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Washing and Caustic Leaching of Hanford Tank C-106 Sludge

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Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

PNNL-11381

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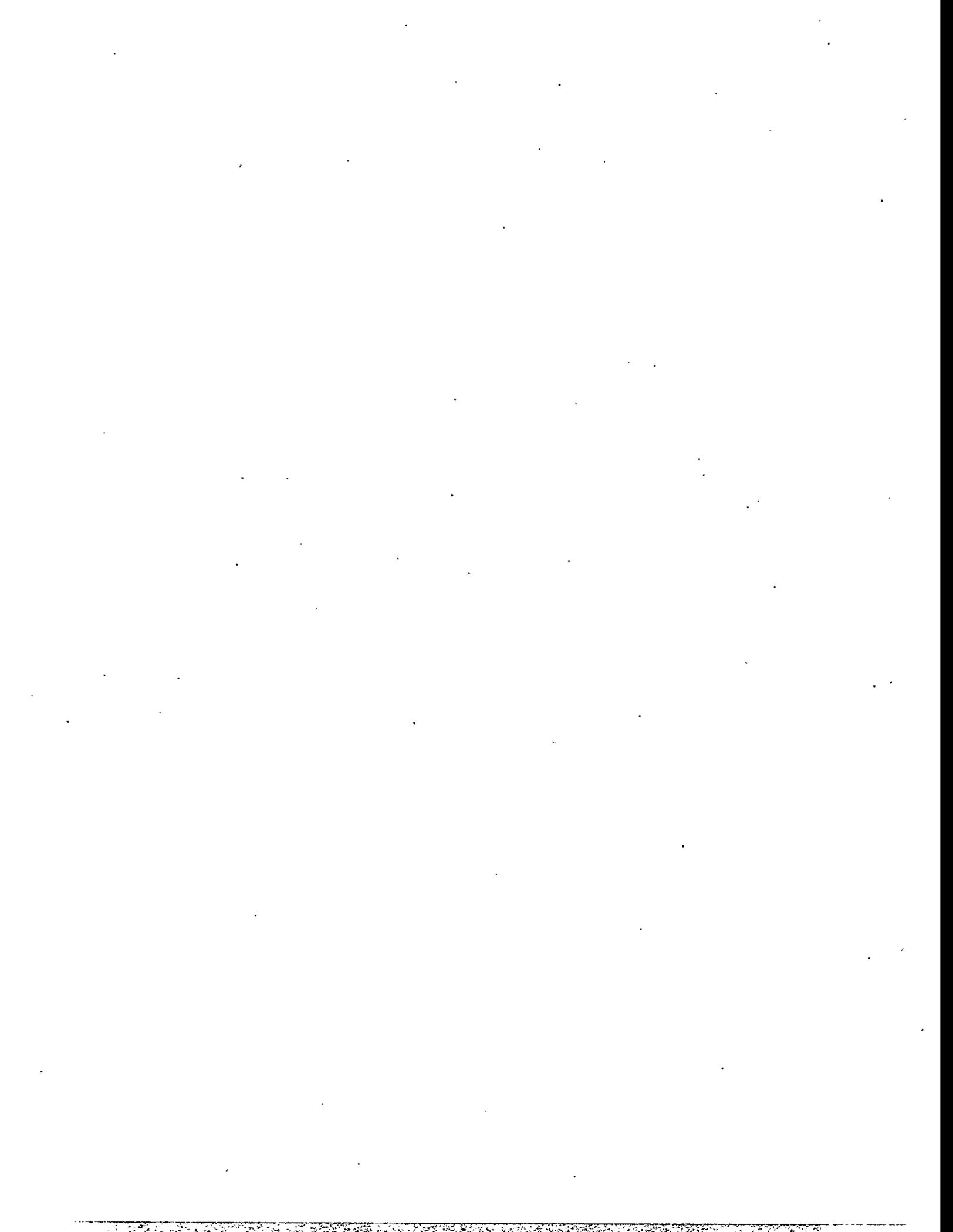
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Richland, Washington 99352



Summary

This report describes the results of a laboratory-scale washing and caustic leaching test performed on sludge from Hanford Tank C-106. The purpose of this test was to determine the behavior of important sludge components when subjected to washing with dilute or concentrated sodium hydroxide solutions. The results of this laboratory-scale test were used to support the design of a bench-scale washing and leaching process used to prepare several hundred grams of high-level waste solids for vitrification tests to be done by private contractors. The laboratory-scale test was conducted at Pacific Northwest National Laboratory in FY 1996 as part of the Hanford privatization effort. The work was funded by the U.S. Department of Energy through the Tank Waste Remediation System (TWRS; EM-30). The results of this work can be summarized as follows.

- The major components of the C-106 sludge were Na (23 wt%), Fe (7.6 wt%), Al (4.8 wt%), Si (3.8 wt%), Ca (0.26 wt%), Pb (0.22 wt%), P (0.21 wt%), Mn (0.19 wt%), and U (0.17 wt%). Of these, the only elements showing appreciable solubility in 0.01 M NaOH were Al (24% dissolved), Ca (5% dissolved), Na (82% dissolved), P (66% dissolved), and U (91% dissolved). Leaching with 3 M NaOH at 100°C improved Al removal to 47%, and 9% of the Si dissolved in caustic. In contrast, caustic leaching had little effect on the other major sludge components.
- A considerable fraction (18%) of the Na in the C-106 sludge appears to be resistant to removal by either dilute hydroxide washing or caustic leaching. It is hypothesized that this fraction of Na is present as sodium aluminosilicate minerals.
- The transuranic elements showed no tendency to dissolve in either the 0.01 M NaOH wash or the 3 M NaOH leach, but a small amount of alpha activity was detected in the 3 M NaOH leach. Cesium-137 was the predominant radioactive isotope in the wash and leach solutions.
- The settling behavior of the C-106 sludge solids was favorable. The settling was slower during the caustic leaching steps compared to the washing steps; this was likely because of the higher viscosity of the leaching solutions.
- Particle-size analysis indicated the mean particle size decreased from 10.6 μm before treatment to 5.6 μm after treatment (based on the particle volume distribution). Before treatment, particles of up to 75 μm were observed, whereas after treatment particles observed were 35 μm .
- Microscopy investigations of the C-106 solids indicated FeOOH to be the predominate species present after caustic leaching. Amorphous aluminum hydroxide appeared to be removed by caustic leaching, while aluminosilicate material was not removed. These observations were consistent with the results of the chemical analyses.
- With the exception of Sn, all of the sludge components were present in quantities below the Envelope D specifications (specifications set forth in the Hanford privatization request for proposals) for both the washed and leached material. Tin was slightly over the Envelope D specification for the leached solids, but high detection limits for this element did not allow for a determination of whether the simple washed solids were within the specification. For the washed material, Al, Fe, Na, and Si were all within 50% of

the Envelope D limits. Caustic leaching moved Al and Na somewhat farther from the limit, but Fe and Si became slightly more concentrated.

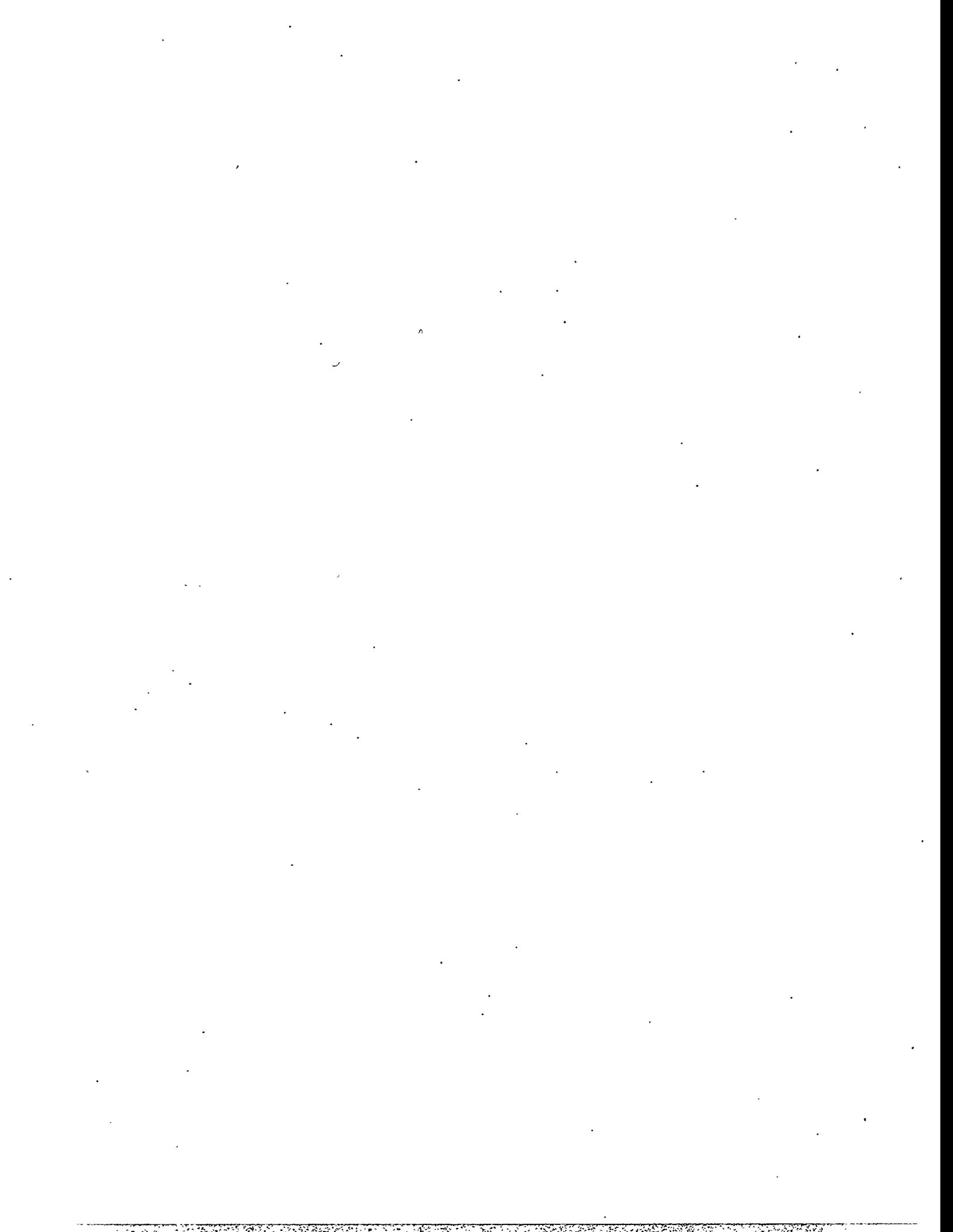
- Comparison of the C-106 results to previous results for C-103 sludge (which is considered to be the same waste type as C-106) indicated excellent agreement. The Al content of the C-103 sludge was about 3-fold higher than for the C-106 sludge, but the Al removal efficiencies were nearly identical (~48%). The C-103 sludge had slightly more P than the C-106 sludge, but the fraction removed by caustic leaching was nearly identical (~67%). More variability was seen for Cr removal—11% removed from C-103 and 32% removed from C-106. Also, the Cr content of the C-103 sludge was slightly higher than the C-106 sludge.

Acknowledgments

The authors gratefully acknowledge the technical assistance of the Analytical Chemistry Laboratory personnel especially M. W. Urie and L. R. Greenwood. We also thank J. Liu and Y.L. Chen for performing the microscopy examinations, and W. C. Cosby, B. M. Rapko, and T. L. Almeida for reviewing this document.

This work was supported by the U.S. Department of Energy, through the Tank Waste Remediation System (TWRS; EM-30). The authors thank the following individuals from the TWRS organization: N. R. Brown, R. A. Gilbert, R. Carreon, R. A. Kirkbride, G. T. MacLean, and R. M. Orme. The authors thank K. J. Kuhl-Klinger for project management support.

Pacific Northwest National Laboratory is operated for the U.S. Department of Energy by Battelle under Contract DE-AC06-76RLO 1830.



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1.0 Introduction

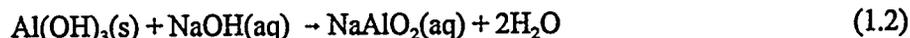
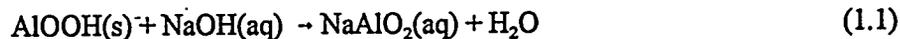
During the past few years, the primary mission at the U.S. Department of Energy's (DOE's) Hanford Site has changed from producing plutonium to restoring the environment. Large volumes of high-level radioactive wastes (HLW), generated during past Pu production and other operations, are stored in underground tanks on site. The current plan for remediating the Hanford tank farms consists of waste retrieval, pretreatment, treatment (immobilization), and disposal. The HLW will be immobilized in a borosilicate glass matrix; the resulting glass canisters will then be disposed of in a geologic repository. Because of the expected high cost of HLW vitrification and geologic disposal, pretreatment processes will be implemented to reduce the volume of borosilicate glass produced in disposing of the tank wastes.

The baseline sludge pretreatment flowsheet involves retrieving the sludge by sluicing and pumping with inhibited water (0.01 M NaOH/0.01 M NaNO₂), leaching the sludge with hot caustic (3 M NaOH), then washing the sludge with inhibited water to remove the added NaOH and the components dissolved during the caustic leaching step. The retrieval, leachate, and wash solutions will be combined and processed to remove ¹³⁷Cs (and possibly other radionuclides). The decontaminated solution will then be routed to the low-level waste (LLW) stream, where it will be immobilized in a glass matrix. The leached solids, which will contain a large fraction of the transuranic (TRU) elements and ⁹⁰Sr, will be immobilized in a glass matrix for deep geologic disposal along with the radionuclides removed from the wash and leach solutions (Orme 1995).

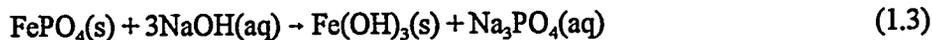
Recently, DOE has been considering "privatizing" certain aspects of the Hanford tank waste remediation effort. The technical baseline for privatization has recently been described by Orme et al. (1996). The privatization effort is to take place in two phases. Phase 1 will serve to demonstrate the privatization concept. In Phase 1, two private contractors will process a relatively small amount of tank liquid into a LLW glass form. Also, one of the contractors might process some HLW sludge into borosilicate glass. In Phase 2 of the privatization effort, one contractor will be charged with processing the remaining Hanford tank wastes into both LLW and HLW forms. Under the current technical baseline, the sludge solids from Tank C-106 are scheduled to be processed in Phase 1 (if HLW immobilization is included in Phase 1).

In support of the Phase 1 privatization effort, the Pacific Northwest National Laboratory (PNNL) has undertaken an effort to provide both Phase 1 contractors with a sample (~100 g) of Tank C-106 sludge solids for vitrification testing. Ideally, these solids would meet the "Envelope D" specifications set forth in the Hanford privatization request for proposals (DOE-RL 1996). To determine if washing with dilute hydroxide solution or a combination of caustic leaching and dilute hydroxide washing would yield solids within the Envelope D specifications, a laboratory-scale (~15 g) screening study was performed on the C-106 sludge solids. The results of this test were then used as a basis for scaling-up the process to get enough material to supply to the private contractors. This report summarizes the results of the laboratory-scale screening test; a description of the larger bench-scale preparation will be reported separately.

The key process in the baseline sludge pretreatment flowsheet is leaching the sludge with caustic. 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).

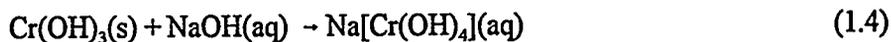


A significant portion of the P is also expected to be removed from the sludge by metathesis of water-insoluble metal phosphates to insoluble hydroxides and soluble Na_3PO_4 . An example of this is shown for iron(III) phosphate in the following equation.



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

Caustic leaching of Hanford tank sludges has resulted in enhanced Cr dissolution when compared to simply washing the sludges with dilute hydroxide solution. This might be caused by the increased solubility of Cr(III) at high hydroxide concentrations (Rai, Sass, and Moore 1987). The increased solubility of Cr(III) at high hydroxide concentration is due to the formation of the tetrahydroxochromium(III) anion.



However, recent studies conducted in our laboratory have suggested the behavior of Cr in the caustic leaching process to be more complex. In particular, the Cr dissolved during caustic leaching of actual tank wastes is invariably present as Cr(VI), suggesting the caustic leaching mixture is somewhat oxidizing. Also, studies of the behavior of Cr(III) in 3 M NaOH have indicated that Cr(III) forms stable solutions at room temperature, but the Cr(III) tends to precipitate when the alkaline solution is heated.

Results of previous studies of the baseline Hanford sludge washing and caustic leaching process have been reported (Lumetta and Rapko 1994; Rapko, Lumetta, and Wagner 1995, Lumetta et al. 1996, Temer and Villareal 1995, 1996).

2.0 Experimental

The materials and methods used in the C-106 sludge washing and caustic leaching screening tests are discussed in this section.

2.1 Materials

The C-106 sludge material used in this study was obtained from Westinghouse Hanford Company (WHC) in late June 1996. The 17 samples delivered to PNNL were "grab" samples rather than core samples; thus, the material used in this study represents only the very top portion of the sludge. Each individual sample was homogenized with a high speed mixer using an ice bath to control the temperature of the samples during homogenization. Twelve of the 17 homogenized samples were transferred to a 2-L carboy until the carboy was approximately giving a 1.5-L batch of material. This batch was homogenized by stirring for approximately 15 minutes with a mechanical stirring motor and a Teflon® stirring rod. Approximately 750 mL of the composite material were transferred to a 1-L jar, and the remaining five homogenized samples were transferred to the carboy where they were composited by the same procedure as the previous samples. In order to prepare a homogeneous composite, a series of cuts were made between the 1-L jar and the 2-L carboy with stirring between each cut. The entire composite sample was then split between the 1-L jar and 2-L carboy. A 15-g aliquot of the composited sludge was taken for the lab-scale sludge washing and caustic leaching test.

Leach and wash solutions were prepared using reagent grade NaOH and NaNO₂. The concentrations of the NaOH solutions were confirmed by titration with standard HCl.

2.2 Testing Procedure

A standard sludge washing and caustic leaching procedure was used for the C-106 screening test; this standard procedure has been described elsewhere (Lumetta et al. 1996). The only deviation from the standard testing method was that the washing or leaching mixtures were not centrifuged before decanting the liquid (a suitable centrifuge was not available in the hot cell for this task). Thus, solutions were decanted following gravity settling. Figure 2.1 provides the details of the C-106 test in schematic form.

2.3 Analytical Methods

Portions of the C-106 sludge were analyzed before and after the sludge washing/caustic leaching treatment. The solid samples were solubilized for analysis by KOH and sodium peroxide fusion methods.^(a) The sodium peroxide fusion allowed for the determination of K and Ni, and also gave a duplicate analytical result for other sludge components. The mean values are reported for those components determined through both fusion methods. The dilute hydroxide wash (B2), the first (E) and second (F) caustic leach, and the final wash (G) solutions were also analyzed. The major metallic elements (Al, Bi, Cr, Fe, Na, etc.) as well as P and Si were determined by inductively coupled plasma/atomic emission spectroscopy

(a) Methods used were from the *Analytical Chemistry Laboratory (ACL) Procedure Compendium*. PNL-MA-599. Analytical Chemistry Laboratory Department. Pacific Northwest National Laboratory, Richland, Washington.

(ICP/AES). Anions were determined by ion chromatography. Alpha spectroscopy was used to determine the TRU elements, and gamma spectroscopy was used to measure the gamma-emitting radionuclides. Uranium concentrations were determined by laser fluorimetry. A proportional beta counter was used to determine ^{90}Sr and ^{99}Tc after chemical separation of these isotopes from the other radionuclides. Established procedures were used for all these analyses.^(a)

Particle-size measurements were made using a Microtrac[®] X100 particle-size analyzer (Leeds & Northrup, North Wales, Pennsylvania) with the particles being slurried in water for the measurement.

Free hydroxide concentrations in the caustic leach solutions were determined by titration with standard HCl, as described previously (Rapko, Lumetta, and Wagner 1995).

The transmission electron microscopy (TEM) samples were prepared by dispersing a drop of the solids slurry on TEM copper grids covered with carbon films. This work was performed on a JEOL 1200 analytical TEM operating at 120 kV. The analyses proceeded as follows: 1) the morphology, distribution, and sizes of particles were evaluated by electron imaging, 2) the chemical compositions of the particles were identified by electron dispersive X-ray spectroscopy (EDS), 3) the crystal structures of the particles were studied by electron diffraction, and 4) the diffraction patterns were compared with the JCPDS-EDD Data Base published by the International Center for Diffraction Data.

(a) Methods used were from the *Analytical Chemistry Laboratory (ACL) Procedure Compendium*. PNL-MA-599. Analytical Chemistry Laboratory Department. Pacific Northwest National Laboratory, Richland, Washington.

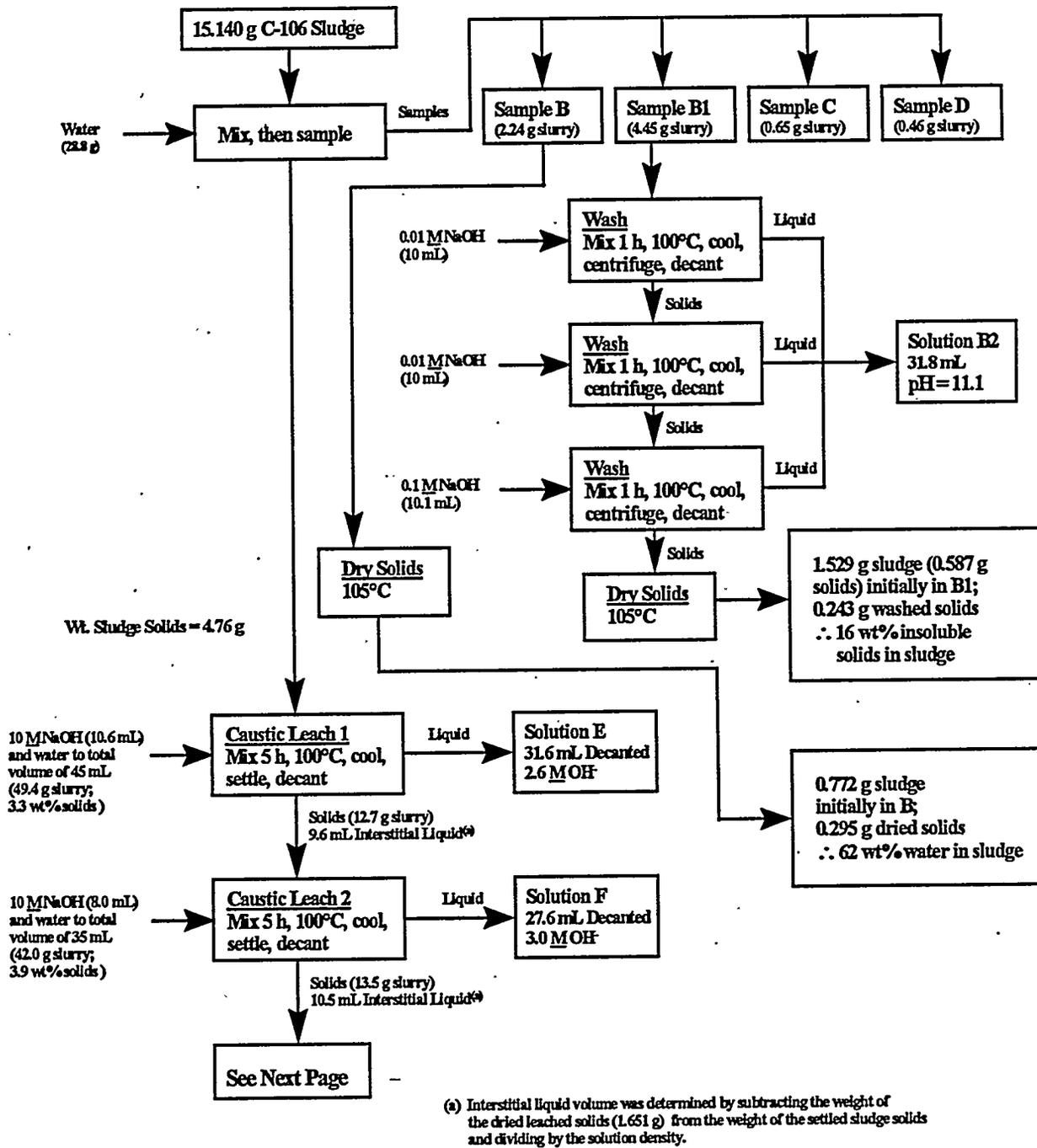
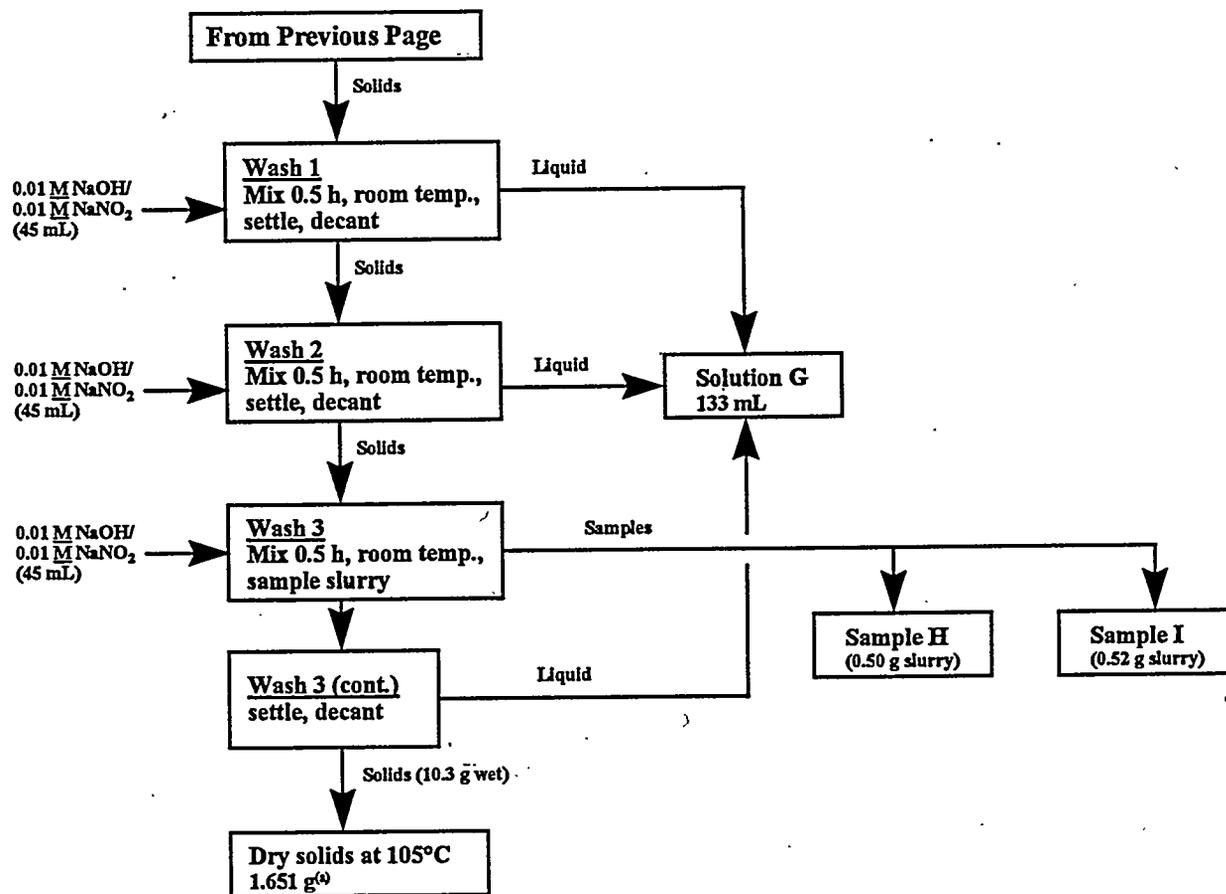


Figure 2.1. Schematic of C-106 Sludge Washing and Caustic Leaching Test



(a) Final weight of dried solids was adjusted for that removed in samples H and I.

C106-LPPT

Figure 2.1. (contd)

3.0 Results

Data obtained from the C-106 sludge washing and caustic leaching screening test are presented in this section.

3.1 Simple Sludge Washing with 0.01 M NaOH

Tables 3.1 and 3.2 show the results of the simple washing portion of the C-106 experiment (washing of portion B1). Analysis of the untreated sludge solids (portion B) by ICP/AES revealed the following major components of the sludge: Na (23 wt%), Fe (7.6 wt%), Al (4.8 wt%), Si (3.8 wt%), Ca (0.26 wt%), Pb (0.22 wt%), P (0.21 wt%), Mn (0.19 wt%), and U (0.17 wt%). For Na, Fe, Al, and Si, the mass recoveries during the simple washing portion of the test were within 5%. For the other nonradioactive components, the mass recoveries were lower, probably due to greater uncertainties in analyzing for these less abundant components.

A significant fraction of the Na (18%) remained in the sludge solids after washing with dilute hydroxide solution, indicating that this fraction of the Na is present in chemical forms that are not water-soluble, such as sodium aluminosilicates. This hypothesis is supported by the fact that little Al (24% removal) or Si (0% removal) were removed during the simple washing process. Little Cr (2%) was removed by simple washing, but the Cr content of this waste was not particularly high (0.06 wt%). Although mostly removed, a large fraction (34%) of the P remained in the washed solids. As expected, Fe is insoluble under the conditions of the dilute hydroxide wash. The behavior of anionic components will be discussed in Section 3.2, as they relate to the caustic leaching results.

Table 3.2 summarizes the behavior of the radionuclides during simple washing of C-106 sludge. Washing removed ^{137}Cs and ^{99}Tc appreciably, but none of the other radionuclides. Unfortunately, the ^{99}Tc detection limit for the analysis of the washed solids was somewhat high; thus, it could only be concluded that > 32% of the Tc dissolved.

3.2 Caustic Leaching

Tables 3.3 through 3.9 summarize the results of the C-106 caustic leaching test. Table 3.3 shows the concentrations for the nonradioactive waste components in each process stream and the mass of each component dissolved in each process step. Mass recoveries (Table 3.4) for most of the important sludge constituents (Na, Fe, Al, Si, Ca, and Pb) were within 20%. Mass recoveries for P and U were somewhat high, while that for Mn was somewhat low.

Table 3.5 shows the concentrations of the anionic components in the various process solutions. As expected, significant amounts of NO_3^- , NO_2^- , and PO_4^{3-} were detected in solution, although the amount of soluble NO_3^- was considerably less than that generally seen for Hanford tank wastes. Additionally, a fair amount of SO_4^{2-} was detected. The amount of SO_4^{2-} found in the first caustic leach solution was approximately (within 13%) the same as that found in the simple wash solution when normalized to the initial amount of sludge solids used. Thus, caustic leaching removed little or no additional SO_4^{2-} . The total extent of SO_4^{2-} removal could not be determined because the sludge solids were not analyzed for this component.

The data in Table 3.6 indicate a significant increase in the amount of Al removed by caustic leaching compared to dilute NaOH washing, but the overall Al removal (47%) was still poor. The amount of Cr

removed was also improved by caustic leaching, with a total of 32% removed by caustic leaching compared to 2% by simple washing. The amounts of Al and Cr dissolved in the first leaching step were greater than in the second leaching step. Given the much lower concentrations of Al and Cr in the second leach solution compared to the first, it is unlikely that solubility limited the removal of these components. No significant improvement in P removal was seen in performing the caustic leach compared to simple washing.

Of special note, a significant amount of Na remained in the treated solids. The amount of Na in the leached solids was 39% of that originally in the sludge solids. Only ~6% of the Na in the treated solids could be attributed to Na in the interstitial liquid before drying the residue; thus, apparently one or more insoluble Na-containing species were present after leaching. As discussed in Section 3.1, simple washing removed 82% of the Na from the C-106 sludge, which is about 20% more than in the caustic leaching test. It is not clear whether this is due to analytical uncertainty or to an actual chemical effect (such as formation of sodium aluminosilicates) during caustic leaching.

Tables 3.7 through 3.9 summarize the radionuclide behavior during the caustic leaching test. Good mass recoveries (Table 3.8) were obtained for most of the radionuclides; the exceptions were ^{241}Am as determined by gamma spectroscopy and ^{154}Eu . For the latter two radionuclides, the mass recoveries were somewhat high. As was observed with the simple washing case, ^{137}Cs and ^{99}Tc were the only radioactive materials significantly solubilized during the caustic leaching test. The amount (40%) of ^{137}Cs remaining in the solids after leaching is unusual. As the solids are to be handled as HLW, the retention of ^{137}Cs in the solid phase is a desirable feature. The dissolution of ^{99}Tc is consistent with this element being present in a soluble form, such as pertechnetate.

3.3 Settling and Particle-Size Data

Table 3.10 and Figures 3.1 and 3.2 present the settling data from the two caustic leaching steps and the final three washing steps. Generally, the solids settled at reasonable rates. Comparison of the maximum observed settling velocities (v_{max}) indicated the settling was slower during the caustic leaching steps compared to the washing steps; this was likely due to the higher viscosity of the leaching solutions. The settling data were normalized according to a formula recommended by personnel at WHC.^(a) The normalized settling data (Figure 3.2) indicated that the settling behavior was very similar for the leaching steps and the three washing steps.

Particle-size data for the untreated and treated sludge solids are presented in Figures 3.3 and 3.4, respectively. In terms of the number distribution, the mean particle size changed very little upon treatment, going from 0.19 to 0.24 μm . However, based on the volume distribution, the mean particle size decreased from 10.6 μm before treatment to 5.6 μm after treatment.

(a) G. T. MacLean, Westinghouse Hanford Company, personal communication, 1996.

Table 3.1. Results of Tank C-106 Sludge Washing: Nonradioactive Components^(a)

Component	Wash Solution (B2)		Washed Solids (B1)		Total Mass, µg	Component Distribution, %		Concentration in Initial Solids µg/g		Recovery, %
	Conc., µg/mL	Mass, µg	Conc., µg/g	Mass, µg		Wash Solution	Washed Solids	Summation Method	Direct Analysis ^(b)	
Ag	0.14	4	1260	306	311	1	99	5.29E+02	9.10E+02	58
Al	205	6519	86400	20995	27514	24	76	4.69E+04	4.85E+04	97
Ba	<0.05	<2	580	141	<143, >141	<1	>99	<243, >240	2.63E+02	-92
Bi	<0.53	<17	<235	<57	<61	--	--	<1.3E+02	<2.3E+02	--
Ca	1.6	51	3900	948	999	5	95	1.70E+03	2.58E+03	66 ^(c)
Cd	<0.08	<3	110	27	<30, >27	<9	>91	<50, >46	4.80E+01	>95
Ce	<0.53	<17	<705	<171	<188	--	--	<321	<675	--
Cr	0.18	6	1300	316	322	2	98	5.48E+02	6.06E+02	90
Fe	<0.26	<8	175700	42695	42695	0	100	7.27E+04	7.64E+04	95
K	16	509	<4685	<1138	<1647	>31	<69	<2.8E+03	9.00E+02	--
La	<0.26	<8	<150	<36	<45	--	--	<7.6E+01	<1.2E+02	--
Mg	<0.53	<17	858	208	<225	<7	>93	<384, >354	4.45E+02	<87, >79
Mn	<0.26	<8	4215	1024	<1033, >1024	<1	>99	<1760, >1744	1.89E+03	-93
Na	4495	113041 ^(d)	101700	24713	137754	82	18	2.35E+05	2.31E+05	102
Nd	<0.53	<17	465	113	<130, >113	<13	>87	<221, >192	3.00E+02	<74, >64
Ni	0.38	12	2140	520	532	2	98	9.06E+02	1.52E+03	60 ^(e)
P	21.3	677	1460	355	1032	66	34	1.76E+03	2.14E+03	82
Pb	<1.1	<35	4020	977	<1012, >977	<3	>97	<1720, >1664	2.15E+03	<80, >77
Si	<2.7	<86	86500	21020	21020	0	100	3.58E+04	3.78E+04	95
Sn	<11	<350	<4685	<1138	<1488	--	--	<2540	<4480	--
Sr	<0.08	<3	49	12	<15, >12	<20	>80	<25, >20	<3.5E+01	--
Th	<4.2	<134	<1875	<456	<482	--	--	<1000	<1800	--
Ti	<0.13	<4	640	156	<160, >156	<3	>97	<272, >265	2.90E+02	<94, >91
U	15	490	191	46	536	91	9	9.13E+02	1.72E+03	53
Zn	<0.26	<8	315	77	<85, >77	<10	>90	<144, >131	1.55E+02	<93, >84
Zr	<0.26	<8	3860	938	<946, >938	<1	>99	<1610, >1595	6.65E+02	-240

(a) Less-than values indicate the analyte was below the detection limit. In such cases, two conditions were considered: 1) the concentration of the analyte was zero, and 2) the concentration of the analyte was the detection limit. This yielded the ranges of values given in the total mass and concentration columns.

(b) Solids were prepared for analysis by both KOH and Na₂O₂ fusion methods; mean values are given for analytes that can be determined by both these methods. The exceptions to this were Ag and P. For Ag, the values obtained by the Na₂O₂ fusion method were consistently lower than those obtained by the KOH fusion, suggesting incomplete Ag dissolution in the Na₂O₂ fusion method. Thus, only the KOH fusion values were used for Ag. In the case of P, high values were obtained in the preparation blanks for the KOH fusions; for this reason, only the P values obtained from the Na₂O₂ fusion method were used.

(c) The calcium concentrations in the fusion-preparation blanks were quite high. Although the blank values were subtracted from the measured values for the samples, these high blank values contributed to the uncertainty associated with the Ca analysis.

(d) Value adjusted for the Na added as 0.01 M NaOH.

(e) Analysis of a laboratory control sample (SRM2710, NIST "Montana Soil") for the fusion preparations resulted in a high Ni value, indicating possible contamination in the control sample or a memory effect or carry-over of Ni from analysis of KOH fusion preparations. In any case, these effects might have also caused a higher Ni value for the untreated material, leading to a low mass balance.

Table 3.2. Results of Tank C-106 Sludge Washing: Radioactive Components^(a)

Component	Wash Solution (B2)		Washed Solids (B1)		Total Activity, μCi	Component Distribution, %		Concentration in Initial Solids, $\mu\text{Ci/g}$		Recovery, %
	Conc., $\mu\text{Ci/mL}$	Activity, μCi	Conc., $\mu\text{Ci/g}$	Activity, μCi		Wash	Washed Solids	Summation/Method	Direct Analysis	
Total Alpha	< 3.2E-04	< 1.0E-02	9.44E+00	2.29E+00	2.29E+00	0	100	3.91E+00	4.11E+00	95
^{239,240} Pu	< 3.2E-04	< 1.0E-02	4.83E+00	1.17E+00	1.17E+00	< 1	> 99	2.00E+00	2.24E+00	89
²⁴¹ Am + ²⁴³ Pu	< 3.2E-04	< 1.0E-02	4.52E+00	1.10E+00	1.10E+00	< 1	> 99	1.87E+00	1.87E+00	100
²⁴¹ Am(g)	< 4.2E-03	< 1.4E-01	4.56E+00	1.11E+00	< 1.24, > 1.11	< 11	> 89	< 2.12, > 1.89	1.34E+00	--
^{241,244} Cm	< 3.2E-04	< 1.0E-02	9.80E-02	2.38E-02	< 0.034, > 0.023	< 30	> 70	< 0.058, > 0.041	1.52E-02	--
¹³⁷ Cs	4.91E+00	1.56E+02	1.03E+03	2.50E+02	4.06E+02	38	62	6.92E+02	6.81E+02	102
⁶⁰ Co	2.55E-04	8.11E-03	6.12E-01	1.49E-01	1.49E-01	0	100	2.53E-01	3.08E-01	82
¹⁵⁴ Eu	< 3.2E-04	< 1.0E-02	4.48E+00	1.09E+00	1.09E+00	< 1	> 99	1.85E+00	1.76E+00	105
¹⁵³ Eu	< 4.2E-03	< 1.4E-01	3.43E+00	8.33E-01	< 0.97, > 0.83	< 14	> 86	< 1.65, > 1.42	1.28E+00	--
¹²⁵ Sb	< 7.4E-03	< 2.4E-01	1.68E+00	4.08E-01	< 0.65, > 0.40	< 37	> 63	< 1.10, > 0.69	9.04E-01	--
⁹⁰ Sr	< 2E-01	< 7E+00	9.01E+02	2.19E+02	< 225, > 219	< 3	> 97	~375	4.09E+02	~92
⁹⁹ Tc	1.06E-03	3.37E-02	< 3E-01	< 7.3E-02	< 0.11, > 0.03	> 32	< 68	< 0.18, > 0.05	< 3E-01	--

(a) Less-than values indicate the analyte was below the detection limit. In such cases, two conditions were considered: 1) the concentration of the analyte was zero, and 2) the concentration of the analyte was the detection limit. This yielded the ranges of values given in the total activity and concentration columns.

Table 3.3. Concentrations of the Nonradioactive C-106 Sludge Components in the Various Streams from the Caustic Leaching Process^(a)

Component	First Leach Solution (E)		Second Leach Solution (F)		Final Wash Solution (G)		Leached Solids (A)		Total Mass, μg
	Conc., $\mu\text{g/mL}$	Mass, $\mu\text{g}^{(b)}$	Conc., $\mu\text{g/mL}$	Mass, $\mu\text{g}^{(b)}$	Conc., $\mu\text{g/mL}$	Mass, $\mu\text{g}^{(b)}$	Conc., $\mu\text{g/g}^{(c)}$	Mass, $\mu\text{g}^{(b)}$	
Ag	<0.7	<29	<0.7	<27	0.4	53	630	1040	<1141, >1093
Al	2048	84378	845	12534	86.8	2672	69100	114084	213667
Ba	<0.3	<12	<0.3	<11	<0.01	<1	630	1040	<1065, >1040
Bi	<2.6	<107	<2.6	<99	<0.22	<29	286	472	<708, >472
Ca	<6.6	<272	<6.6	<251	0.95	126	6505	10740	<11320, >10866
Cd	<0.4	<16	<0.4	<15	<0.02	<3	125	206	<241, >206
Ce	<2.6	<107	<2.6	<99	<0.1	<13	828	1367	<1587, >1367
Cr	15.1	622	8.8	190	0.65	0	1046	1727	2539
Fe	2.3	95	3.8	123	0.07	0	187000	308737	308954
K	58	2390	<53	0	3.2	426	6710	11078	13893
La	<1.3	<54	<1.3	<50	<0.06	<8	229	378	<489, >378
Mg	<2.6	<107	<2.6	<99	<0.11	<15	1060	1750	<1971, >1750
Mn	<1.3	<54	<1.3	<50	<0.06	<8	4235	6992	<7103, >6992
Na	73500	3028200	71505	2018741	6963	175277	89700	148095	915212 ^(d)
Nd	<2.6	<107	<2.6	<99	<0.11	<15	668	1103	<1324, >1103
Ni	<0.8	<33	<0.8	<30	0.08	11	2020	3335	<3401, >3337
P	189	7787	69.2	822	8.8	444	2553	4215	13268
Pb	7.7	317	7.5	212	0.3	0	5107	8432	8961
Si	81	3337	260	9128	38.6	2404	87400	144297	159167
Sn	<26	<1071	<26	<911	<1	<133	4660	7694	<9888, >7694
Sr	<0.4	<16	<0.4	<15	<0.02	<3	65	107	<142, >107
Th	<21	<865	<21	<800	<0.9	<120	<1500	<2477	<4262
Ti	<0.7	<29	<0.7	<27	<0.03	<4	787	1299	<1359, >1299
U	234	9641	85	992	5.12	0	613	1012	11645
Zn	<1.3	<54	<1.3	<50	0.13	17	155	256	<376, >256
Zr	1.6	66	<1.3	0	<0.03	<4	6210	10253	10319

(a) Less-than values indicate the analyte was below the detection limit. In such cases, two conditions were considered: 1) the concentration of the analyte was zero, and 2) the concentration of the analyte was the detection limit. This yielded the ranges of values given in the total mass column.

(b) Mass values represent the mass of material dissolved in a given step; these values are corrected for interstitial solution carried over from the previous step.

(c) See footnote (b) in Table 3.1.

(d) Value adjusted for the Na added as NaOH.

**Table 3.4. Concentrations of the Nonradioactive C-106 Sludge
Components in the Initial Sludge Solids as Determined
in the Caustic Leaching Test^(a)**

Component	Concentration in Initial Solids, $\mu\text{g/g}$		Mass Recovery, %
	Summation Method ^(b)	Direct Analysis ^(c)	
Ag	< 240, > 230	9.10E+02	~26
Al	4.49E+04	4.85E+04	93
Ba	< 225, > 215	2.63E+02	~84
Bi	< 150, > 95	< 2.3E+02	--
Ca	< 2380, > 2280	2.58E+03	< 93, > 88
Cd	< 55, > 40	4.80E+01	> 83
Ce	< 335, > 285	< 6.8E+02	--
Cr	5.33E+02	6.06E+02	88
Fe	6.49E+04	7.64E+04	85
K	2.92E+03	9.00E+02	324
La	< 105, > 75	< 1.2E+02	--
Mg	< 415, > 365	4.45E+02	< 94, > 82
Mn	< 1495, > 1465	1.89E+03	< 80, > 77
Na	1.92E+05	2.31E+05	83
Nd	< 280, > 230	3.00E+02	< 94, > 76
Ni	< 715, > 700	1.52E+03	~47
P	2.79E+03	2.14E+03	130
Pb	1.88E+03	2.15E+03	88
Si	3.34E+04	3.78E+04	88
Sn	< 2080, > 1615	< 4.5E+03	--
Sr	< 30, > 20	< 3.5E+01	--
Th	< 900	< 1800	--
Ti	< 285, > 270	2.90E+02	< 99, > 93
U	2.45E+03	1.72E+03	142
Zn	< 80, > 50	1.55E+02	< 52, > 32
Zr	2.17E+03	6.65E+02	326

(a) Less-than values indicate the analyte was below the detection limit in one or more of the process streams. In such cases, two conditions were considered: 1) the concentration of the analyte was zero, and 2) the concentration of the analyte was the detection limit. This yielded the concentration ranges given here.

(b) Value determined by summing the amount of a given component in the caustic leaching solutions, the subsequent washing solutions, and the leached solids; the total concentration was then determined by dividing the sum by the amount of solids used.

(c) See footnote (b) in Table 3.1.

Table 3.5. Anion Concentrations in the Various C-106 Process Solutions

Component	Wash Solution (B2)		First Leach Solution (E)		Second Leach Solution (F)		Final Wash Solution (G)	
	Conc., $\mu\text{g/mL}$	Dissolved, $\mu\text{g/g}$ sludge solids ^(a)	Conc., $\mu\text{g/mL}$	Dissolved, $\mu\text{g/g}$ sludge solids ^(a)	Conc., $\mu\text{g/mL}$	Dissolved, $\mu\text{g/g}$ sludge solids ^(a)	Conc., $\mu\text{g/mL}$	Dissolved, $\mu\text{g/g}$ sludge solids ^(a)
OH ⁻	Not Determined	Not Determined	44,200	N/A ^(b)	51,000	N/A ^(b)	Not Determined	Not Determined
NO ₃ ⁻	32	1,734	200	1,731	160	877	18	150
NO ₂ ⁻	800	43,339	4,100	35,487	1300	2137	200	N/A ^(c)
PO ₄ ³⁻	42	2,275	470	4,068	180	493	12	0
SO ₄ ²⁻	187	10,130	1020	8,829	310	424	20	0
F ⁻	<250	<13,550	<250	<2,200	<250	<2,000	<2.5	<70
Cl ⁻	10	542	90	779	<12.5	<100	<2.5	<70
Br ⁻	<12.5	<670	<12.5	<110	<12.5	<100	<2.5	<70

(a) Amount of component dissolved in a given process step.

(b) Hydroxide added as NaOH.

(c) Nitrite was added in this step as part of the washing solution (0.01 M NaOH/0.01 M NaNO₂).

**Table 3.6. Distribution of Nonradioactive C-106 Sludge Components
Between the Various Streams in the Caustic Leaching Process**

Component	Component Distribution, % ^(a)			
	First Leach Solution (E)	Second Leach Solution (F)	Final Wash Solution (G)	Leached Solids
Ag	< 3	< 2	4	> 91
Al	39	6	1	53
Ba	< 1	< 1	0	> 98
Bi	< 15	< 14	< 4	> 67
Ca	< 2	< 2	< 1	> 95
Cd	< 7	< 6	< 1	> 86
Ce	< 7	< 6	< 1	> 86
Cr	24	7	0	68
Fc	0	0	0	100
K	17	0	3	80
La	< 11	< 10	< 2	> 77
Mg	< 5	< 5	< 1	> 89
Mn	< 1	< 1	0	> 98
Na	--	--	--	39 ^(b)
Nd	< 8	< 7	< 1	> 83
Ni	< 1	< 1	0	> 98
P	59	6	3	32
Pb	4	2	0	94
Si	2	6	2	91
Sn	< 11	< 10	< 1	> 78
Sr	< 12	< 11	< 2	> 76
Th	(c)	(c)	(c)	(c)
Ti	< 2	< 2	0	> 96
U	83	9	0	9
Zn	< 14	< 15	6	> 65
Zr	1	0	0	99

(a) Amounts reported are adjusted for carry over of interstitial liquid; that is, the values reported for the solutions represent the amount of material actually dissolved during that step.

(b) Amount of Na in residue determined by comparing the amount of Na in the untreated solid to that in the leached solid.

(c) Analyte was below detection limit for all process streams

Table 3.7. Concentrations of the Radioactive C-106 Sludge Components in the Various Streams from the Caustic Leaching Process^(a)

Component	First Leach Solution (E)		Second Leach Solution (F)		Final Wash Solution (G)		Leached Solids		Total Activity, μCi
	Conc., $\mu\text{Ci}/\text{mL}$	Activity, $\mu\text{Ci}^{(b)}$	Conc., $\mu\text{Ci}/\text{mL}$	Activity, $\mu\text{Ci}^{(b)}$	Conc., $\mu\text{Ci}/\text{mL}$	Activity, $\mu\text{Ci}^{(b)}$	Conc., $\mu\text{Ci}/\text{g}$	Activity, μCi	
Total Alpha	2.10E-03	8.65E-02	4.31E-03	1.44E-01	<0.011	<1.5	1.24E+01	2.05E+01	<22.1, >20.7
^{239,240} Pu	1.46E-03	6.02E-02	3.87E-03	1.33E-01	<0.011	<1.5	6.25E+00	1.03E+01	<11.9, >10.5
²⁴¹ Am+ ²⁴³ Pu	1.70E-04	7.00E-03	4.47E-04	1.54E-02	<0.011	<1.5	5.98E+00	9.87E+00	<11.4, >9.9
²⁴¹ Am(β)	<4.2E-02	<1.8E+00	<7.4E-03	<2.9E-01	<2.2E-03	<0.3	5.79E+00	9.56E+00	<11.9, >9.56
^{243,244} Cm	<5.3E-05	<2.2E-03	<4.2E-05	<1.6E-03	<0.011	<1.5	1.50E-01	2.48E-01	<1.71, >0.25
²⁴² Cm	<5.3E-05	<2.2E-03	<4.2E-05	<1.6E-03	<0.011	<1.5	2.13E-02	3.52E-02	<1.5, >0.035
¹³⁷ Cs	3.99E+01	1.64E+03	1.82E+01	3.10E+02	1.61E+00	2.30E+01	7.85E+02	1.30E+03	3.27E+03
⁶⁰ Co	<6E-04	<3E-02	<3E-04	<2E-02	4.44E-04	5.91E-02	7.67E-01	1.27E+00	<1.38, >1.33
¹⁵⁴ Eu	<2.1E-03	<8.7E-02	<8.4E-04	<3.2E-02	<7.7E-05	<1.1E-02	6.64E+00	1.10E+01	1.10E+01
¹⁵⁵ Eu	<4.2E-02	<1.8E+00	<7.4E-03	<2.9E-01	<2.2E-03	<3.0E-01	5.38E+00	8.88E+00	<11.2, >8.8
¹²⁵ Sb	<5.3E-02	<2.2E+00	<2.1E-02	<8.0E-01	<2.2E-03	<3.0E-01	2.03E+00	3.35E+00	<6.63, >3.35
⁹⁰ Sr	<2E-01	<8E+00	<2E-01	<8E+00	1.04E-03	1.38E-01	1.23E+03	2.03E+03	2.03E+03
⁹⁹ Tc	7.81E-03	3.22E-01	1.67E-03	0	9.83E-05	0	<0.03	<0.05	<0.37, >0.32

(a) Less-than values indicate the analyte was below the detection limit. In such cases, two conditions were considered: 1) the concentration of the analyte was zero,

and 2) the concentration of the analyte was the detection limit. This yielded the ranges of values given in the total activity column.

(b) Activity values represent the activity of material dissolved in a given step; these values are corrected for interstitial solution

Table 3.8. Concentrations of the Radioactive Components in the Initial C-106 Sludge Solids as Determined in the Caustic Leaching Test^(a)

Component	Concentration in Initial Solids, $\mu\text{Ci/g}$		Recovery, %
	Summation Method ^(b)	Direct Analysis	
Total Alpha	<4.66, > 4.35	4.11E+00	~106
^{239,240} Pu	<2.51, > 2.21	2.24E+00	~99
²⁴¹ Am+ ²³⁸ Pu	<2.39, > 2.08	1.87E+00	~111
²⁴¹ Am(g)	<2.49, > 2.01	1.34E+00	~150
^{243,244} Cm	<0.36, > 0.05	1.52E-02	--
²⁴² Cm	<0.32, > 0.007	Not Detected	--
¹³⁷ Cs	6.88E+02	6.81E+02	101
⁶⁰ Co	<0.29, > 0.28	3.08E-01	~90
¹⁵⁴ Eu	2.3E+00	1.76E+00	131
¹⁵⁵ Eu	<2.35, > 1.87	1.28E+00	--
¹²⁵ Sb	<1.39, > 0.70	9.04E-01	--
⁹⁰ Sr	4.27E+02	4.09E+02	104
⁹⁹ Tc	<0.078, > 0.068	< 3E-01	--

(a) Less-than values indicate the analyte was below the detection limit in one or more of the process streams. In such cases, two conditions were considered: 1) the concentration of the analyte was zero, and 2) the concentration of the analyte was the detection limit. This yielded the concentration ranges given here.

(b) Value determined by summing the amount of a given component in the caustic leaching solutions, the subsequent washing solutions, and the leached solids; the total concentration was then determined by dividing the sum by the amount of solids used.

Table 3.9. Distribution of Radioactive C-106 Sludge Components Between the Various Process Streams in the Caustic Leaching Process

Component	Component Distribution, % ^(a)			
	First Leach Solution (E)	Second Leach Solution (F)	Final Wash Solution (G)	Leached Solids
Total Alpha	0	<1	<6	>93
^{239,240} Pu	<1	<1	<12	>86
²⁴¹ Am+ ²³⁸ Pu	0	0	<13	>87
²⁴¹ Am(g)	<15	<2	<2	>81
^{243,244} Cm	0	0	<85	>15
²⁴² Cm	0	0	<97	>3
¹³⁷ Cs	50	9	1	40
⁶⁰ Co	<2	0	<4	>93
¹⁵⁴ Eu	<1	0	0	>99
¹⁵⁵ Eu	<15	<3	<3	>79
¹²⁵ Sb	<33	<12	<4	>51
⁹⁰ Sr	0	0	0	100
⁹⁹ Tc	>87	0	0	<13

(a) Amounts reported are adjusted for carryover of interstitial liquid; that is, the values reported for the solutions represent the amount of material actually dissolved during that step.

Table 3.10. Settling Data From the C-106 Caustic Leaching Test^(a)

First Caustic Leach				Second Caustic Leach				First Wash			
t, min	h, mm	T	H	t, min	h, mm	T	H	t, min	h, mm	T	H
0	47	0.00	1.00	0	40	0.00	1.00	0	60	0.00	1.00
2	45	0.03	0.96	2	38	0.02	0.95	1	58	0.06	0.97
5	43	0.07	0.91	5	37	0.06	0.93	2	55	0.11	0.92
10	40	0.14	0.85	10	35	0.11	0.88	3	52	0.16	0.87
15	38	0.22	0.81	15	33	0.17	0.83	4	49	0.22	0.82
20	36	0.29	0.77	20	30	0.23	0.75	5	45	0.27	0.75
25	34	0.36	0.72	25	28	0.28	0.70	6	41	0.33	0.68
35	31	0.51	0.66	30	26	0.34	0.65	7	37	0.39	0.62
45	26	0.65	0.55	35	25	0.39	0.63	8	35	0.44	0.58
50	23	0.72	0.49	40	24	0.45	0.60	10	32	0.55	0.53
55	21	0.80	0.45	45	23	0.51	0.58	12	29	0.66	0.48
65	19	0.94	0.40	55	21	0.62	0.53	14	25	0.77	0.42
95	16	1.37	0.34	65	18	0.73	0.45	16	22	0.88	0.37
125	14	1.81	0.30	75	16	0.84	0.40	18	20	0.99	0.33
155	14	2.24	0.30	90	15	1.01	0.38	22	19	1.21	0.32
215	12	3.11	0.26	105	14	1.18	0.35	25	18	1.37	0.30
275	12	3.98	0.26	165	13	1.86	0.33	30	17	1.65	0.28
1325	12	19.17	0.26	225	13	2.53	0.33	40	15	2.20	0.25
				285	12	3.21	0.30	50	13	2.75	0.22
				345	12	3.88	0.30	80	12	4.40	0.20
				1305	11	14.68	0.28	110	12	6.05	0.20
								170	12	9.35	0.20
								230	12	12.65	0.20
								290	11	15.95	0.18
								410	11	22.55	0.18
								1310	11	72.05	0.18

Second Wash				Third Wash			
t, min	h, mm	T	H	t, min	h, mm	T	H
0	56	0.00	1.00	0	60	0.00	1.00
1	55	0.04	0.98	2	55	0.14	0.92
2	53	0.09	0.95	3	53	0.20	0.88
4	50	0.17	0.89	6	50	0.41	0.83
5	48	0.21	0.86	8	48	0.55	0.80
6	45	0.26	0.80	12	45	0.82	0.75
7	43	0.30	0.77	16	30	1.09	0.50
8	41	0.34	0.73	18	20	1.23	0.33
10	37	0.43	0.66	20	19	1.37	0.32
12	34	0.51	0.61	25	18	1.71	0.30
15	30	0.64	0.54	30	16.5	2.05	0.28
18	28	0.77	0.50	35	15	2.39	0.25
20	25	0.86	0.45	45	14	3.08	0.23
25	20	1.07	0.36	75	12	5.13	0.20
30	18	1.29	0.32	115	11	7.86	0.18
45	16	1.93	0.29	195	11	13.33	0.18
60	15	2.57	0.27	1100	11	75.17	0.18
90	13	3.86	0.23				
105	12	4.50	0.21				
165	12	7.07	0.21				
225	11	9.64	0.20				
405	10	17.36	0.18				
1440	10	61.71	0.18				

(a) t = time, h = sludge height, T = normalized time value = $t \cdot v_{max} / h_0$, H = h/h_0 .

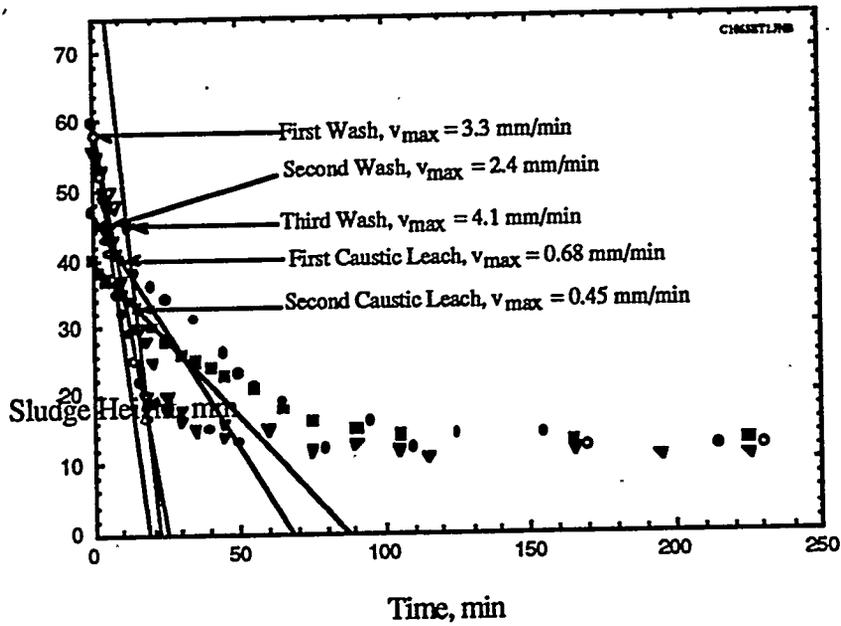


Figure 3.1. Settling Data From the C-106 Caustic Leaching Test

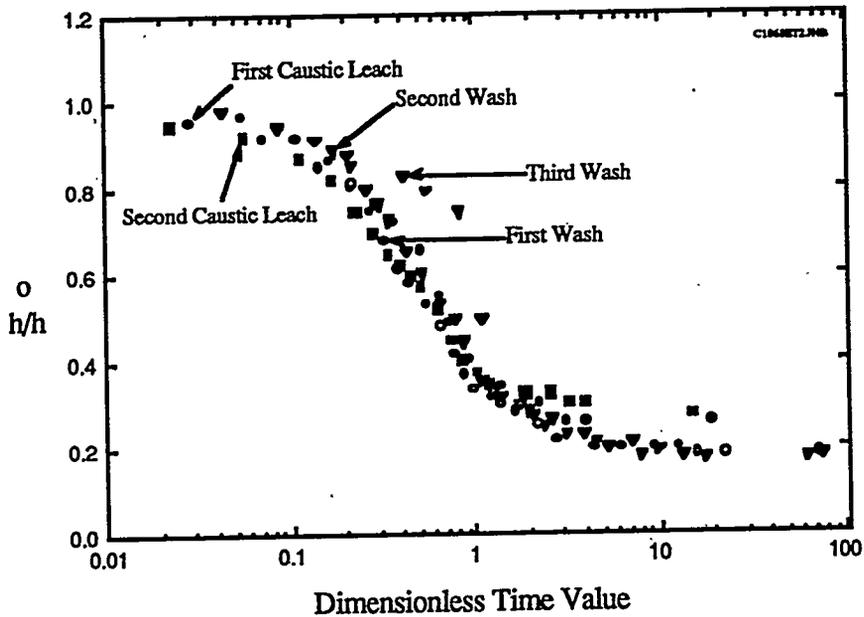
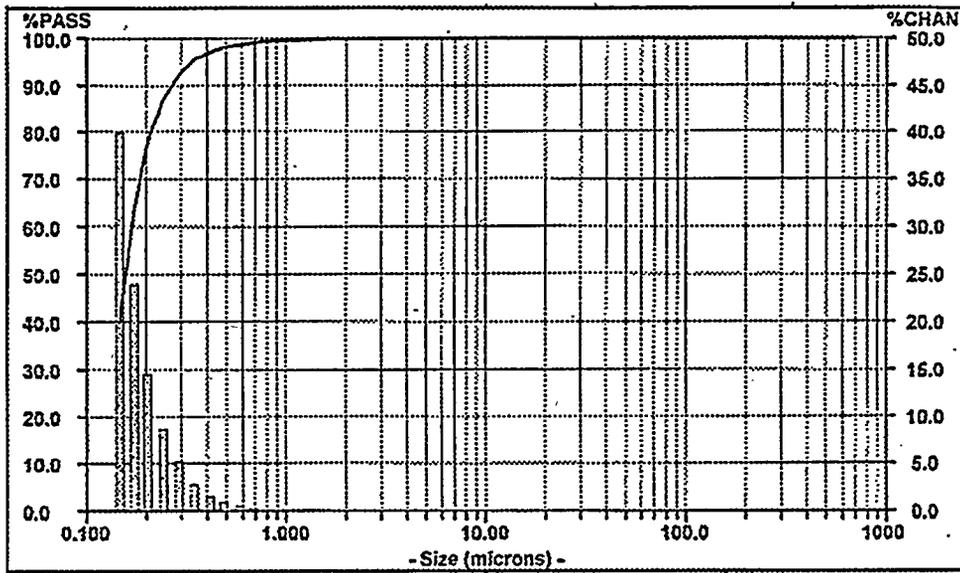
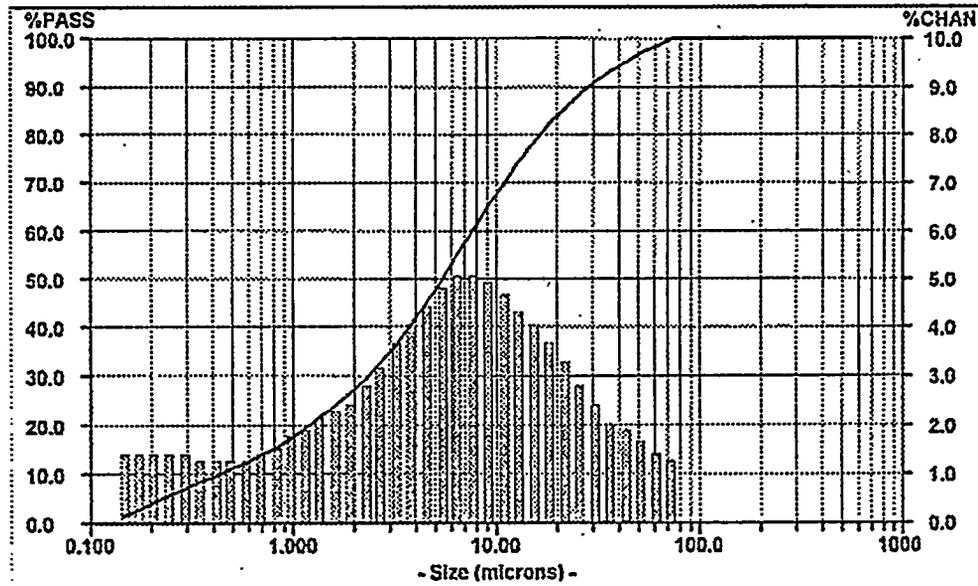


Figure 3.2. Normalized Settling Data From the C-106 Caustic Leaching Test



(a)



(b)

Figure 3.3. Particle-Size Distributions for the Untreated C-106 Sludge: a) Number Distribution, b) Volume Distribution.

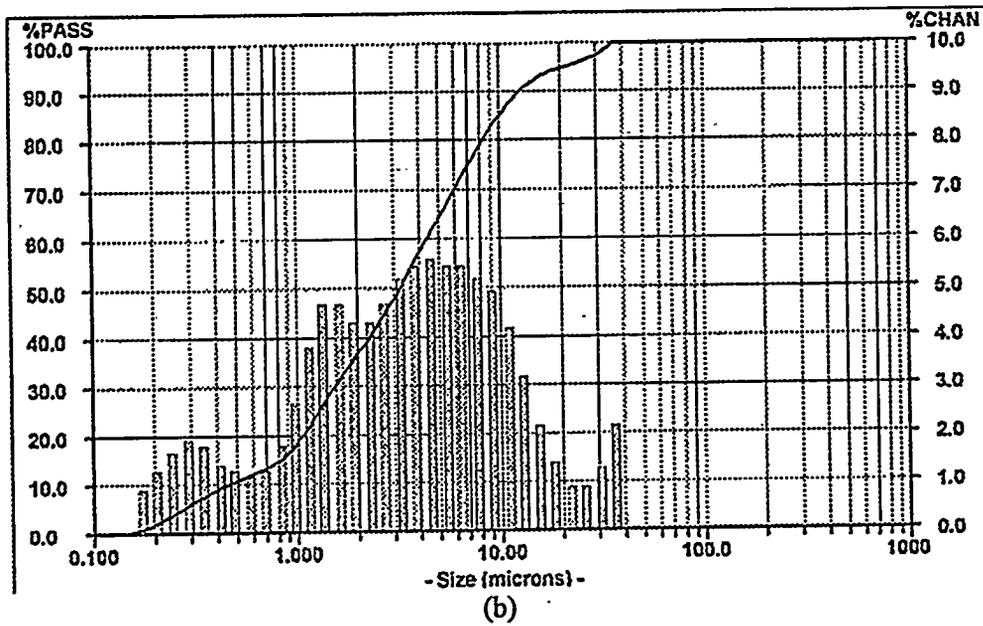
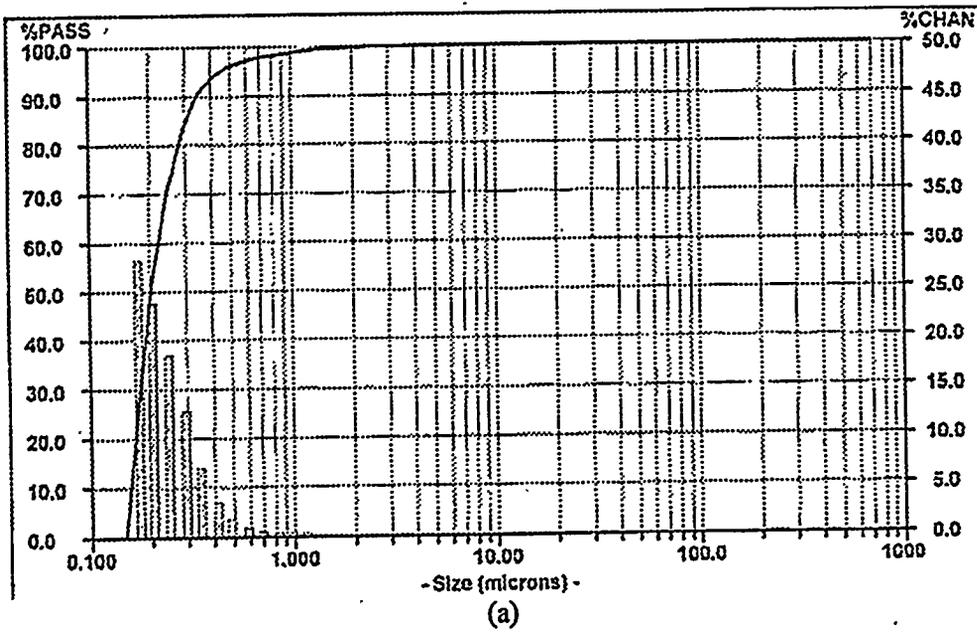


Figure 3.4. Particle-Size Distributions for the Treated C-106 Sludge: a) Number Distribution, b) Volume Distribution.

3.4 Microscopy Studies

Samples of the untreated C-106 sludge solids and the solids remaining after caustic leaching were examined by TEM coupled with EDS and electron diffraction. The EDS spectrum taken over a large sample area indicated the dominant elements in the untreated solids to be Na, Al, Si, and Fe (Figure 3.5). This result was consistent with the ICP/AES result (Section 3.1). Aluminum was present as both amorphous aluminum hydroxide and as amorphous aluminosilicate; some Fe appeared to be associated with the aluminosilicate species (Figure 3.6). After leaching, Fe was the predominant element evident in the large sample area EDS spectrum (Figure 3.7). The Fe was present as FeOOH in both highly crystalline and poorly crystalline forms (Figure 3.8). The Al remaining after leaching existed predominantly as amorphous aluminosilicate (Figure 3.9). Crystalline silver oxide particles (confirmed by the diffraction pattern) were observed along with poorly crystalline ZrO₂ in the leached residue (Figure 3.10).

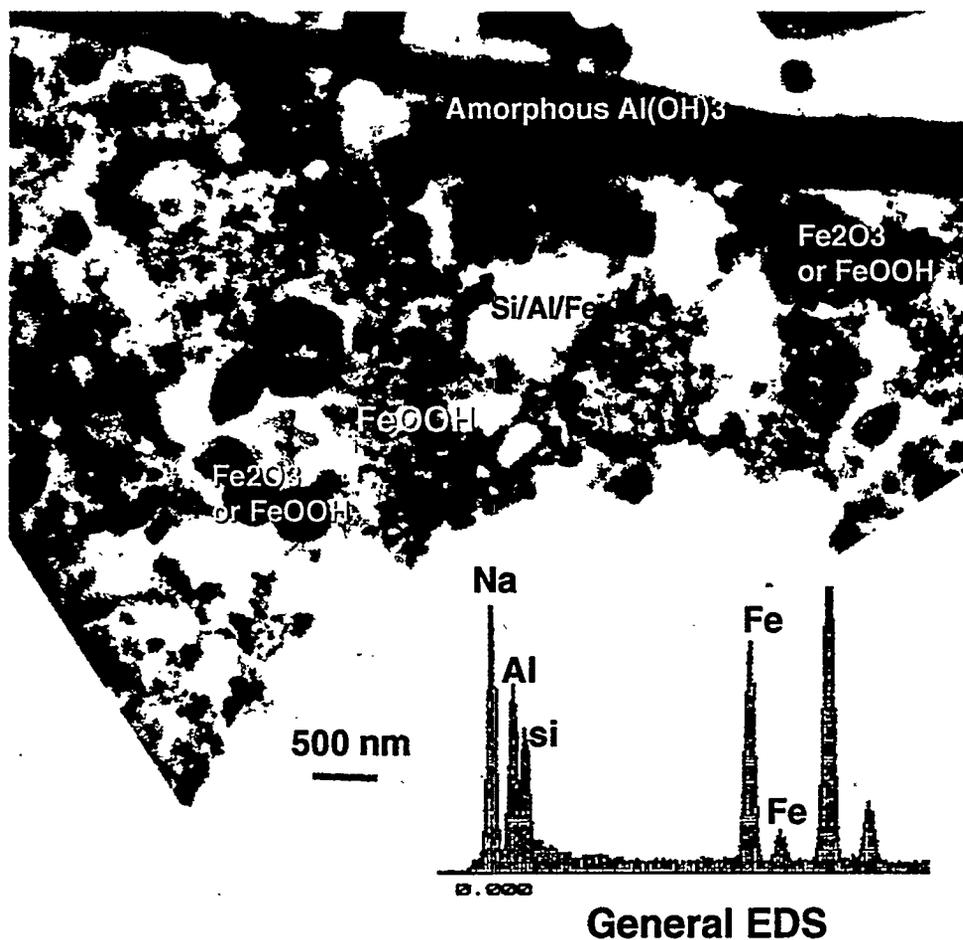


Figure 3.5. TEM and EDS of a Large Sample Area of the Untreated C-106 Solids.

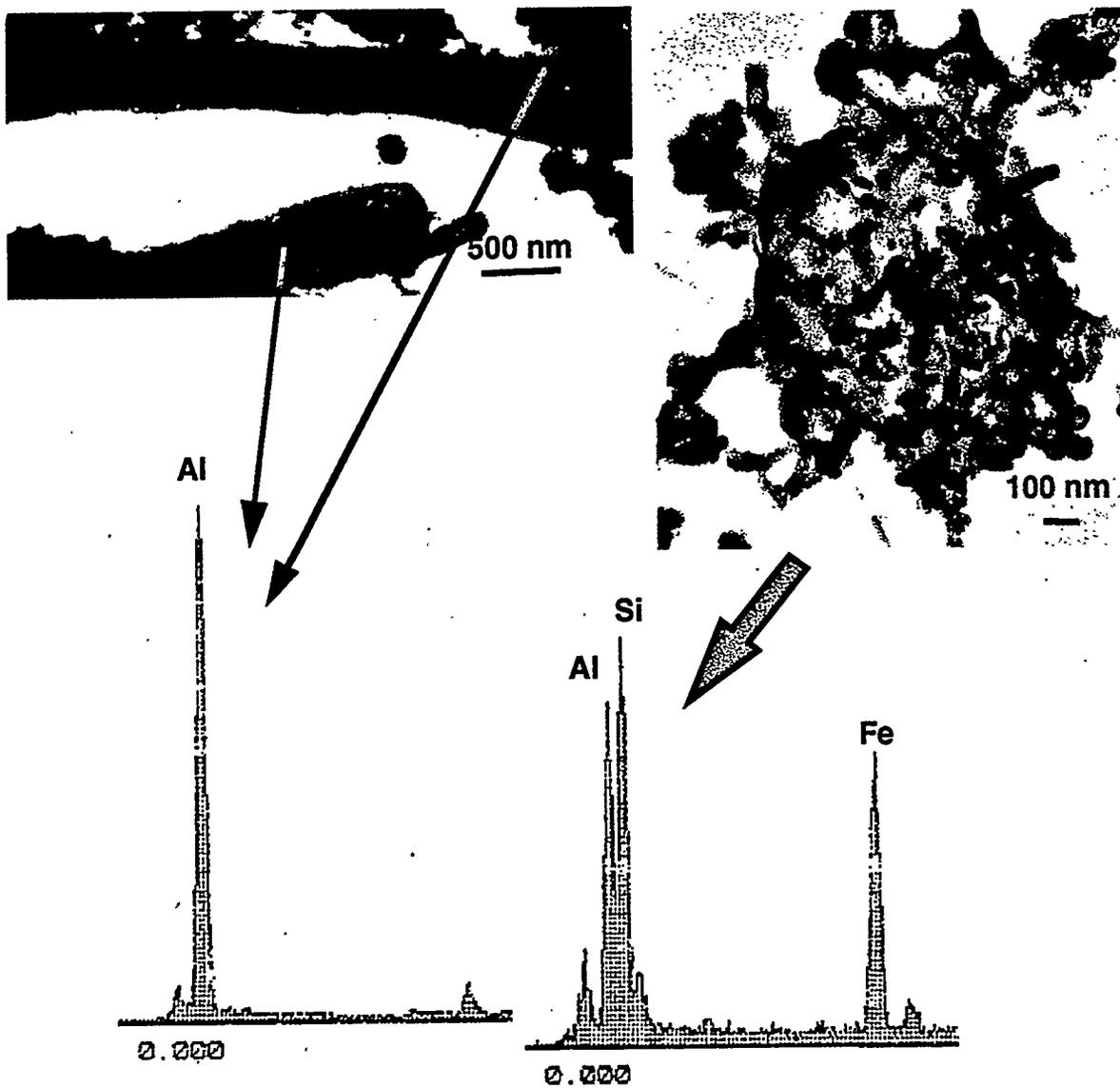


Figure 3.6. Amorphous Aluminum Hydroxide and Aluminosilicate in the Untreated C-106 Solids.

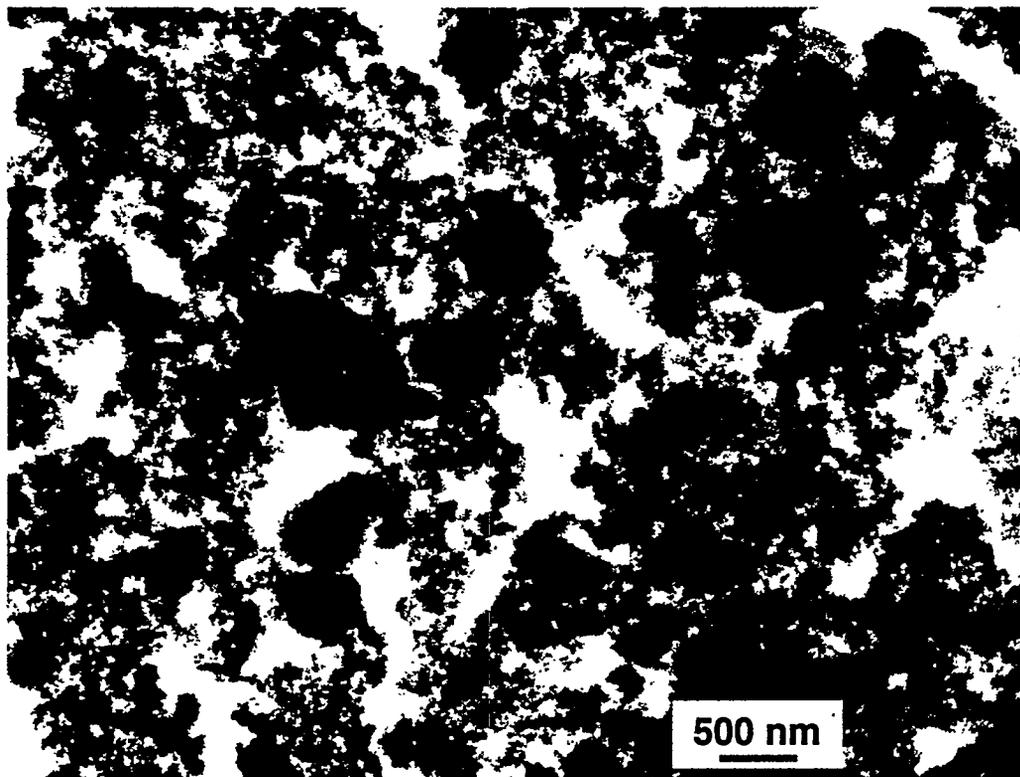


Figure 3.7. TEM and EDS of a Large Sample Area of the Treated C-106 Solids.

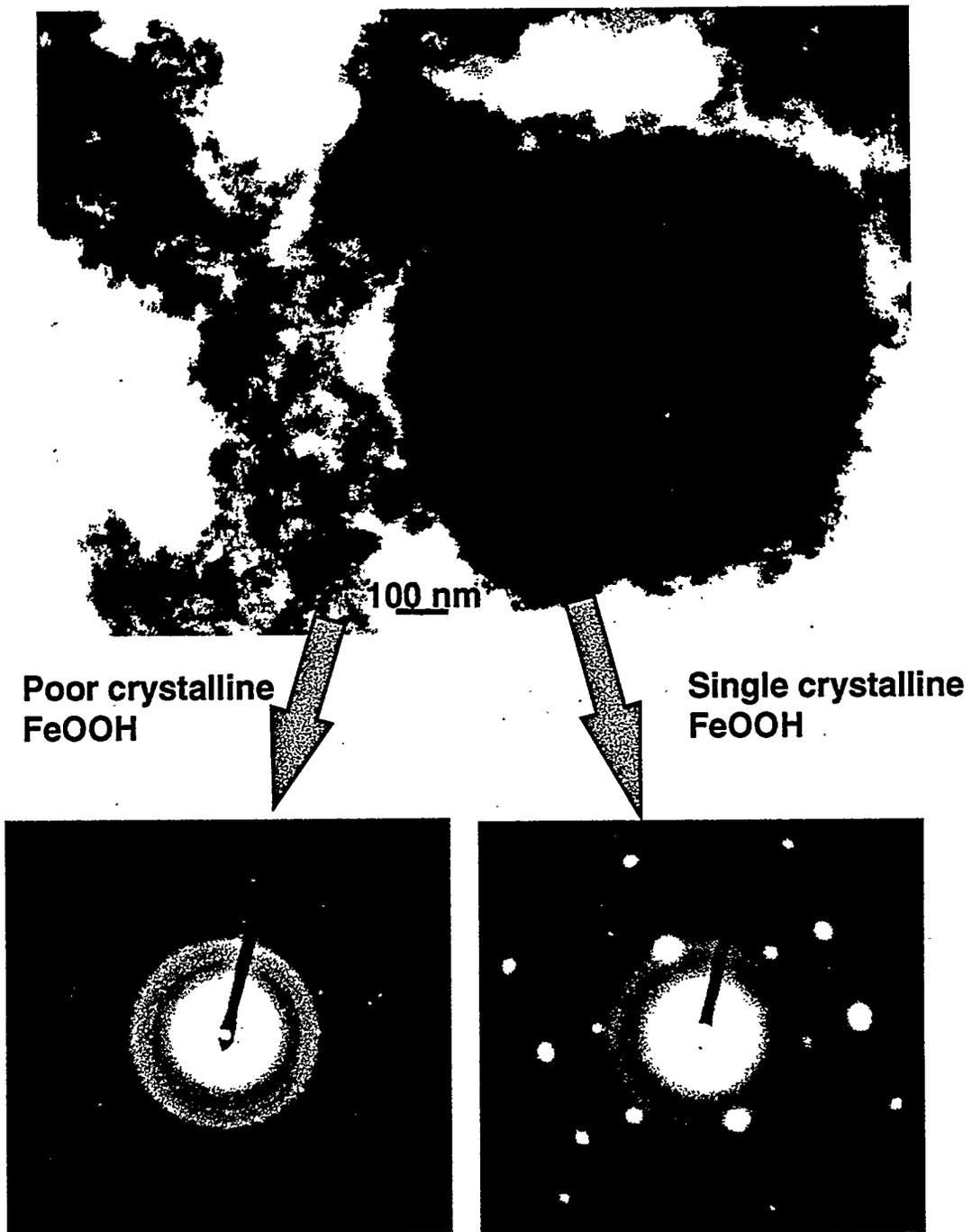


Figure 3.8. Iron Oxide Hydroxide Phases in the Treated C-106 Solids

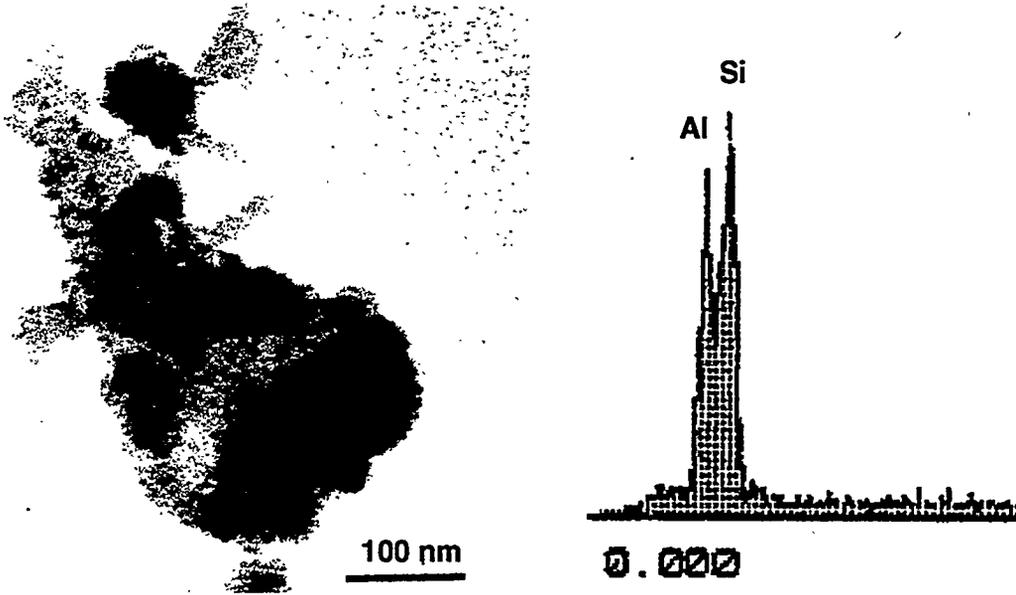


Figure 3.9. Amorphous Aluminosilicate Phase in the Treated C-106 Solids.

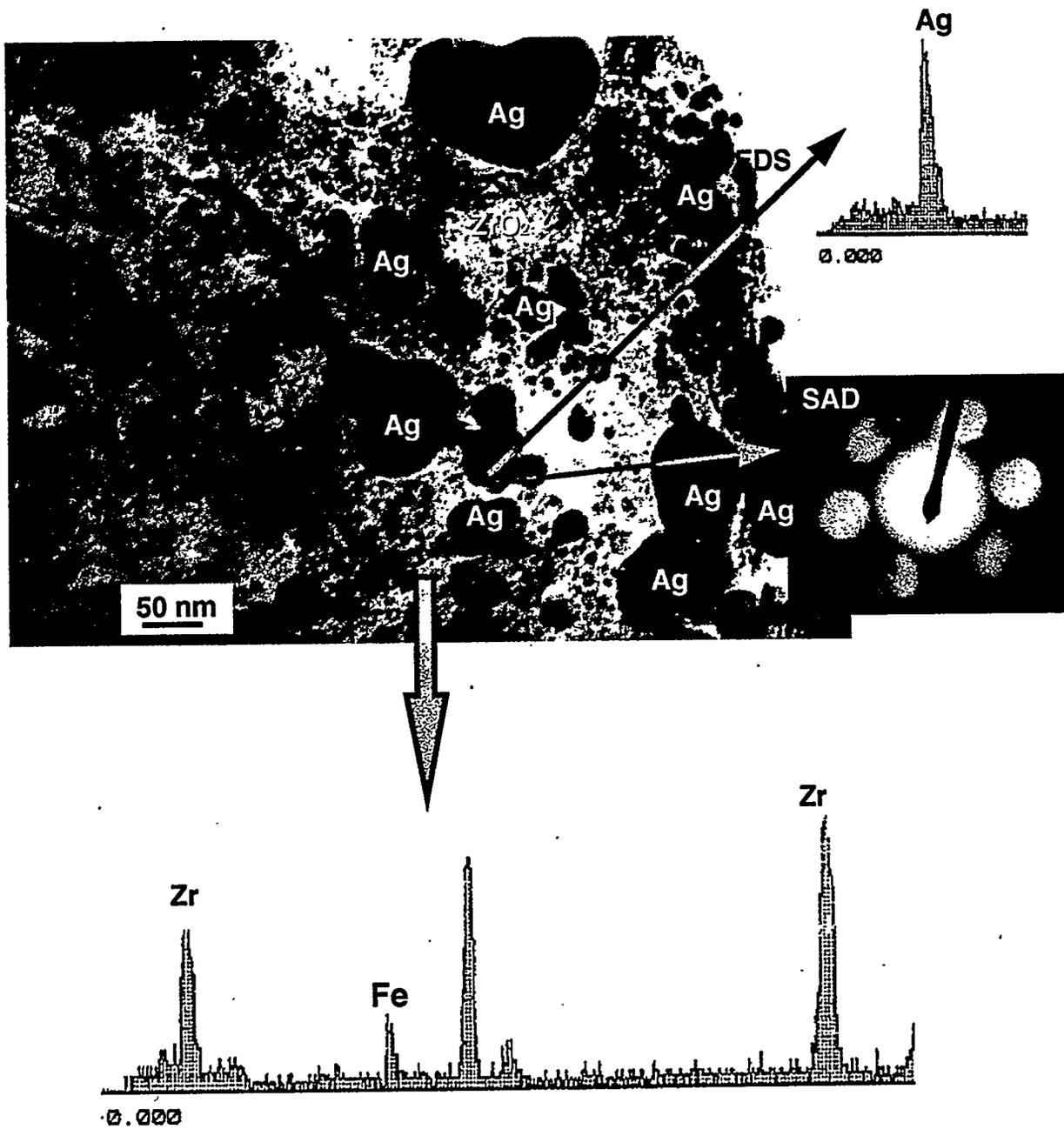


Figure 3.10. Silver Oxide and Zirconium Particles in the Treated C-106 Solids.

4.0 Discussion

The implications of the experimental results presented in Section 3.0 to the processing of Hanford tank sludge are discussed in this section.

4.1 Comparison of Sludge Composition to Envelope D Specification

The objective of the C-106 sludge washing and caustic leaching screening test was to determine if the washed or leached solids met the Envelope D specifications laid out in the TWRS privatization request for proposals (DOE-RL 1996). Table 4.1 compares the composition of the simple-washed sludge and the caustic leached sludge to the Envelope D specifications. With the exception of Sn, all of the components were present in quantities below the Envelope D specifications for both the washed and leached material. Tin was significantly over the Envelope D specification for the leached solids, but high detection limits for this element did not allow for a determination of whether the simple washed solids were within the specification. For the washed material, Al, Fe, Na, and Si were all within 50% of the Envelope D limits. Caustic leaching moved Al and Na somewhat farther from the limit, but Fe and Si became slightly more concentrated.

Envelope D also specifies minimum concentrations for Al (1.3 g/L), Fe (2.6 g/L), Na (2.3 g/L), and Ni (0.05 g/L). These specifications are based on 31 g of waste oxides per liter; the data in Table 4.1 need to be compared on this basis. The leached sludge material contained an estimated 0.77 g oxide/g of dry solids, so 40.3 g of dry solids/L are needed to get 31 g oxides/L. Assuming the density to be 1 g/mL, the minimum concentration specifications can be converted to a g/g solids basis by dividing by 40.3. Table 4.2 compares the resulting minimum concentration specifications to the actual concentrations. In all cases, the minimum concentration specifications were met for Al, Fe, Na, and Ni.

4.2 Comparison of C-103 and C-106 Caustic Leaching Results

Colton (1996) has recently estimated how efficiently washing and caustic leaching are expected to remove various components from the Hanford tank sludges. These estimates rely on extrapolating experimental data from tank sludges tested in the laboratory to tanks containing similar waste types (for which no experimental data are available). Because these estimates are used for flowsheet planning, it is of interest to compare experimental results between tanks that contain similar types of waste. Such a comparison for the first 24 tanks investigated has been recently discussed (Lumetta et al. 1996).

Tanks C-103 and C-106 are considered to contain similar types of waste (Hill, Anderson, and Simpson 1995); thus, it is informative to compare the experimental results from these two tank sludges. Table 4.3 presents such a comparison. The Al content of the C-103 sludge was about 3-fold higher than for the C-106 sludge, but the Al removal efficiencies were nearly identical (~48%). The C-103 sludge had slightly more P than the C-106 sludge, but the fraction removed by caustic leaching was nearly identical (~67%). More variability was seen for Cr removal—11% removed from C-103 and 32% removed from C-106. Also, the Cr content of the C-103 sludge was slightly higher than the C-106 sludge. Nevertheless, the experimental results from these two tanks agree quite well.

Table 4.1. Comparison of Washed and Leached Solids to Envelope D Specifications

Component	Concentration, $\mu\text{g/g}$		Envelope D Spec., $\mu\text{g/g}$ ^(a)
	Washed Solids	Leached Solids	
Ag	1260	630	4250
Al	86400	69100	107500
Ba	580	630	35000
Bi	< 235	286	21500
Ca	3900	6505	55000
Cd	110	125	35000
Ce	< 705	828	6250
Cr	1300	1046	5250
Fe	175700	187000	222500
K	< 4685	6710	10250
La	< 150	229	20000
Mg	858	1060	16250
Mn	4215	4235	50000
Na	101700	89700	150000
Nd	465	668	13250
Ni	2140	2020	18250
P	1460	2553	13500
Pb	4020	5107	8500
Si	86500	87400	145000
Sn	< 4685	4660	275
Sr	49	65	4000
Th	< 1875	< 1500	4000
Ti	640	787	10000
U	191	613	105000
Zn	315	155	3250
Zr	3860	6210	115000

(a) Envelope D specifications were obtained in a personnel communication from G.E. Stegen, Westinghouse Hanford Company, Richland, Washington (1996). These values are based on an assumption of 31 g of waste oxides/liter.

Table 4.2. Comparison of the Minimum Envelop D Concentrations For Al, Fe, Na, and Ni to the Actual Concentrations

Component	Envelope D Spec., $\mu\text{g/g}$ solid	Washed Solids, $\mu\text{g/g}$ solids	Leached Solids, $\mu\text{g/g}$ solids
Al	32,300	86,400	69,100
Fe	64,500	175,700	187,000
Na	57,100	101,700	89,700
Ni	1,250	2,140	2,020

Table 4.3. Comparison of C-103 and C-106 Caustic Leaching Results

Tank	Aluminum		Chromium		Phosphorus	
	Initial, wt % ^(a)	Removed, % ^(b)	Initial, wt % ^(a)	Removed, % ^(b)	Initial, wt % ^(a)	Removed, % ^(b)
C-103 ^(c)	14.0	48	0.16	11	0.50	66
C-106	4.85	47	0.06	32	0.21	68

(a) Based on dry weight of sludge solids

(b) Cumulative removal achieved by high caustic leaching followed by washing with dilute caustic

(c) C-103 data taken from Rapko, Lumetta, and Wagner 1995.

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