%	5135	5943	86%
Cu	--	--	--	--	--	--	--	--	--	--	--
Dy	--	--	--	--	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--	--	--	--	--
Fe	[6]	[244]	[1]	[140]	220860	300149	300534	(b)	119878	140000	86%
K	[61]	[2389]	--	--		N/A	N/A		N/A	N/A	N/A
La	--	--	--	--	[120]	[163]	[163]	(b)	[65]	[80]	81%
Li	--	--	--	--	--	--	--	--	--	--	--
Mg	--	--	--	--	[1420]	[1930]	[1930]	(b)	[770]	[1400]	55%
Mn	--	--	--	--	780	1060	1060	(b)	423	[992]	43%
Mo	--	--	--	--	--	--	--	--	--	--	--
Na	25252	995222	5866	550244	56910	77341	1622807	95%	N/A	76400	N/A
Nd	--	--	--	--	--	--	--	--	--	--	--
Ni	--	--	--	--	--	--	--	--	N/A	N/A	N/A
P	5132	202258	449	42111	1850	2514	246883	99%	98477	88300	112%
Pb	--	--	--	--	950	1291	1291	(b)	515	[660]	78%
Pd	--	--	--	--	--	--	--	--	--	--	--
Rh	--	--	--	--	--	--	--	--	--	--	--
Ru	--	--	--	--	--	--	--	--	--	--	--
Sb	--	--	--	--	--	--	--	--	--	--	--
Se	--	--	--	--	--	--	--	--	--	--	--
Si	1920	75687	286	26782	69600	94586	197056	52%	78602	79867	98%
Sn	--	--	--	--	--	--	--	--	--	--	--
Sr	--	--	--	--	1990	2704	2704	(b)	1079	1170	92%
Te	--	--	--	--	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--	--	--	--	--
Ti	--	--	--	--	[66]	[90]	[90]	(b)	[36]	[70]	51%
Tl	--	--	--	--	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--	--	--	[5100]	--
V	--	--	--	--	--	--	--	--	--	--	--
W	--	--	--	--	--	--	--	--	--	--	--
Y	--	--	--	--	--	--	--	--	--	--	--
Zn	--	--	--	--	[340]	[462]	[462]	(b)	[184]	[267]	69%
Zr	--	--	--	--	--	--	--	--	--	--	--

(a) If blank, the analyte was below detection limit. Potassium and Ni were not determined in the solids because of the fusion method used to dissolve the solids for analysis. The amount of Na removed could not reasonably be calculated due to the realtively large amount of Na added as NaOH during leaching.
(b) No detectable removal.

Table B.5. Results of Leaching T-110 Sludge With 3 M NaOH At 80°C[(a)]

	Leaching Solution		*Washing Solution*		*Leached Solids*						
	Solution Mass, g:	41.241	Solution Mass, g:	93.060	Solids Mass, g:	1.204					
Component	Conc., µg/g	Mass, µg	Conc., µg/g	Mass, µg	Conc., µg/g	Mass, µg	Total Mass, µg	Removed, %	Calc. Conc. In Washed Solids, µg/g	Measured Conc. In Washed Solids, µg/g	Recovery %
Ag	--	--	--	--	--	--	--	--	--	--	--
Al	[13]	[544]	[7]	[677]	500	602	[1823]	67%	[725]	1048	69%
As	--	--	--	--	--	--	--	--	--	--	--
B	29	1192	38	3554			4746	100%	1887	[343]	550%
Ba	[0.6]	[25.9]	[1]	[90]	[100]	[120]	[237]	49%	[94]	[62]	152%
Be	--	--	--	--	--	--	--	--	--	--	--
Bi	[10]	[409]	[3]	[282]	298000	358792	359483	0.2%	142935	146000	98%
Ca	[7]	[294]	[13]	[1185]	3090	3720	[5199]	28%	[2067]	3580	58%
Cd	--	--	--	--	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--	--	--	--	--
Cr	190	7841	17	1594	3690	4443	13877	68%	5518	5943	93%
Cu	--	--	--	--	--	--	--	--	--	--	--
Dy	--	--	--	--	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--	--	--	--	--
Fe	15	616	[1]	[135]	251860	303239	303991	0.2%	120871	140000	86%
K	[81]	[3360]			N/A	N/A	N/A			N/A	N/A
La	--	--	--	--	[140]	[169]	[169]	(b)	[67]	[80]	84%
Li	--	--	--	--	--	--	--	--	--	--	--
Mg	--	--	--	--	1620	1950	1950	(b)	776	[1400]	55%
Mn	--	--	--	--	970	1168	1168	(b)	464	[992]	47%
Mo	--	--	--	--	--	--	--	--	--	--	--
Na	58374	2407385	6275	583949	33510	40346	3031680	99%	1205439	76400	N/A
Nd	--	--	--	--	[170]	[205]	[205]	(b)	[81]		
Ni	--	--	--	--	N/A	N/A	N/A			N/A	N/A
P	4875	201044	415	38648	[810]	[975]	240667	100%	95693	88300	108%
Pb	[4]	[152]			[1000]	[1204]	[1356]	11%	[539]	[660]	82%
Pd	--	--	--	--	--	--	--	--	--	--	--
Rh	--	--	--	--	--	--	--	--	--	--	--
Ru	--	--	--	--	--	--	--	--	--	--	--
Sb	--	--	--	--	--	--	--	--	--	--	--
Se	--	--	--	--	--	--	--	--	--	--	--
Si	2754	113568	298	27731	47800	57551	198850	71%	79065	79867	99%
Sn	--	--	--	--	--	--	--	--	--	--	--
Sr	--	--	--	--	2230	2685	2685	(b)	1068	1170	91%
Te	--	--	--	--	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--	--	--	--	--
Ti					[73]	[88]	[88]	(b)	[35]	[70]	50%
Tl	--	--	--	--	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--	--	--	[5100]	--
V	--	--	--	--	--	--	--	--	--	--	--
W	--	--	--	--	--	--	--	--	--	--	--
Y	--	--	--	--	--	--	--	--	--	--	--
Zn	[6]	[256]			[230]	[277]	[533]	48%	[212]	[267]	79%
Zr	--	--	--	--	--	--	--	--	--	--	--

(a) If blank, the analyte was below detection limit. Potassium and Ni were not determined in the solids because of the fusion method used to dissolve the solids for analysis.
The amount of Na removed could not reasonably be calculated due to the realtively large amount of Na added as NaOH during leaching.
(b) No detectable removal.

Table B.6. Results of Leaching T-110 Sludge With 5 M NaOH At 80°C[(a)]

	Leaching Solution		*Washing Solution*		*Leached Solids*						
	Solution Mass, g:	45.888	Solution Mass, g:	91.593	Solids Mass, g:	1.053					
Component	Conc., µg/g	Mass, µg	Conc., µg/g	Mass, µg	Conc., µg/g	Mass, µg	Total Mass, µg	Removed, %	Calc. Conc. In Washed Solids, µg/g	Measured Conc. In Washed Solids, µg/g	Recovery %
Ag	--	--	--	--	--	--	--	--	--	--	--
Al	[14]	[653]	[9]	[822]	290	305	[1781]	83%	[708]	1048	68%
As	--	--	--	--	--	--	--	--	--	--	--
B	28		67	6119	[780]	[821]	[6941]	88%	[2760]	[343]	805%
Ba	[0.3]		[1]	[100]	110	116	216	46%	[86]	[62]	139%
Be	--	--	--	--	--	--	--	--	--	--	--
Bi	[6]	[261]			287000	302211	302472	0.1%	120267	146000	82%
Ca	[7]	[308]	[18]	[1690]	3580	3770	[5767]	35%	[2293]	3580	64%
Cd	--	--	--	--	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--	--	--	--	--
Cr	188	8618	22	1973	2940	3096	13687	77%	5442	5943	92%
Cu	--	--	--	--	--	--	--	--	--	--	--
Dy	--	--	--	--	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--	--	--	--	--
Fe	27	1218	2	196	256860	270474	271888	1%	108106	140000	77%
K	--	--	--	--	N/A	N/A	N/A	N/A	N/A	N/A	N/A
La	--	--	--	--	110	116	116	(b)	46	[80]	58%
Li	--	--	--	--	--	--	--	--	--	--	--
Mg	--	--	--	--	1740	1832	1832	(b)	729	[1400]	52%
Mn	--	--	--	--	980	1032	1032	(b)	410	[992]	41%
Mo	--	--	--	--	--	--	--	--	--	--	--
Na	95785	4395385	13661	1251241	51510	54240	5700867	N/A	N/A	76400	N/A
Nd	--	--	--	--	--	--	--	--	--	--	--
Ni	--	--	--	--	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P	4349	199574	479	43839	[1300]	[1369]	[244782]	99%	[97329]	88300	110%
Pb	[5]	[226]	--	--	890	937	1163	#VALUE!	462	[660]	70%
Pd	--	--	--	--	--	--	--	--	--	--	--
Rh	--	--	--	--	--	--	--	--	--	--	--
Ru	--	--	--	--	--	--	--	--	--	--	--
Sb	--	--	--	--	--	--	--	--	--	--	--
Se	--	--	--	--	--	--	--	--	--	--	--
Si	2757	126513	398	36441	40700	42857	205811	79%	81833	79867	102%
Sn	--	--	--	--	--	--	--	--	--	--	--
Sr	--	--	--	--	2340	2464	2464	(b)	980	1170	84%
Te	--	--	--	--	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--	--	--	--	--
Ti					65	68	68	(b)	27	[70]	39%
Tl	--	--	--	--	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--	--	--	[5100]	--
V	--	--	--	--	--	--	--	--	--	--	--
W	--	--	--	--	--	--	--	--	--	--	--
Y	--	--	--	--	--	--	--	--	--	--	--
Zn	[7]	[333]	--	--	150	158	[491]	68%	[195]	[267]	73%
Zr	--	--	--	--	--	--	--	--	--	--	--

(a) If blank, the analyte was below detection limit. Potassium and Ni were not determined in the solids because of the fusion method used to dissolve the solids for analysis. The amount of Na removed could not reasonably be calculated due to the realtively large amount of Na added as NaOH during leaching.
(b) No detectable removal.

Table B.7. Results of Leaching T-110 Sludge With 1 M NaOH At 100°C(a)

	Leaching Solution		*Washing Solution*		*Leached Solids*						
	Solution Mass, g:	44.622	Solution Mass, g:	91.634	Solids Mass, g:	1.324					
Component	Conc., µg/g	Mass, µg	Conc., µg/g	Mass, µg	Conc., µg/g	Mass, µg	Total Mass, µg	Removed, %	Calc. Conc. In Washed Solids, µg/g	Measured Conc. In Washed Solids, µg/g	Recovery %
Ag	--	--	--	--	--	--	--	--	--	--	--
Al	[6]	[255]	[6]	[587]	630	834	1676	50%	669	1048	64%
As	--	--	--	--	--	--	--	--	--	--	--
B	38		45	4137	[880]	[1165]	[5302]	78%	[2115]	[343]	617%
Ba	[1]		[2]	[143]	82	109	251	57%	[100]	[62]	162%
Be	--	--	--	--	--	--	--	--	--	--	--
Bi	[27]	[1205]			250000	331000	332205	0.4%	132511	146000	91%
Ca	[8]	[344]	[11]	[1006]	2900	3840	5189	26%	[2070]	3580	58%
Cd	--	--	--	--	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--	--	--	--	--
Cr	116	5159	10	909	4990	6607	12674	48%	5055	5943	85%
Cu	--	--	--	--	--	--	--	--	--	--	--
Dy	--	--	--	--	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--	--	--	--	--
Fe	[6]	[258]	[1]	[134]	204860	271235	271627	0.1%	108347	140000	77%
K	[68]		--	--	N/A	N/A	N/A	N/A	N/A	N/A	N/A
La	--	--	--	--	--	--	--	--	--	[80]	--
Li	--	--	--	--	--	--	--	--	--	--	--
Mg	--	--	--	--	1290	1708	1708	(b)	681	[1400]	49%
Mn	--	--	--	--	860	1139	1139	(b)	454	[992]	46%
Mo	--	--	--	--	--	--	--	--	--	--	--
Na	23853	1064381	5735	525534	74310	98386	1688302	N/A	N/A	76400	N/A
Nd	--	--	--	--	--	--	--	--	--	--	--
Ni	--	--	--	--	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P	4556	203286	397	36340	2130	2820	242446	99%	96708	88300	110%
Pb	--	--	--	--	870	1152	1152	(b)	459	[660]	70%
Pd	--	--	--	--	--	--	--	--	--	--	--
Rh	--	--	--	--	--	--	--	--	--	--	--
Ru	--	--	--	--	--	--	--	--	--	--	--
Sb	--	--	--	--	--	--	--	--	--	--	--
Se	--	--	--	--	--	--	--	--	--	--	--
Si	1793	80025	280	25662	65400	86589.6	192277	55%	76696	79867	96%
Sn	--	--	--	--	--	--	--	--	--	--	--
Sr	--	--	--	--	1820	2410	2410	(b)	961	1170	82%
Te	--	--	--	--	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--	--	--	--	--
Ti	--	--	--	--	[75]	[99]	[99]	(b)	[40]	[70]	57%
Tl	--	--	--	--	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--	--	--	[5100]	--
V	--	--	--	--	--	--	--	--	--	--	--
W	--	--	--	--	--	--	--	--	--	--	--
Y	--	--	--	--	--	--	--	--	--	--	--
Zn	--	--	--	--	320	424	424	(b)	169	[267]	63%
Zr	--	--	--	--	--	--	--	--	--	--	--

(a) If blank, the analyte was below detection limit. Potassium and Ni were not determined in the solids because of the fusion method used to dissolve the solids for analysis.
The amount of Na removed could not reasonably be calculated due to the realtively large amount of Na added as NaOH during leaching.
(b) No detectable removal.

Table B.8. Results of Leaching T-110 Sludge With 3 M NaOH At 100°C[(a)]

	Leaching Solution		*Washing Solution*		*Leached Solids*						
	Solution Mass, g:	49.644	Solution Mass, g:	91.192	Solids Mass, g:	1.140					
Component	Conc., µg/g	Mass, µg	Conc., µg/g	Mass, µg	Conc., µg/g	Mass, µg	Total Mass, µg	Removed, %	Calc. Conc. In Washed Solids, µg/g	Measured Conc. In Washed Solids, µg/g	Recovery %
Ag	--	--	--	--	--	--	--	--	--	--	--
Al	[12.4]	[613]	[7.2]	[661]	380	433	1707	75%	[681]	1048	65%
As	--	--	--	--	--	--	--	--	--	--	--
B	16	793	41	3743	660	752	5289	86%	2110	[343]	615%
Ba	[0.4]	[22]	[0.6]	[55]	110	125	203	38%	[81]	[62]	130%
Be	--	--	--	--	--	--	--	--	--	--	--
Bi	[21.9]	[1088]	--	--	298000	339720	340808	0.3%	135943	146000	93%
Ca	[8]	[385]	[11]	[1018]	3640	4150	5553	25%	[2215]	3580	62%
Cd	--	--	--	--	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--	--	--	--	--
Cr	200	9911	13	1153	2310	2633	13697	81%	5464	5943	92%
Cu	--	--	--	--	--	--	--	--	--	--	--
Dy	--	--	--	--	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--	--	--	--	--
Fe	15	750	1	105	246860	281420	282275	0.3%	112595	140000	80%
K	[91]	[4496]	--	--	N/A	N/A	N/A	N/A	N/A	N/A	N/A
La	--	--	--	--	120	137	137	(b)	55	[80]	68%
Li	--	--	--	--	--	--	--	--	--	--	--
Mg	--	--	--	--	1740	1984	1984	(b)	791	[1400]	57%
Mn	--	--	--	--	920	1049	1049	(b)	418	[992]	42%
Mo	--	--	--	--	--	--	--	--	--	--	--
Na	59339	2945840	5131	467894	49210	56099	3469834	N/A	N/A	76400	N/A
Nd	--	--	--	--	--	--	--	--	--	--	--
Ni	--	--	--	--	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P	4121	204591	256	23340	[1900]	[2166]	230097	99%	91782	88300	104%
Pb	[3]	[169]	--	--	1000	1140	1309	13%	522	[660]	79%
Pd	--	--	--	--	--	--	--	--	--	--	--
Rh	--	--	--	--	--	--	--	--	--	--	--
Ru	--	--	--	--	--	--	--	--	--	--	--
Sb	--	--	--	--	--	--	--	--	--	--	--
Se	--	--	--	--	--	--	--	--	--	--	--
Si	2067	102598	231	21055	42700	48678	172332	72%	68740	79867	86%
Sn	--	--	--	--	--	--	--	--	--	--	--
Sr	--	--	--	--	2220	2531	2531	(b)	1009	1170	86%
Te	--	--	--	--	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--	--	--	--	--
Ti	--	--	--	--	66	75	75	(b)	30	[70]	43%
Tl	--	--	--	--	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--	--	--	[5100]	--
V	--	--	--	--	--	--	--	--	--	--	--
W	--	--	--	--	--	--	--	--	--	--	--
Y	--	--	--	--	--	--	--	--	--	--	--
Zn	[5]	[248]	--	--	250	285	533	46%	[212]	[267]	80%
Zr	--	--	--	--	--	--	--	--	--	--	--

(a) If blank, the analyte was below detection limit. Potassium and Ni were not determined in the solids because of the fusion method used to dissolve the solids for analysis. The amount of Na removed could not reasonably be calculated due to the realtively large amount of Na added as NaOH during leaching.
(b) No detectable removal.

Table B.9. Results of Leaching T-110 Sludge With 5 M NaOH At 100°C[(a)]

	Leaching Solution		*Washing Solution*		*Leached Solids*						
	Solution Mass, g:	50.598	Solution Mass, g:	90.594	Solids Mass, g:	1.162					
Component	Conc., µg/g	Mass, µg	Conc., µg/g	Mass, µg	Conc., µg/g	Mass, µg	Total Mass, µg	Removed, %	Calc. Conc. In Washed Solids, µg/g	Measured Conc. In Washed Solids, µg/g	Recovery %
Ag	--	--	--	--	--	--	--	--	--	--	--
Al	16	808	[4]	[333]	295	343	1484	77%	590	1048	56%
As	--	--	--	--	--	--	--	--	--	--	--
B	40	2026	[15]	[1359]	[795]	[924]	[4309]	79%	[1713]	[343]	500%
Ba	[1]	[29]	[0.3]	[31]	110	128	187	32%	74	[62]	120%
Be	--	--	--	--	--	--	--	--	--	--	--
Bi	[6]	[317]	--	--	290000	336980	337297	0.1%	134114	146000	92%
Ca	[8]	[405]	[10]	[915]	3650	4241	5561	24%	2211	3580	62%
Cd	--	--	--	--	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--	--	--	--	--
Cr	189	9582	13	1168	2715	3155	13904	77%	5529	5943	93%
Cu	--	--	--	--	--	--	--	--	--	--	--
Dy	--	--	--	--	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--	--	--	--	--
Fe	24	1201	1	119	248860	289175	290496	0.5%	115505	140000	83%
K	[103]	[5191]	--	--	N/A	N/A	N/A	N/A	N/A	N/A	N/A
La	--	--	--	--	150	174	174	(b)	69	[80]	87%
Li	--	--	--	--	--	--	--	--	--	--	--
Mg	--	--	--	--	1780	2068	2068	(b)	822	[1400]	59%
Mn	--	--	--	--	900	1046	1046	(b)	416	[992]	42%
Mo	--	--	--	--	--	--	--	--	--	--	--
Na	91741	4641901	7470	676740	50860	59099	5377740	N/A	N/A	76400	N/A
Nd	--	--	--	--	240	279	279	(b)	111		
Ni	--	--	--	--	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P	4180	211520	272	24601	[2030]	[2359]	[238480]	99%	[94823]	88300	107%
Pb	[7]	[336]			1100	1278	1614	21%	642	[660]	97%
Pd	--	--	--	--	--	--	--	--	--	--	--
Rh	--	--	--	--	--	--	--	--	--	--	--
Ru	--	--	--	--	--	--	--	--	--	--	--
Sb	--	--	--	--	--	--	--	--	--	--	--
Se	--	--	--	--	--	--	--	--	--	--	--
Si	2716	137428	231	20912	35200	40902	199243	79%	79222	79867	99%
Sn	--	--	--	--	--	--	--	--	--	--	--
Sr	--	--	--	--	2230	2591	2591	(b)	1030	1170	88%
Te	--	--	--	--	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--	--	--	--	--
Ti	--	--	--	--	74	86	86	(b)	34	[70]	49%
Tl	--	--	--	--	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--	--	--	[5100]	--
V	--	--	--	--	--	--	--	--	--	--	--
W	--	--	--	--	--	--	--	--	--	--	--
Y	--	--	--	--	--	--	--	--	--	--	--
Zn	[8]	[380]	--	--	160	186	566	67%	225	[267]	84%
Zr	--	--	--	--	--	--	--	--	--	--	--

(a) If blank, the analyte was below detection limit. Potassium and Ni were not determined in the solids because of the fusion method used to dissolve the solids for analysis.
The amount of Na removed could not reasonably be calculated due to the realtively large amount of Na added as NaOH during leaching.
(b) No detectable removal.

Appendix C

Radionuclide Behavior

Appendix C: Radionuclide Behavior

Table C.1. Radionuclide Behavior During Leaching of T-110 Solids at 60°C[a]

Leaching With 1 M NaOH at 60°

	Leaching Solution		***Washing Solution***		***Leached Solids***					
	Solution Mass, g:	42.308	Solution Mass, g:	91.767	Solids Mass, g:	1.363				
	Conc., µCi/g	Activity, µCi	Conc., µCi/g	Activity, µCi	Conc., µCi/g	Activity, µCi	Total Activity, µCi	Removed, %	Calc. Conc. In Washed Solids, µCi/g	Measured Conc. In Washed Solids, µCi/g
Cs-137	7.57E-03	3.20E-01	4.60E-03	4.22E-01	9.69E-02	1.32E-01	8.74E-01	85%	3.50E-01	1.55E-01
Am-241(γ)					7.38E-02	1.01E-01	1.01E-01	(b)	4.03E-02	3.83E-02
Pu-239/240	1.00E-06	4.24E-05			1.08E+00	1.47E+00	1.47E+00	0.003%	5.89E-01	6.73E-01
Am-241+Pu-238	2.23E-07	9.42E-06			7.52E-02	1.03E-01	1.03E-01	0.01%	4.11E-02	4.49E-02
Cm-243/244					3.86E-03	5.26E-03	5.26E-03	(b)	2.11E-03	1.40E-03
Total Alpha	1.23E-06	5.19E-05			1.16E+00	1.58E+00	1.58E+00	0.003%	6.33E-01	7.19E-01

Leaching With 3 M NaOH at 60°

	Leaching Solution		***Washing Solution***		***Leached Solids***					
	Solution Mass, g:	44.928	Solution Mass, g:	92.944	Solids Mass, g:	1.22				
	Conc., µCi/g	Activity, µCi	Conc., µCi/g	Activity, µCi	Conc., µCi/g	Activity, µCi	Total Activity, µCi	Removed, %	Calc. Conc. In Washed Solids, µCi/g	Measured Conc. In Washed Solids, µCi/g
Cs-137	7.61E-03	3.42E-01	8.18E-04	7.60E-02	1.20E-01	1.46E-01	5.64E-01	74%	2.26E-01	1.55E-01
Am-241(γ)					8.06E-02	9.83E-02	9.83E-02	(b)	3.94E-02	3.83E-02
Pu-239/240	1.98E-05	8.89E-04	6.76E-07	6.28E-05	1.27E+00	1.55E+00	1.55E+00	0.1%	6.20E-01	6.73E-01
Am-241+Pu-238					8.87E-02	1.08E-01	1.08E-01	(b)	4.33E-02	4.49E-02
Cm-243/244					5.80E-03	7.08E-03	7.08E-03	(b)	2.83E-03	1.40E-03
Total Alpha	1.98E-05	8.89E-04	6.76E-07	6.28E-05	1.36E+00	1.66E+00	1.66E+00	0.1%	6.64E-01	7.19E-01

Leaching With 5 M NaOH at 60°

	Leaching Solution		***Washing Solution***		***Leached Solids***					
	Solution Mass, g:	53.042	Solution Mass, g:	91.265	Solids Mass, g:	1.173				
	Conc., µCi/g	Activity, µCi	Conc., µCi/g	Activity, µCi	Conc., µCi/g	Activity, µCi	Total Activity, µCi	Removed, %	Calc. Conc. In Washed Solids, µCi/g	Measured Conc. In Washed Solids, µCi/g
Cs-137	6.59E-03	3.49E-01	6.02E-04	5.50E-02	1.08E-01	1.27E-01	5.31E-01	76%	2.13E-01	1.55E-01
Am-241(γ)					9.42E-02	1.10E-01	1.10E-01	(b)	4.42E-02	3.83E-02
Pu-239/240	2.93E-04	1.56E-02	1.13E-06	1.03E-04	1.35E+00	1.58E+00	1.60E+00	1%	6.40E-01	6.73E-01
Am-241+Pu-238	2.09E-06	1.11E-04			1.01E-01	1.18E-01	1.19E-01	0.1%	4.74E-02	4.49E-02
Cm-243/244					6.60E-03	7.74E-03	7.74E-03	(b)	3.10E-03	1.40E-03
Total Alpha	2.96E-04	1.57E-02	1.13E-06	1.03E-04	1.46E+00	1.71E+00	1.73E+00	1%	6.92E-01	7.19E-01

(a) Analyte was below detection limit if left blank.
(b) No detectable removal.

Table C.2. Radionuclide Behavior During Leaching of T-110 Solids at 80°C[(a)]

Leaching With 1 M NaOH at 80°

	Leaching Solution		*Washing Solution*		*Leached Solids*					
	Solution Mass, g:	39.411	Solution Mass, g:	93.806	Solids Mass, g:	1.359				
	Conc., µCi/g	Activity, µCi	Conc., µCi/g	Activity, µCi	Conc., µCi/g	Activity, µCi	Total Activity, µCi	Removed, %	Calc. Conc. In Washed Solids, µCi/g	Measured Conc. In Washed Solids, µCi/g
Cs-137	9.20E-03	3.63E-01	9.31E-04	8.73E-02	1.28E-01	1.74E-01	6.24E-01	72%	2.49E-01	1.55E-01
Am-241(γ)					8.32E-02	1.13E-01	1.13E-01	(b)	4.51E-02	3.83E-02
Pu-239/240	6.64E-07	2.62E-05			1.25E+00	1.70E+00	1.70E+00	0.002%	6.77E-01	6.73E-01
Am-241+Pu-238					9.50E-02	1.29E-01	1.29E-01	(b)	5.15E-02	4.49E-02
Cm-243/244					6.89E-03	9.36E-03	9.36E-03	(b)	3.73E-03	1.40E-03
Total Alpha	6.64E-07	2.62E-05			1.35E+00	1.83E+00	1.83E+00	0.001%	7.31E-01	7.19E-01

Leaching With 3 M NaOH at 80°

	Leaching Solution		*Washing Solution*		*Leached Solids*					
	Solution Mass, g:	41.241	Solution Mass, g:	93.06	Solids Mass, g:	1.204				
	Conc., µCi/g	Activity, µCi	Conc., µCi/g	Activity, µCi	Conc., µCi/g	Activity, µCi	Total Activity, µCi	Removed, %	Calc. Conc. In Washed Solids, µCi/g	Measured Conc. In Washed Solids, µCi/g
Cs-137	7.91E-03	3.26E-01	6.55E-04	6.09E-02	1.49E-01	1.79E-01	5.66E-01	68%	2.25E-01	1.55E-01
Am-241(γ)					7.67E-02	9.23E-02	9.23E-02	(b)	3.67E-02	3.83E-02
Pu-239/240	6.05E-05	2.49E-03			1.25E+00	1.50E+00	1.51E+00	0.2%	5.99E-01	6.73E-01
Am-241+Pu-238	9.75E-07	4.02E-05			9.50E-02	1.14E-01	1.14E-01	0.04%	4.55E-02	4.49E-02
Cm-243/244					6.89E-03	8.30E-03	8.30E-03	(b)	3.30E-03	1.40E-03
Total Alpha	6.16E-05	2.54E-03			1.35E+00	1.62E+00	1.63E+00	0.2%	6.47E-01	7.19E-01

Leaching With 5 M NaOH at 80°

	Leaching Solution		*Washing Solution*		*Leached Solids*					
	Solution Mass, g:	45.888	Solution Mass, g:	91.593	Solids Mass, g:	1.053				
	Conc., µCi/g	Activity, µCi	Conc., µCi/g	Activity, µCi	Conc., µCi/g	Activity, µCi	Total Activity, µCi	Removed, %	Calc. Conc. In Washed Solids, µCi/g	Measured Conc. In Washed Solids, µCi/g
Cs-137	7.58E-03	3.48E-01	8.28E-04	7.58E-02	8.57E-02	9.02E-02	5.14E-01	82%	2.04E-01	1.55E-01
Am-241(γ)					9.06E-02	9.54E-02	9.54E-02	(b)	3.79E-02	3.83E-02
Pu-239/240	3.64E-03	1.67E-01	3.95E-05	3.62E-03	1.26E+00	1.33E+00	1.50E+00	11%	5.95E-01	6.73E-01
Am-241+Pu-238	3.38E-05	1.55E-03	3.35E-06	3.07E-04	1.04E-01	1.09E-01	1.11E-01	2%	4.43E-02	4.49E-02
Cm-243/244					4.76E-03	5.01E-03	5.01E-03	(b)	1.99E-03	1.40E-03
Total Alpha	3.66E-03	1.68E-01	4.28E-05	3.92E-03	1.37E+00	1.44E+00	1.61E+00	11%	6.42E-01	7.19E-01

(a) Analyte was below detection limit if left blank.

(b) No detectable removal.

Table C.3. Radionuclide Behavior During Leaching of T-110 Solids at 100°C[(a)]

Leaching With 1 M NaOH at 100°

	Leaching Solution		*Washing Solution*		*Leached Solids*					
	Solution Mass, g:	44.622	Solution Mass, g:	91.634	Solids Mass, g:	1.324				
	Conc., µCi/g	Activity, µCi	Conc., µCi/g	Activity, µCi	Conc., µCi/g	Activity, µCi	Total Activity, µCi	Removed, %	Calc. Conc. In Washed Solids, µCi/g	Measured Conc. In Washed Solids, µCi/g
Cs-137	7.20E-03	3.21E-01	9.67E-04	8.86E-02	1.10E-01	1.45E-01	5.55E-01	74%	2.22E-01	1.55E-01
Am-241(γ)					6.43E-02	8.51E-02	8.51E-02	(b)	3.40E-02	3.83E-02
Pu-239/240	5.45E-07	2.43E-05	3.90E-06	3.58E-04	1.12E+00	1.48E+00	1.48E+00	0.03%	5.91E-01	6.73E-01
Am-241+Pu-238					7.87E-02	1.04E-01	1.04E-01	(b)	4.16E-02	4.49E-02
Cm-243/244					4.26E-03	5.64E-03	5.64E-03	(b)	2.25E-03	1.40E-03
Total Alpha	5.45E-07	2.43E-05	3.90E-06	3.58E-04	1.20E+00	1.59E+00	1.59E+00	0.02%	6.34E-01	7.19E-01

Leaching With 3 M NaOH at 100°

	Leaching Solution		*Washing Solution*		*Leached Solids*					
	Solution Mass, g:	49.644	Solution Mass, g:	91.192	Solids Mass, g:	1.14				
	Conc., µCi/g	Activity, µCi	Conc., µCi/g	Activity, µCi	Conc., µCi/g	Activity, µCi	Total Activity, µCi	Removed, %	Calc. Conc. In Washed Solids, µCi/g	Measured Conc. In Washed Solids, µCi/g
Cs-137	7.35E-03	3.65E-01	4.83E-04	4.40E-02	1.40E-01	1.59E-01	5.68E-01	72%	2.27E-01	1.55E-01
Am-241(γ)					8.51E-02	9.70E-02	9.70E-02	(b)	3.87E-02	3.83E-02
Pu-239/240	5.34E-04	2.65E-02			1.35E+00	1.54E+00	1.56E+00	2%	6.24E-01	6.73E-01
Am-241+Pu-238	4.97E-06	2.47E-04			9.71E-02	1.11E-01	1.11E-01	0.2%	4.43E-02	4.49E-02
Cm-243/244					6.77E-03	7.72E-03	7.72E-03	(b)	3.08E-03	1.40E-03
Total Alpha	5.43E-04	2.69E-02			1.45E+00	1.65E+00	1.68E+00	2%	6.70E-01	7.19E-01

Leaching With 5 M NaOH at 100°

	Leaching Solution		*Washing Solution*		*Leached Solids*					
	Solution Mass, g:	50.598	Solution Mass, g:	90.594	Solids Mass, g:	1.162				
	Conc., µCi/g	Activity, µCi	Conc., µCi/g	Activity, µCi	Conc., µCi/g	Activity, µCi	Total Activity, µCi	Removed, %	Calc. Conc. In Washed Solids, µCi/g	Measured Conc. In Washed Solids, µCi/g
Cs-137	9.66E-03	4.89E-01	6.55E-04	5.94E-02	5.76E-02	6.69E-02	6.15E-01	89%	2.44E-01	1.55E-01
Am-241(γ)					8.64E-02	1.00E-01	1.00E-01	(b)	3.99E-02	3.83E-02
Pu-239/240	4.61E-03	2.33E-01	1.66E-05	1.50E-03	1.20E+00	1.39E+00	1.63E+00	14%	6.48E-01	6.73E-01
Am-241+Pu-238	6.51E-05	3.30E-03			1.02E-01	1.18E-01	1.22E-01	3%	4.84E-02	4.49E-02
Cm-243/244					6.82E-03	7.92E-03	7.92E-03	(b)	3.15E-03	1.40E-03
Total Alpha	4.69E-03	2.37E-01	1.66E-05	1.50E-03	1.31E+00	1.52E+00	1.76E+00	14%	7.00E-01	7.19E-01

(a) Analyte was below detection limit if left blank.
(b) No detectable removal.

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