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Investigation of Leaching of Radionuclides and Hazardous Materials from Low-Level Wastes at Oak Ridge National Laboratory

H. A. Friedman
A. D. Kelmers

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Chemical Technology Division

INVESTIGATION OF LEACHING OF RADIONUCLIDES AND HAZARDOUS MATERIALS FROM LOW-LEVEL WASTES AT OAK RIDGE NATIONAL LABORATORY

H. A. Friedman
A. D. Kelmers

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EXECUTIVE SUMMARY

A laboratory investigation of the leaching of both radioactive and hazardous material contaminants from typical ORNL low activity, low-level wastes (LLW) was undertaken to support the Central Waste Disposal Facility (CWDF) project. The CWDF project was developing a low-level radioactive waste disposal site at Chestnut Ridge for the three plants on the Oak Ridge Reservation. Information on the leachability of waste contaminants is useful in identifying the radioactive and hazardous material components of representative wastes from the waste generators at each of the sites, in identifying wastes that could be segregated or that would require enhanced isolation for some disposal option alternatives, in quantifying the degree of enhanced isolation provided by alternative waste treatment procedures, and in supporting the pathways analysis calculation of more realistic (i.e., less conservative) contaminant release rates or source terms for disposal options. The CWDF project goals for FY 1985 included evaluation of a number of these waste characterization aspects, and this work was in support of those goals.

Standard hazardous material toxicity characteristic leach methodology was followed in this work because these methods model the geochemical acidity conditions in disposal site trench leachates which result from anaerobic digestion of organic waste components, and the use of existing accepted methodology avoided the need to develop new radioactive waste leach methods. Both the current Environmental Protection Agency (EPA) Toxic Waste Extraction Procedure (EP) and a proposed EPA Toxicity Characteristic Leach Procedure (TCLP) were used. These methods involve an approximately 1-d leach in a pH 5 acetic acid or acetate-buffered solution, followed by filtration and analysis of the leachate. Such single-time-point batch leach tests are useful in categorizing waste contaminants as leachable/nonleachable, or in comparing the contaminant leach characteristics of various wastes. Quantitative leach rate information is not generated by such methodology.

For the investigation of the radioactive contaminants in the LLW, there were three general experimental goals: (1) to explore the leachability of the radionuclides (degree of solubilization of the radionuclides from the waste into a typical trench leachate solution) for representative wastes, (2) to compare the effects of the waste form on the leachability of the radionuclides, and (3) to compare the effectiveness of both the current EP and the proposed TCLP methods in measuring the leachability of radionuclides. For the study of the hazardous material contaminants, the goals were: (1) to see if inorganic elements were present in representative wastes which could fall within Resource Conservation and Recovery Act (RCRA) hazardous material toxic waste classifications, and to explore the leachability of these materials, if present; and (2) to compare the effectiveness of both the current EP and the proposed TCLP methods in measuring the leachability of these inorganic hazardous materials.

Because of CWDF project time constraints, only a limited number of low-activity LLW were collected from selected ORNL waste generators and leached in the laboratory. Wastes currently going to the Solid Waste Storage Area 6 (SWSA-6) site for shallow-landfill disposal were sampled because these wastes likely are representative of the wastes that could be sent to the CWDF Chestnut Ridge site in the future. Only low-activity wastes (<200-mrem/h surface activity) were sampled. These low-activity wastes account for >90% of the volume of LLW at ORNL. High-activity LLW ($\geq$200-mrem/h surface activity), which currently go primarily to SWSA-6 for auger hole disposal, were too radioactive to be handled in a radiochemical laboratory and were not studied. Low-activity wastes such as blotter paper, mops, cloth coveralls, plastic shoe covers, synthetic wipes, etc., were collected from various ORNL waste generators. The buildings sampled included Fission Product Utilization, Isotopes Production, High Flux Isotope Reactor, Central Research Laboratory complex, and Manipulator Repair Shop.

Cesium, both ^{137}Cs and ^{134}Cs, was present in many of the waste samples. Since much of the cesium handled at ORNL is in the form of CsCl,

it was anticipated that cesium would be readily leachable from the wastes. The results of both the EP and TCLP tests, however, showed otherwise. The average fraction leached for cesium from all the waste samples was only about 0.4. In one leach rate test that was extended to 96 h, about 0.5 of the cesium was leached in the first hour or less, and no additional cesium was leached in the additional 95 h. In future work, it would be interesting to explore the cause of this partial extraction of cesium and see if credit could be taken for this effect in the pathways analysis modeling to reduce the cesium source term. Possibly sorption onto the bulk waste could account for the limited leachability of cesium observed.

Cobalt, as ^{60}Co, was present in about two-thirds of the samples tested. The analytical results showed considerable scatter. Cobalt fraction-leached values ranged from about 0.2 to 0.7 for various waste samples. Since both cobalt metal and soluble cobalt salts are handled at ORNL, it seemed reasonable that cobalt could be readily leached from some wastes but could be more nonleachable in others. The TCLP method proved nearly twice as effective in extracting cobalt as did the EP method. One sample of an ion-exchange resin used to decontaminate the HFIR pool water was also tested. For this waste, the cobalt was essentially nonleachable the fraction-released value was <0.0001. The limited information obtained suggests that it might be possible for the pathways analysis modeling of the source term to take credit for the lower leachability of some cobalt-containing waste streams. Additional waste sampling and leach rate work would be needed to identify the fraction of the cobalt source term that could be reduced due to the effects of leach rate.

Strontium, as ^{90}Sr, was found in all but one of the waste samples tested. Considerable scatter was observed in the individual analytical values; however, it appeared that between one-half to essentially all the strontium was leached from the various wastes. Much of the strontium handled at ORNL is in the form of $SrCl_2$, so ready leachability seemed reasonable. Pathways analysis modeling of the strontium source term may have to continue to assume rapid solubilization of strontium into groundwater.

Selenium, as ^{75}Se, was identified in one-half of the waste samples studied, although in low concentrations in some samples. The presence of selenium was surprising, since selenium is not listed as a radionuclide for the current LLW disposal site nor in the computer data base of the three-plant LLW. The fraction-leached values for selenium were about 0.2 for both the EP and TCLP methods. The results of the one leach rate test conducted suggest that selenium may continue slowly leaching with time; more work would be needed to confirm this single observation. Even though the limited waste sampling and analysis carried out in this work does not represent a comprehensive survey of LLW at ORNL, the finding of selenium in one-half of these samples suggests that it may be a prevalent waste radionuclide. It seems possible that selenium should be added to the waste source term in future pathways analysis modeling calculations.

Europium, present as both ^{152}Eu and ^{154}Eu, was identified in only two of the waste samples. The europium was essentially nonleachable; the fraction-released values were <0.1. Europium oxides have very low solubilities (saturated solution concentration) in solutions with near-neutral pH, thus very low extraction of europium by the EP or TCLP leach methods seems reasonable. Additional work would be necessary to establish if the low leachability resulted from a solution solubility limit or a low leach rate.

Only a few of the wastes studied contained inorganic elements at a sufficient concentration to approach or exceed the element toxic characteristic limit in the leachate if they were completely extracted. Cadmium, chromium, and lead were the only elements detected at concentrations sufficient to be of potential concern. Only the leachate for the few wastes so identified were analyzed for inorganic elements. In no case did the extract exceed the EPA toxicity characteristic limit. In two cases, cadmium in a plastic shoe cover extract and lead in a synthetic wipe extract, the leachate concentration was one-half to two-thirds of the EPA limit. For a number of the wastes tested, the proposed TCLP method was more effective in extracting inorganic elements than was the current EP method.

INVESTIGATION OF LEACHING OF RADIONUCLIDES AND HAZARDOUS MATERIALS FROM LOW-LEVEL WASTES AT OAK RIDGE NATIONAL LABORATORY

H. A. Friedman
A. D. Kelmers

ABSTRACT

Leaching of both radioactive contaminants and Resource Conservation and Recovery Act (RCRA) hazardous material contaminants from representative low-level radioactive wastes generated at Oak Ridge National Laboratory (ORNL) was investigated using two different leaching methodologies: the current Environmental Protection Agency (EPA) Toxic Waste Extraction Procedure (EP) and a proposed EPA Toxicity Characteristic Leach Procedure (TCLP). Cesium, both ^{137}Cs and ^{134}Cs, was present in many of the waste samples. The average fraction leached for cesium was only ~0.4. Since much of the cesium handled at ORNL is in the form of CsCl, the limited leaching observed was surprising. Cobalt, as ^{60}Co, was present in many samples; the fraction leached ranged from about 0.2 to 0.7 for various samples. Strontium, as ^{90}Sr, was present in all but one waste sample. Strontium was readily leached from most samples; this result seemed reasonable because much of the strontium handled at ORNL is in the form of $SrCl_2$. Selenium, present as ^{75}Se, was identified in one-half the samples tested. This observation was surprising because selenium is not currently listed as a radioactive waste component in ORNL low-level wastes. The selenium fraction leached was only ~0.2. Chromium, cadmium, and lead were the only inorganic elements identified in a few waste samples at sufficient concentrations to be of potential environmental concern. In no case, however, did the leach extract exceed the EPA toxicity characteristic limit. For a number of the wastes tested, the proposed TCLP leach methodology was more effective in extracting contaminants than was the current EP method.

1. INTRODUCTION

1.1 BACKGROUND

The Central Waste Disposal Facility (CWDF) project was responsible for the development of a centralized disposal site for low-level radioactive wastes generated at the three Oak Ridge Reservation plants: Oak Ridge National Laboratory (ORNL), the Y-12 Production Plant (Y-12), and the Oak Ridge Gaseous Diffusion Plant (K-25). A candidate site at West Chestnut Ridge was selected, and preliminary work to characterize the site geology and hydrology,[1] mineralogy,[2] and geochemistry[3] was conducted. A pathways analysis to evaluate possible radioactivity releases was completed,[4] and a draft environmental impact statement (EIS) was issued.[5] Subsequent to public comment on the draft EIS, the need for additional information to support the disposal site design and analysis was identified.[6]

This work was undertaken because no information was available describing the leach rate of low-level wastes (LLW) generated at the three plants. In the draft EIS, the pathways analysis modeling of predicted radioactivity releases took a conservative approach and assumed rapid (instantaneous) leaching of all radionuclides from the wastes to reach the calculated saturated solution concentration of the respective radionuclide species in a typical groundwater composition solution. This solution concentration, when multiplied by an assumed groundwater flux through the CWDF, was used to calculate the release source term. While technically valid and defensible in the absence of leach rate data, this conservative source-term modeling approach resulted in the calculation of predicted releases for some radionuclides which were high enough to be of potential concern.[4,5] One means of making the radioactivity release modeling more realistic (i.e., less conservative) and reducing the calculated release rates would be to take credit in the analysis for radionuclide leach rates from the waste forms. The assumption of instant solubility used in the draft EIS likely is overly conservative, since some radionuclides may be only slowly released from some waste forms into the intruding groundwater, and the assumption probably results in unrealistically large calculated

release rates for some radionuclides. Therefore, during the latter half of FY 1985 a limited laboratory activity was undertaken to explore the leachability of radioactive contaminants from some of the LLW at ORNL. Hazardous materials, as identified by the Resource Conservation and Recovery Act (RCRA), were also considered. For this work, it was assumed that currently generated LLW would be typical of those to be sent in the future from ORNL to the CWDF. The laboratory work was limited to wastes from ORNL. The Y-12 Plant conducted similar laboratory investigations independently,[7] and the K-25 Plant ceased operation during the work period.

Currently, all low-level radioactive wastes generated at ORNL are disposed of in the Solid Waste Storage Area 6 (SWSA-6) site by shallow-land burial techniques. (A description of the wastes and storage practices can be found in National Research Council,[6] Boegly,[8] and in Boegly et al.[9] A summary of the radioactivity stored at SWSA-6 is given in Table B-3 of ref. 8. No information appears to be available relative to the hazardous materials content, if any, or extractability of the LLW generated at ORNL.[9] The LLW are separated into two broad categories: low activity waste (<200 mrem/h surface reading), which is placed in trenches, and high activity waste ($\geq$200 mrem/h surface reading), which is primarily disposed of in auger holes. The leach work described in this report was limited to the low activity wastes. These low activity wastes constitute the bulk of the waste volume (>90%) and consist primarily of contaminated materials such as cloth, paper, wood, metal, concrete, etc.[10] Thus, improved knowledge of the leach behavior of radionuclides or hazardous materials in this low activity LLW fraction would help quantify the contaminant release performance of these high-volume LLW at ORNL. The leach work was restricted to these low activity wastes, of necessity, in order to comply with radioactivity safety requirements for work in radiochemical laboratories. Most of the high activity waste is composed of neutron-activated reactor parts and concentrated fission products. Hot-cell techniques would be required to study these high activity wastes, and the CWDF project time frame and budget did not provide for such hot-cell work.

A number of programmatic changes occurred as this laboratory leach work was under way during the latter half of FY 1985. As a result of interactions with the State of Tennessee and the Environmental Protection Agency (EPA), emphasis on the CWDF candidate site at West Chestnut Ridge diminished and both interim storage and large-scale demonstration of enhanced disposal techniques (techniques offering greater environmental isolation than shallow land burial methods) began receiving greater attention. Nonetheless, information on the radionuclide leach rate remains important to characterize the wastes, to demonstrate the degree of isolation enhancement obtained by alternative treatments, and to calculate potential future radioactivity releases for various disposal or storage methodologies which may be considered. Also, it seems important to consider the possible hazardous materials content and leachability of these LLW streams with respect to RCRA regulations.

1.2 EXPERIMENTAL DESIGN

The experimental work plan was designed to support the CWDF project goals by developing information on the radionuclide and hazardous material contaminant content of selected low activity LLW wastes from ORNL, and by developing information on the leachability of these contaminants under site-relevant geochemical conditions. This initial activity was designed to provide screening-level evaluation of the potential for release of radionuclides or hazardous materials from as many ORNL wastes as possible by the end of September 1985. The information obtained will help the CWDF project to identify wastes that may be acceptable/unacceptable for disposal in their present as-generated form. The screening tests will help focus attention on potential ways of improving waste acceptability such as segregation by the generator, improved confinement, or development of enhanced waste forms.

Additional future work would be required to develop accurate leach-rate information for both radionuclides and hazardous materials to support the pathways analysis modeling calculations. Development of quantitative data would be an iterative process involving the pathways

analysis modeling calculations, and the greatest leach-test effort would be directed toward those contaminants and wastes that appear to represent the greatest environmental concerns. Both laboratory- and field-scale experiments involving batch-contact and column-chromatographic methodology would be required in some cases in order to obtain accurate and defensible release rates.

Standard leach methodology for determining the toxicity characteristics of hazardous materials was followed in the batch contact work completed in FY 1985. This methodology was selected because it probably models the geochemical conditions that may exist in the waste in trench leachates, and because it is generally recognized as a waste leachability screening tool. The current EPA Toxic Waste Extraction Procedure (EP) (40 CFR Part 261.24) and a proposed EPA Toxicity Characterization Leach Procedure (TCLP)[11] were followed. Both of these leach methods (described in detail in Appendix A) employ an approximately 1-d leach at near pH 5 in acetic acid or an acetate buffer. In shallow-land-burial sites, anerobic digestion of the organic waste components (paper, wood, etc.) frequently results in the generation of organic acids and produces mildly acidic leachates. The pH 5 leach solution is designed to simulate the trench leachate acidity. It is likely that the low activity LLW would experience similar conditions in the trenchs following disposal practices such as those followed at SWSA-6; therefore, the use of the EPA methodology seemed appropriate. Also, the use of both the current standard and the proposed new method allowed a comparison of the effectiveness of the two leach methods.

2. DESCRIPTION OF LOW-LEVEL WASTES STUDIED

The first series of low activity LLW were collected from Building 3517, Fission Product Utilization, on May 29, 1985. Building 3517 is a hot-cell facility. The primary activity is the production of radioactive sources, principally ^{90}Sr, ^{60}Co, and ^{137}Cs. Other isotopes are handled occasionally. The following samples, representing a variety of typical

hot-cell wastes, were collected: plastic shoe covers, cloth coveralls, blotter paper, paper coveralls, a coarse mop, and a fine mop. The mops were damp since they had been used to mop up liquids. The other samples were dry.

A sample of ion-exchange resin was obtained from Building 7900, High Flux Isotope Reactor, on May 16, 1985. This sample was of used resin (used to decontaminate the reactor pool water) from a shipment sent to the SWSA-6 storage site for auger hole disposal. The gross surface gamma activity for this sample was about 180 mrem/h, and we were able to handle this material safely in the radiochemical laboratory with due caution. No other samples were collected from Building 7900 at this time, since most of the waste is high activity neutron-activated reactor parts.

At this point, a change in the philosophy of sample collection became necessary. In order to sample wastes from as many ORNL generators as possible and complete the laboratory leach work by September 1985, we decided to limit the samples to a single waste form that could be handled easily in the laboratory. Synthetic wipes were chosen since they are obtained from stores for nearly all glove-box or hot-cell operations and used to clean contaminated surfaces. In addition, we found that these synthetic wipes would shred readily in the Wiley mill to produce a blended waste sample that could be easily handled in the two leach test methods. Some of the other wastes had proven much more difficult to handle. Natural fiber-based cloth materials tended to bind the mill and require repeated disassembly of the mill during the shredding of the radioactive samples (with concomitant operator exposure), but pulverized paper-based materials adsorbed so much liquid during the leach step that leaching and the subsequent filtration proved difficult.

Synthetic wipe samples were then obtained during June, July, and August from a number of additional ORNL generators. The following buildings were sampled: (1) Building 3019, a hot-cell production facility that has processed appreciable amounts of ^{233}U in the past; (2) Building 3047, the Isotope Production facility, where large quantities of isotopes are handled on a routine basis; (3) Building 7920, the

Transuranium Processsing Facility; (4) two different laboratories in Buildings 4500N and 4501 in the main research laboratory complex; and (5) Building 3074, the Manipulator Repair Shop. The various facilities were chosen to attempt to obtain a somewhat representative cross section of typical ORNL low activity LLW in the time available.

3. RADIONUCLIDE LEACHING

3.1 EP AND TCLP TEST RESULTS

3.1.1 Test Goals

Three general goals were established for the single-time-point batch leach tests performed with the various ORNL low-level waste samples:

1. To explore the leachability of radionuclides (degree of solubilization from the waste into a typical trench leachate solution) for representative wastes. Laboratory tests were necessary because we were unable to identify published reports that characterized the leachability of any radionuclide from any LLW at ORNL. Considering the variety of radionuclides and waste forms present in ORNL LLW, it seemed likely that some radionuclides that are handled at ORNL facilities would be expected to be readily leached or solubilized (for example, CsCl or NH_4TcO_4), while others could be expected to be leached relatively slowly or essentially insoluble (for example, cobalt metal or radionuclides incorporated within a metal matrix). The leach test work described in this report was performed during FY 1985 and was designed to screen as many actual ORNL wastes as possible in the time available in order to broadly categorize the radionuclides as leachable (readily solubilized) or nonleachable (poorly solubilized). The use of standard waste toxicity characteristic leach test methodology was chosen in order to avoid the need to develop experimental techniques.
2. To compare the effect of the waste form on the leachability of radionuclides. The various operations at ORNL produce a wide variety of LLW composed of various bulk waste forms, and it seemed

likely that some wastes might be characteristically leachable or nonleachable. Such leachability information about the various waste streams generated could help in the segregation of wastes for treatment options such as conversion to enhanced waste forms or storage instead of disposal.

3. To compare the effectiveness of both the current EP method and the proposed TCLP method in measuring the leachability of radionuclides (see Appendix A for a description of the leach methods). Since no standard methodology exists to characterize the leachability of radionuclides from LLW, this work provided an opportunity to test the applicability of the EP and TCLP methods for radioactivity leaching performance.

The results of the radionuclide tests are presented in the following sections by element. This method of presentation was selected since it seemed possible that the leaching behavior might be dominated by the chemical form of the various elements. A summary of the data (fraction leached and element balance, see Sect. A.4) is given in the tables in these sections, and a complete record of all radionuclide analytical numbers is contained in Appendix B. Emphasis was given to the fraction-leached value because that is the information of primary interest, and to the element balance because that value showns the quality of the analytical values used to calculate the fraction leached.

3.1.2 Cesium

The results for both ^{137}Cs and ^{134}Cs were combined and are presented in Table 3.1. The data for these two radionuclides were combined because (1) their chemistries should be identical, and (2) they likely are in the same radioactive waste component. Much of the cesium handled at ORNL is in the form of CsCl for use in radiation sources, and ^{137}Cs is one of the major radionuclides currently being discharged to the SWSA-6 storage site (Table B-3 of ref. 8). CsCl has a high solubility (saturated solution concentration) in all aqueous solutions and usually exhibits rapid dissolution rates; therefore, cesium may be expected to show appreciable leachability.

Table 3.1 Summary of results for ^{137}Cs and ^{134}Cs

Identification	Element balance: Avg. percent ± 1 σ	Element balance: No. of tests[a]	Fraction leached: Avg. ± 1 σ	Fraction leached: No. of tests[b]
Waste samples (both leach methods)				
Blotter paper, Bldg. 3517	64 ± 8	7	0.28 ± 0.06	7
Coarse mop, Bldg. 3517	107 ± 47	3	0.27 ± 0.05	4
Fine mop, Bldg. 3517	72 ± 4	4	0.20 ± 0.03	4
Cloth coveralls, Bldg. 3517	82 ± 29	4	0.17 ± 0.03	4
Plastic shoe covers, Bldg. 3517	91 ± 22	4	0.44 ± 0.16	4
Paper coveralls, Bldg. 3517	85 ± 10	4	0.37 ± 0.05	5
Synthetic wipe, Bldg. 3019	51 ± 23	3	0.35 ± 0.19	4
Synthetic wipe, Bldg. 7920	33 ± 2	4	0.31 ± 0.02	4
Synthetic wipe, Bldg. 4501	68 ± 3	4	0.57 ± 0.05	8
Synthetic wipe, Bldg. 3074	62 ± 14	8	0.43 ± 0.11	8
Synthetic wipe, Bldg. 3047	c		c	
Leach methods (for all samples)				
EP	75 ± 33	21	0.33 ± 0.15	25
TCLP	65 ± 16	24	0.39 ± 0.14	27

[a]Values >200% omitted.

[b]Values >2.00 omitted.

[c]Not detected.

As shown in Table 3.1, cesium was found in all but one of the waste samples. For most of the samples from Building 3517, the element balance ranged from 64 ± 8 to 107 ± 47%. (For these and all following values, the standard deviation (σ) numbers express the $1/\sigma$ statistical variation of the values used to compute the average and do not represent analytical counting errors.) Even though the ideal element balance value should be 100%, an element balance in the 70 to 130% range probably should be considered adequate for scouting tests. Since the element balance number involves combining the results of several analyses on both solid and liquid samples, it represents a severe test of the analytical accuracy. The element balance for the synthetic wipe samples from the other waste generators was significantly lower, ranging from 33 ± 2 to 68 ± 3%. No reason was apparent for the lower element balance numbers with the synthetic wipe samples. For some of the samples, the standard deviation was an appreciable fraction of the value, indicating that the individual numbers had a significant spread.

The fraction-leached values ranged from a low of 0.17 ± 0.03 to a high of 0.57 ± 0.05, but many of the values were close to 0.3. The small standard deviation values show that the individual values for the respective tests with a given waste yielded a relatively narrow spread of results, and suggest that the differences in fraction leached observed between the various samples could be significant. The surprisingly low leachablilty measured is of more importance. Fraction-leached values close to 1.0 had been anticipated, based on the chemistry of CsCl in these leach solutions. However, the results show that approximately two-thirds of the cesium was not leached. Unfortunately, the laboratory work had been completed before this anomalous behavior became apparent, and it was not explored further. Sorption of cesium onto the waste bulk solids could be a plausible, but untested, explanation of the results. In future work, it would be desirable to run additional blanks and control samples to attempt to differentiate between actual waste performance and systematic experimental or analytical bias.

No significant difference was observed between the EP and TCLP leach methodologies. Both showed that only about one-third of the cesium was leachable.

3.1.3 Cobalt

The results for ^{60}Co are shown in Tables 3.2 and B.10. Cobalt-60 is also one of the major radionuclides currently being discharged to the SWSA-6 storage site [Table B-3 of ref. 8]. Some of the cobalt handled at ORNL is in the form of cobalt metal for radiation sources and might be expected to be relatively insoluble. However, some cobalt solutions or soluble salts are also used. Thus, ^{60}Co in some LLW might be either easily leached or nonleachable. It was possible, therefore, that different waste samples might show quite different cobalt leach results. In addition to the waste samples from Building 3517 and the synthetic wipe samples from a number of ther ORNL generators, a single sample of used ion-exchange resin was obtained from Building 7900. This resin is a very different waste form than the superficially contaminated materials from the other buildings since it is used to scavenge ^{60}Co and other elements from the High Flux Isotope Reactor (HFIR) pool water. Therefore, the ^{60}Co results for the resin are reported separately in Table B.10.

Cobalt was found in about two-thirds of the waste samples tested (Table 3.2). The element balance generally was less than 100%; the results for individual samples ranged for a low of 47 ± 10% to a high of 119 ± 38%. Data for a number of the leach tests were rejected in preparing the results in Table 3.2 because of unrealistically high (>200%) element balance values. It appeared that more difficulty was encountered in the analysis for cobalt than for cesium. Whether this was due to (1) uneven distribution of the cobalt in the waste materials (i.e., a single particle of cobalt metal would not be evenly mixed in the shredded and blended sample), or (2) unknown problems in the analysis.

The fraction-leached values for cobalt in Table 3.2 cover a considerable spread: from 0.16 ± 0.05 to 0.66 ± 0.34. This spread may be realistic, considering the various possible chemical forms of cobalt that

Table 3.2 Summary of results for ^{60}Co

Identification	Element balance: Avg. percent ± 1 σ	Element balance: No. of tests[a]	Fraction leached: Avg. ± 1 σ	Fraction leached: No. of tests[b]
Waste samples (both leach methods)				
Blotter paper, Bldg. 3517	53 ± 21	4	0.16 ± 0.05	3
Coarse mop, Bldg. 3517	73 ± 3	4	0.20 ± 0.01	4
Fine mop, Bldg. 3517	72 ± 3	4	0.35 ± 0.02	4
Cloth coveralls, Bldg. 3517	58	1	0.34 ± 0.08	4
Plastic shoe covers, Bldg. 3517	c		c	
Paper coveralls, Bldg. 3517	c		c	
Synthetic wipe, Bldg. 3019	47 ± 10	4	0.29 ± 0.06	4
Synthetic wipe, Bldg. 7920	c		c	
Synthetic wipe, Bldg. 4501	c		c	
Synthetic wipe, Bldg. 3074	119 ± 38	4	0.66 ± 0.34	4
Synthetic wipe, Bldg. 3047	83 ± 16	4	0.45 ± 0.40	4
Leach methods (for all samples)				
EP	68 ± 24	12	0.26 ± 0.15	13
TCLP	79 ± 33	13	0.44 ± 0.30	14

[a]Values >200% omitted.

[b]Values >2.00 omitted.

[c]Not detected.

could be in the waste samples. The activities in Building 3517 primarily involve ^{60}Co as cobalt metal, and we anticipated that it would be poorly leached in the samples from this building. The results show otherwise, however, and it is possible that very small particles of cobalt metal may be easily oxidized to soluble chemical forms. In general, the results show that ^{60}Co is relatively leachable in these wastes.

A substantial difference in the performance of the EP and TCLP methods can be seen in Table 3.2. Significantly greater amounts of cobalt were leached by the proposed TCLP method (0.44 ± 0.30) as compared to the current EP method (0.26 ± 0.15). It is possible that the greater acetate anion concentration in the buffered solution used in the TCLP method may aid in the leaching of cobalt as an acetate complex.

The leach test results with the ion exchange resin (Table B.10) also showed considerable scatter in the element balance numbers. Additionally, difficulty was experienced in the cobalt analysis for this sample; it seems less likely that the ionic form of ^{60}Co in the resin would be unevenly distributed, and thus the data scatter may more likely be an analytical problem. Very little of the cobalt was solubilized in the leach tests. The fraction-released values ranged from 0.00002 to 0.00029 (i.e., cobalt was essentially completely nonleachable). Again, the TCLP method gave greater, although very low, leach values than the EP method.

3.1.4 Strontium

The leach test results for ^{90}Sr are given in Table 3.3. This radionuclide also is a major contributor to the radioactivity current discharged by ORNL to the SWSA-6 storage site [Table B.3 of ref. 8] and is of particular environmental concern because of its half-life, biological effects, and geologic mobility. Much of the ^{90}Sr handled at ORNL is in the form of $SrCl_2$, which should be relatively soluble in the leach test solutions.

Strontium was found in all but one of the waste samples. The data summary (Table 3.3) shows considerable scatter in both the element balance and fraction leached values. Even though the overall element balance

Table 3.3 Summary of results for ^{90}Sr

Identification	Element balance: Avg. percent ± 1 σ	Element balance: No. of tests[a]	Fraction leached: Avg. ± 1 σ	Fraction leached: No. of tests[b]
Waste samples (both leach methods)				
Blotter paper, Bldg. 3517	86 ± 39	2	0.68 ± 0.32	4
Coarse mop, Bldg. 3517	63 ± 23	4	0.28 ± 0.04	4
Fine mop, Bldg. 3517	110 ± 11	4	0.81 ± 0.05	4
Cloth coveralls, Bldg. 3517	151 ± 3	2	0.91 ± 0.21	4
Plastic shoe covers, Bldg. 3517	129 ± 5	2	0.80 ± 0.10	3
Paper coveralls, Bldg. 3517	74 ± 10	4	0.54 ± 0.10	4
Synthetic wipe, Bldg. 3019	89 ± 9	2	0.08 ± 0.03	4
Synthetic wipe, Bldg. 7920	c		c	
Synthetic wipe, Bldg. 4501	153	1	0.96 ± 0.34	4
Synthetic wipe, Bldg. 3074	89 ± 31	4	0.69 ± 0.36	4
Synthetic wipe, Bldg. 3047	157 ± 27	4	0.43 ± 0.07	3
Leach methods (for all samples)				
EP	107 ± 44	17	0.49 ± 0.27	20
TCLP	101 ± 32	12	0.75 ± 0.36	18

[a]Values >200% omitted.

[b]Values >2.00 omitted.

[c]Not detected.

numbers averaged close to 100%, the standard deviation values show that the individual values for each sample had considerable scatter. Thus, caution is suggested in comparing results for various samples. With the exception of two samples (the coarse mop from Building 3517 and the wipe from Building 3019), more than half to essentially all the strontium was leached. This value is consistent with the expected solubility behavior of $SrCl_2$.

Although there is considerable scatter in the data, the TCLP method apparently leached more strontium (0.75 ± 0.36) than did the EP method (0.49 ± 0.27).

3.1.5 Selenium

Selenium was identified in half of the samples tested (see Table 3.4). The presence of selenium in these samples from throughout the ORNL area was surprising because ^{75}Se is neither listed as a radionuclide in the ORNL information for the current SWSA-6 disposal site[8] nor has it been incorporated in the current computer data base for low activity LLW radionuclide characterization.[10] Under the geochemical conditions of the leachate solution, selenium would probably be present as anionic selenates such as SeO_3^{2-} or SeO_4^{2-} and could exhibit appreciable solubility and site mobility.

The element balance for all the samples (Table 3.4) was considerably less than 100%. Since no high values were rejected in compiling these data, it seems possible that the low element balance values could have resulted from an analytical bias in some of the solution or solid analyses. Nonetheless, the results are particularly interesting since ^{75}Se may not generally be recognized as a radioactive contaminant in LLW streams at ORNL.

With only one exception, the fraction leached was close to 0.2. It is difficult to know what significance to attach to this rather poor leachability. Since we do not know the chemical form of selenium in the waste, meaningful predictions of its behavior can not be made. In any case, the leach results were highly reproducible. The standard deviation

Table 3.4 Summary of results for ^{75}Se

Identification	Element balance: Avg. percent ± 1 σ	Element balance: No. of tests[a]	Fraction leached: Avg. ± 1 σ	Fraction leached: No. of tests[b]
Waste samples (both leach methods)				
Blotter paper, Bldg. 3517	c		c	
Coarse mop, Bldg. 3517	66 ± 2	4	0.30 ± 0.01	4
Fine mop, Bldg. 3517	81 ± 4	4	0.19 ± 0.02	4
Cloth coveralls, Bldg. 3517	c		c	
Plastic shoe covers, Bldg. 3517	c		c	
Paper coveralls, Bldg. 3517	c		c	
Synthetic wipe, Bldg. 3019	50 ± 17	4	0.20 ± 0.01	4
Synthetic wipe, Bldg. 7920	c		c	
Synthetic wipe, Bldg. 4501				
Synthetic wipe, Bldg. 3074	61 ± 10	4	0.25 ± 0.02	4
Synthetic wipe, Bldg. 3047	71 ± 8	4	0.21 ± 0.01	4
Leach methods (for all samples)				
EP	62 ± 17	10	0.23 ± 0.04	10
TCLP	69 ± 9	10	0.23 ± 0.04	10

[a]Values >200% omitted.

[b]Values >2.00 omitted.

[c]Not detected.

was always low and represented only a small fraction of the fraction-leached value. In future waste leach work, it could be desirable to give additional attention to ^{75}Se.

The EP and TCLP leach methods were equally effective in leaching selenium; the average fraction leached was identical for the two methods (0.23 ± 0.04).

3.1.6 Europium

The results for ^{152}Eu and ^{154}Eu were combined since their chemistries should be identical, and both radionuclides are likely present in the same radioactive waste component. As shown in Table 3.5, only two of the samples contained identifiable amounts of europium — the two mops from Building 3517. While europium radionuclides are listed as the largest source of radioactivity now being discharged by ORNL to the SWSA-6 storage site [Table B-3 of ref. 8], most of the europium from ORNL is contained in high activity neutron-activated waste components from the HFIR and would not be present in the low activity samples we are working with. At the near-neutral pH of the test leach solution, europium oxides should have very low solubilities, thus europium might be expected to be poorly leachable.

The element balance (Table 3.5) showed that about three-quarters of the europium was accounted for in the leach solution and residue. For both mops, the fraction leached was <0.1. As anticipated, europium was poorly leachable. The TCLP method appeared to give better leaching of the europium than did the EP method. However, both fraction-leached values were so low (0.03 ± 0.01 for the EP and 0.08 ± 0.03 for the TCLP) and the standard deviation so great that this apparent difference may not be significant. Additional work would be necessary to confirm this observation.

Table 3.5 Summary of results for ^{152}Eu and ^{154}Eu

Identification	Element balance: Avg. percent ± 1 σ	Element balance: No. of tests[a]	Fraction leached: Avg. ± 1 σ	Fraction leached: No. of tests[b]
Waste samples (both leach methods)				
Blotter paper, Bldg. 3517	c		c	
Coarse mop, Bldg. 3517	82 ± 12	7	0.04 ± 0.01	8
Fine mop, Bldg. 3517	74 ± 8	6	0.09 ± 0.03	6
Cloth coveralls, Bldg. 3517	c		c	
Plastic shoe covers, Bldg. 3517	c		c	
Paper coveralls, Bldg. 3517	c		c	
Synthetic wipe, Bldg. 3019	c		c	
Synthetic wipe, Bldg. 7920	c		c	
Synthetic wipe, Bldg. 4501	c		c	
Synthetic wipe, Bldg. 3074	c		c	
Synthetic wipe, Bldg. 3047	c		c	
Leach methods (for all samples)				
EP	82 ± 12	5	0.03 ± 0.01	6
TCLP	77 ± 10	8	0.08 ± 0.03	8

[a]Values >200% omitted.

[b]Values >2.00 omitted.

[c]Not detected.

3.2 RATE TEST RESULTS

While single-time-point leach tests such as those conducted with the EP and TCLP methods (Sect. 4.1) were useful in qualitatively categorizing radionuclides as leachable/nonleachable in order to scope the behavior of as many waste samples as possible in the limited time available during FY 1985, the pathways analysis modeling calculations for the CWDF will require actual leach rate values if credit is to be taken for slow radionuclide dissolution kinetics in estimating future site behavior and environmental releases. Single-time-point results give no hint as to the dissolution rate as a function of time, nor do they show if the leach experiment had reached steady state in the time period of the test. Therefore, in future work it is essential to include leach rate experiments for all the important or key radionuclides and waste forms (and, of course, hazardous materials, if any). Selection of the radionuclides and wastes to be studied should be made in conjunction with the pathways analysis group so that the test work is focused on those radionuclides and wastes likely to be of greatest environmental concern. This interaction would be an iterative process, since the information developed in the rate tests would help in the pathways analysis identification of the key wastes and radionuclides.

Only a few leach rate experiments were carried out during FY 1985 due to the programmatic time constraints. Two synthetic wipe samples were leached for time periods of 1 to 96 h using replicate samples (one for each time point) with the TCLP method. The methodology is described in Appendix A. These tests were done to explore the performance of the TCLP method with these wastes and to see if the 1-d test period (used in the single-time-point tests) was sufficient to allow these two waste/leachant systems to reach steady state, or if leaching was still continuing after the 1-d time. Because only two waste samples were tested in the time available, it was not possible to draw general conclusions as to leach rates for other LLW at ORNL. The leach rate work completed was only considered sufficient to explore the test methodology.

The leach rate test results for a synthetic wipe sample from Building 7920 are given in Table B.9. The sample contained ^{134}Cs, ^{137}Cs, ^{75}Se, ^{144}Ce, and ^{90}Sr. For all of these radionuclides, the element balance was low; only about one-half to two-thirds of the amount of each radionuclide present in the waste was accounted for in the leachates and residues. The cause of this low element balance is not known. Since the element balance values are similar for radionuclides that have different chemistries in the leachate solution, it seems possible that a systematic sampling or analytical error could be responsible. The fraction leached for the two cesium isotopes was essentially identical for all time points (1, 3, 5, 24, 48, and 96 h) and showed that all leachable cesium had been solubilized by the first time point (1 h). The fraction leached value was close to one-half, however, and was nearly the same as the element balance value. Thus, little confidence should be placed in the value for the fraction leached but only in the fact that it did not change with time. This waste sample also contained ^{75}Se. For selenium, the fraction released was low, less than one-fourth the initial selenium content, and appeared to increase slightly with time. The ^{144}Ce content of the waste was largely insoluble, and the fraction-released values did not show a significant trend with time. The ^{90}Sr data also indicate no trend with time; about one-third of the strontium was leached in 1 h or less.

A synthetic wipe waste from building 4500N which contained ^{99}Tc also was leached vs time. The results (Table B.9), after excluding one obvious error in residue analysis, show an excellent element balance (98 ± 2%) for all time points. The fraction-leached values show that essentially all the technetium (0.99) was leached in 1 h or less. Complete and rapid leaching is reasonable since the technetium handled in the laboratory from which the sample was obtained is NH_4TcO_4, which is known to be highly soluble.

The results of these few initial leach rate tests were sufficient to show that the TCLP method offers a practical and convenient method of doing multiple leach samples at different time points. The various waste/leachant mixtures in the glass bottles can be prepared simultaneously and clamped in the rotary extractor. Then at the desired times, single bottles

can be removed from the extractor and filtered. Filtration is much more rapid with the TCLP method than with the EP method for some wastes; therefore, the filtration time does not contribute significantly to the total leach time (time of contact between waste and leachant).

4. HAZARDOUS MATERIAL LEACHING

4.1 TEST GOALS

There were two general goals for the leach tests performed with the various ORNL low-activity LLW. These were:

1. To classify the wastes as RCRA hazardous/nonhazardous from the characteristics of extraction procedures, and to explore the leachability of these materials, if present, into a typical trench leachate solution. Current ORNL waste disposal practices prohibit the inclusion of hazardous materials in low-level radioactive wastes, but analytical confirmation of this practice apparently is not available. As with the work for radionuclides, screening-level categorization (leachable/nonleachable) of as many wastes as possible was undertaken in the limited time available. The leachate composition was compared with the RCRA waste toxicity characteristics regulation (40 CFR Part 261.24). The inorganic elements listed in that regulation are arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver.
2. To compare the effectiveness of both the current EP method and the proposed TCLP method in measuring the leachability of hazardous materials. ORNL has been developing the new proposed TCLP method[11] for the EPA and this work with actual waste samples provided an excellent opportunity to compare the two methods.

Because of the limited time available during FY 1985, it was possible to gather only preliminary information on a few waste samples. The results are presented in summarized form in this section, but all analytical values obtained are presented in Appendix C.

4.2 ANALYSIS OF WASTE SAMPLES

A few of the waste samples contained amounts of elements listed in 40 CFR Part 261.24, which could approach or exceed the toxic characteristic limit for the element in the leachate if the element was partially or completely leached into the test extract. These wastes and their analyses are shown in Table 4.1. (The complete analysis for all the wastes is given in Table C.1.) The analysis of EP and TCLP leach tests for these metals were subsequently carried out only on the leachate of these waste samples. The other wastes were considered to be of no interest for the hazardous materials studies. Cadmium, chromium, and lead were the only elements detected in concentrations in the waste samples to be of potential concern (i.e., these elements could approach or exceed the EPA concentrations for toxicity characteristics in the leachate solutions).

4.3 TOXICITY CHARACTERISTICS OF WASTE EXTRACTS

Both EP and TCLP leach tests were run in duplicate on the wastes. The results of the leach tests are given in Table 4.2 for only those elements of interest. A complete analytical record is presented in Table C.2. In no case did the extract concentration exceed the EPA toxicity characteristic limit; however, in two cases the concentration was an appreciable fraction of the limit. Cadmium in the plastic shoe cover EP and TCLP extracts was about one-half the EPA limit, but lead in the TCLP extract from the wipe from Building 3019 was about two-thirds of the limit.

Because of the very limited sampling of LLW that was conducted at ORNL during the time available, it is not possible to draw general conclusions as to the hazardous material content or potential toxicity of these wastes. Even though none of the extracts of the few samples tested exceeded the EPA limits, in a small percentage of the elements, the leachate concentration was a significant fraction of the limiting concentration. If there is interest in the future in studying the hazardous material content of LLW at ORNL, then a much more extensive sampling and analysis program would be required.

Table 4.1 Toxic element concentration in waste samples[a]
(all analyses are in μg/g)

Element[b]	Bldg. 3517			Bldg. 7920	Bldg. 3019
	Plastic shoe cover	Paper coveralls	Fine mop	Wipe	Wipe
As	c	c	c	c	c
Ba	c	c	c	c	c
Cd	890	40	13	c	c
Cr	780	c	70	31	c
Pb	110	c	52	c	210
Hg	c	c	c	c	c
Se	c	c	c	c	c
Ag	c	c	c	c	c

[a]Only samples and elements having potentially significant concentrations are shown in this table. A complete analytical record is given in Table C.1.

[b]From 40 CFS Part 261.24.

[c]Value too low to be significant in leachate.

Table 4.2 Analyses of waste extracts[a]
(all analyses in μg/g)

Element	Toxic characteristic limit[b]	Bldg. 3517						Bldg. 7920		Bldg. 3019	
		Plastic shoe cover		Paper coveralls		Fine mop		Wipe		Wipe	
		EP[c]	TCLP[c]	EP[c]	TCLP[c]	EP[c]	TCLP[c]	EP[c]	TCLP[c]	EP[c]	TCLP[c]
As	5.0	d	d	d	d	d	d	d	d	d	d
Ba	100.0	d	d	d	d	d	d	d	d	d	d
Cd	1.0	0.57	0.50	0.011	0.041	0.10	0.17	d	d	d	d
Cr	5.0	<0.02	0.26	d	d	<0.02	0.026	<0.02	<0.02	d	d
Pb	5.0	<0.2	1.7	d	d	<0.2	0.35	d	d	0.35	3.9
Hg	0.2	d	d	d	d	d	d	d	d	d	d
Se	1.0	d	d	d	d	d	d	d	d	d	d
Ag	5.0	d	d	d	d	d	d	d	d	d	d

[a]Summary data in this table are limited to elements of potential concern. Complete analysis is given in Table C.2.

[b]Data taken from 40 CFR Part 261.24.

[c]All values are an average of two duplicate tests.

[d]Insufficient amount in solid waste to represent potential concern.

The data in Table 4.2 show that in several cases the proposed TCLP method was more agressive than the current EP method in extracting toxic elements from the waste. For example, the chromium concentration in the plastic shoe cover EP method extract was <0.02 μg/g, but the TCLP extract was 0.26 μg/g. The lead concentration in the extract from the fine mop was <0.02 μg/g for the EP leach but was 0.35 μg/g for the TCLP leach. The extracts for the synthetic wipe from Building 3019 contained 0.35 μg/g lead by the EP method and 3.9 μg/g by the TCLP method.

5. ACKNOWLEDGMENTS

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7. APPENDIXES

APPENDIX A - EXPERIMENTAL METHODS

A.1 SAMPLE PREPARATION

The samples of waste received from the various ORNL generators were shredded and blended to obtain a homogenous starting material for the leach tests. Because duplicate tests of two leach methods were employed with many of the wastes, it was considered important to generate a blended starting material from the various waste samples. It seemed unlikely that any contamination would be evenly distributed throughout the samples (rags, mops, coveralls, etc.) as received. Each entire waste sample (with the exception of the ion-exchange resin from Building 7900) was shredded in a No. 4 Wiley mill. Because of the level of radioactivity in many of the samples, the mill was placed in a radiochemical hood, and appropriate protective clothing and apparatus were worn by the operator (see Fig. A.1). The mill was smeared and counted between samples. No transferable counts were detected, so we assume cross contamination between samples did not occur in the mill. The shredded samples were discharged from the Wiley mill into a large plastic bag and further blended by shaking and turning the plastic bag. An aliquot of the blended sample was submitted for analysis.

A.2 EPA LEACH METHODS

Two batch leaching methods were used to measure the extractability of the radionuclides and hazardous materials in the waste samples collected from the various generators. The methods used were the following: (1) the current EPA waste toxicity extraction procedure, 40 CFR Part 261.24, identified in this report as "EP" toxicity characteristic test, and (2) a proposed modified toxicity characteristic leaching procedure being developed for the EPA,[11] identified as "TCLP" in this report.

ORNL PHOTO 4230-85

Fig. A.1. Operator feeding waste sample into the Wiley mill mounted in a radiochemical hood.

A.2.1 EP Toxicity Test Procedure

A 100-g aliquot of shredded and blended waste was weighed into a 1-gal glass bottle, and 1600 mL of distilled water was added. The mixture was then stirred by a motor-driven four-blade paddle. (In some cases, a greater water-to-waste ratio had to be employed in order to allow the sample to stir.) The experimental setup is shown in Fig. A.2. Sufficient 0.5 M acetic acid was added from the burette over about 10 to 30 min to adjust the pH to 5.0. The pH of the solution was then maintained at 5.0 with a Chemtrix autotitrator for the entire leach period. All leaching was at ambient temperature (25°C). Leaching was terminated after the waste had stirred for 24 h at pH 5.0, at which time additional distilled water was added to bring the total volume of liquid added to 2000 mL. (This addition was not made for those samples which had required additional liquid initially to permit stirring.) The leach solution and solid were then promptly separated by a Millipore filter apparatus, as shown in Fig. A.3. The filter medium was 0.45-μm-pore size Millipore No. 142/50. Air pressures as high as 85 psi were used in some cases to force the solution through the filter. The leachate solution was stored at 4°C until it was analyzed. The solid residue on the filter was submitted for analysis. The water content of the wet residue was calculated from the weight loss on drying.

A.2.2 TCLP Toxicity Characteristic Leaching Procedure

A 100-g aliquot of the shredded and blended waste was placed in a special screw-top borosilicate glass bottle (see Fig. A.4). Then 2000 mL of a 0.1 M sodium acetate-acetic acid buffer at pH 4.8 (prepared by diluting 10.50 g of anhydrous sodium acetate and 4.12 mL of glacial acetic acid to a final volume of 2000 mL with distilled water) was added to the bottle. The buffer solution was prepared as described,[11] but we obtained a pH of 4.8 rather than 5.0 as indicated in the reference. The bottle was capped, clamped in the rotary extractor, and rotated at 30 rpm for 18 h at ambient temperature (25°C). After completion of the leaching period, the solution and solids were separated by filtration with the

ORNL PHOTO 4231-85

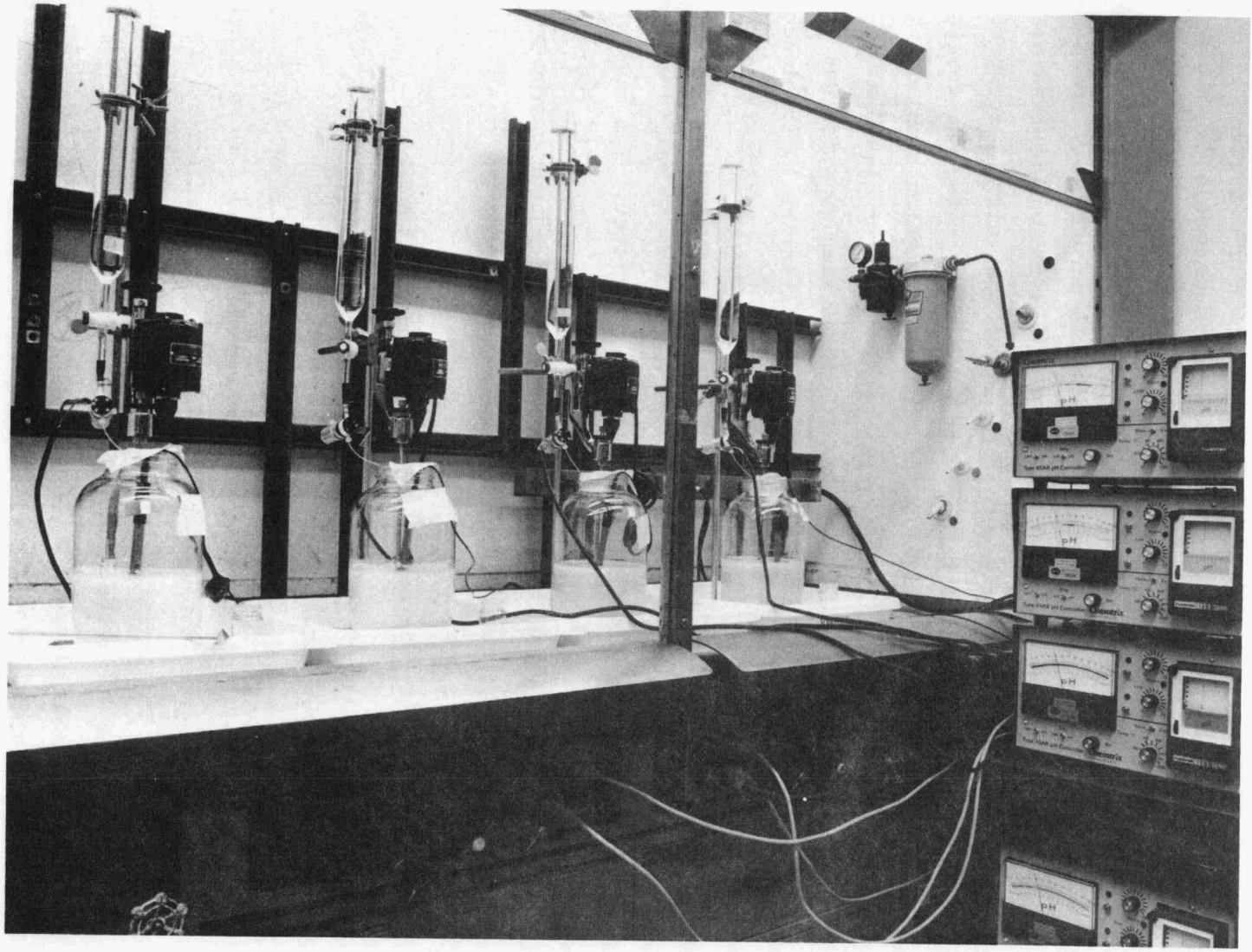

Fig. A.2. Experimental setup for EP leach tests.

ORNL PHOTO 4227-85

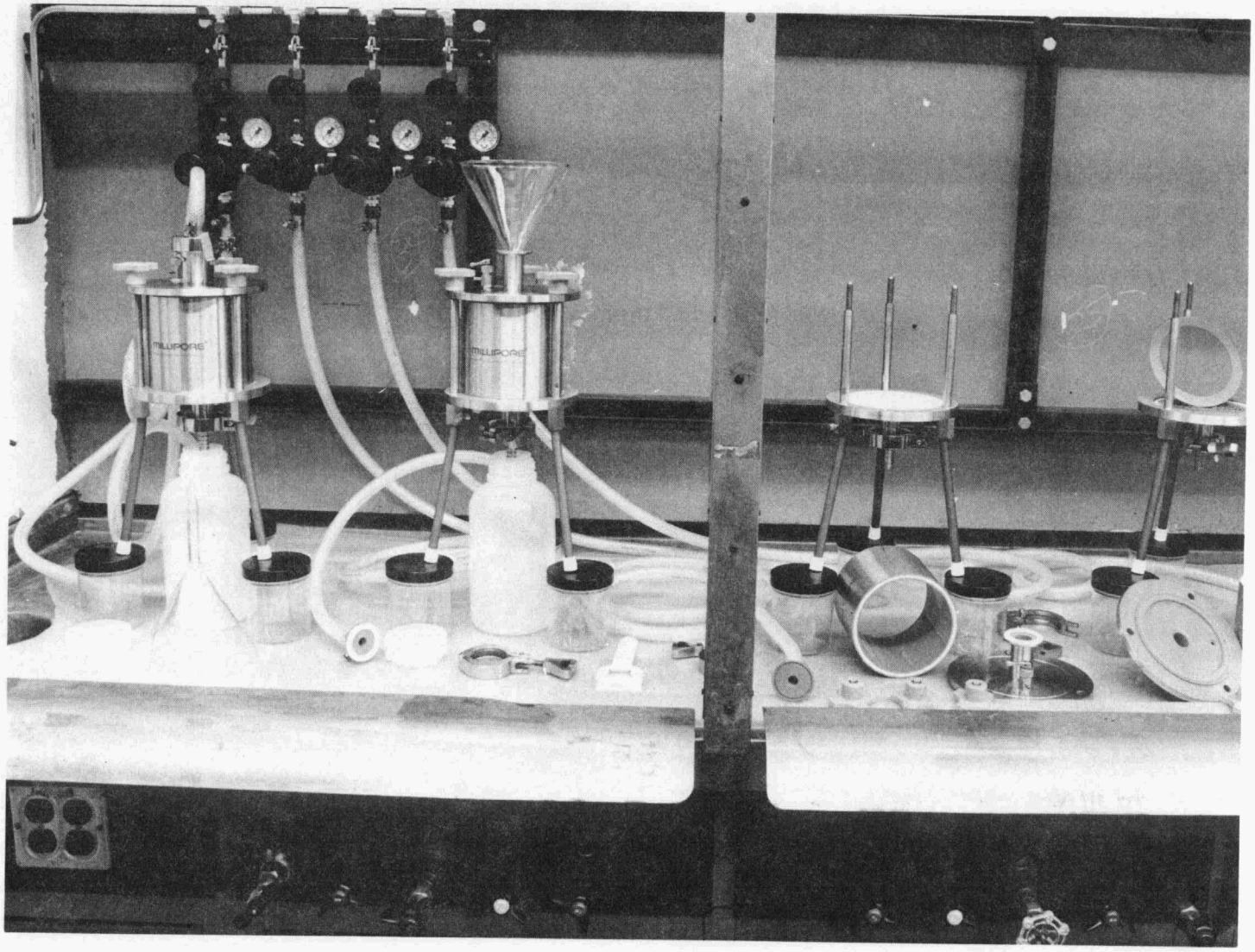

Fig. A.3. Filtration apparatus used in both EP and TCLP methods.

ORNL PHOTO 4228-85

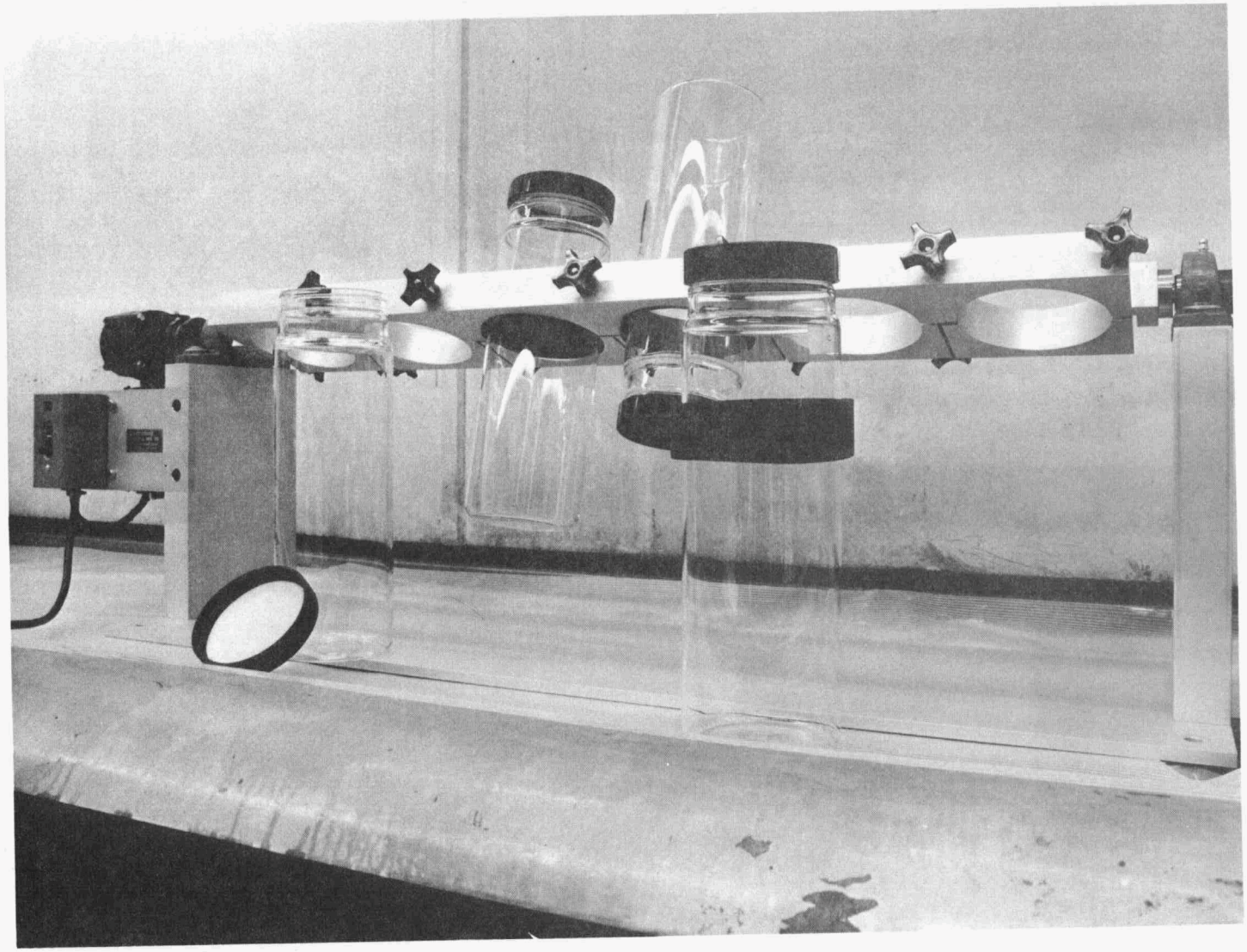

Fig. A.4. Experimental setup for TCLP leach tests.

Millipore apparatus. The filter medium was 0.6-μm (Whatman borosilicate glass filter No. EPM 2000) which contained no binder. Very little air pressure was needed to force the liquid through the filter. The solution was stored at 4°C until it was analyzed. The solids were submitted for analysis. The water content of the wet residue was calculated from the weight loss after drying.

A.2.3 Rate Experiments

A few experiments were carried out to explore the rate of solubilization of some of the radionuclides. These tests followed the TCLP method with the exception that a series of six replicate leach mixtures were prepared and tests run for leach periods of 1, 3, 5, 24, 48, and 96 h.

A.3 SAMPLE ANALYSIS

All analytical work was performed by the ORNL Analytical Chemistry Division.

A.3.1 Initial Waste Samples

An aliquot of each of the shredded and blended wastes was analyzed as follows: (1) by inductively coupled plasma spectrometry (ICP) for 31 elements (see Table C.1 for a listing of the elements), (2) by atomic absorption (AA) for mercury and selenium, (3) for gross alpha activity using a gas flow proportional alpha detector, (4) when a significant level of gross alpha activity was detected, the alpha emitters were identified by alpha spectrometry using a multichannel analyzer, (5) for gross beta activity by a gas flow beta proportioning counting technique, (6) when beta activity was detected, a ^{90}Sr analysis was performed by chemically separating the strontium and counting the ^{90}Sr beta activity using a low-background gas flow beta proportional counter, and, (7) by gamma spectrometry employing a Ge(Li) detector with a multichannel analyzer to identify and quantify the gamma-emitting radionuclides present. As appropriate, a portion of the solid samples was solubilized before the respective analyses.

A.3.2 Leach Test Solutions and Residues

Each leach test solution and residue was analyzed for the radionuclides present in the initial waste sample. The solutions and residues were analyzed by ICP and AA for all the hazardous materials. The analytical methods used were those described for the starting materials.

A.4 CALCULATION OF FRACTION SOLUBILIZED AND ELEMENT BALANCE

The data for the radionuclides were reported by ORNL Analytical Chemistry Division as Becquerels (Bq) per 1000 mL or 1000 g of sample; the nonradioactive inorganic elements were reported as μg/g. The total amount of a given element in a liquid or solid sample was then calculated by multiplying by the appropriate sample volume or weight. The amount of element in the leached residue was calculated by first determining the concentration for the dry residue and then the total amount in the dry residue by the following equations:

$$a = [b - (c)(d)]/e, \tag{1}$$

$$F = a/g, \tag{2}$$

where

- a = concentration of element per 1000 g dry residue,
- b = residue analysis value,
- c = liquid analysis value,
- d = fraction of water in sample,
- e = fraction of solid in sample (1.00 - d),
- F = amount of element in dry residue,
- g = weight of starting material.

The fraction leached was calculated by dividing the total amount of element in the solution by the total amount in the starting sample. The element balance then was the sum of the amount of the element in the solution and residue divided by the amount in the starting sample.

Note that the radioactivity values in the tables have been rounded to two significant figures for presentation, but in some cases where the analytical precision was adequate, three significant figures were used in the calculation of the element balance and fraction leached.

APPENDIX B - DATA FOR RADIONUCLIDES

The analytical data for the radioactive elements and the calculated concentration in the leachate, analytical element balance, and fraction leached are given in the following tables.

Table B.1 ^{137}Cs leach results for samples from fission product utilization building low-level waste (Building 3517)

Waste sample	Test conditions				Starting sample	Leachate		Residue	Element balance	Fraction leached
	Leach method	Test No.	Waste (g)	Leachate (mL)	(∑Bq)	(∑Bq)	mol/L	(∑Bq)	(%)	
Blotter paper (BP052985)	EP	1	100	2000	5.4E4	1.3E4	1.3E-11	2.0E4	63	0.24
	EP	2	100	2000	5.4E4	1.4E4	1.4E-11	2.6E4	74	0.25
	TCLP	1	100	2000	5.4E4	1.9E4	1.9E-11	2.0E4	71	0.35
	TCLP	2	100	2000	5.4E4	1.9E4	1.9E-11	1.8E4	69	0.35
Coarse mop (CM052985)	EP	1	100	2683	7.1E2	1.9E2	1.4E-13	3.2E2	72	0.27
	EP	2	100	2675	7.1E2	1.9E2	1.4E-13	1.0E3	173	0.27
	TCLP	1	100	2000	7.1E2	2.2E2	2.2E-13	1.7E3	267	0.26
	TCLP	2	100	2000	7.1E2	2.2E2	2.2E-13	3.2E2	76	0.26
Fine mop (FM052985)	EP	1	100	2000	8.6E2	1.5E2	1.5E-13	4.2E2	67	0.17
	EP	2	100	2000	8.6E2	1.4E2	1.4E-13	4.7E2	71	0.16
	TCLP	1	100	2000	8.6E2	2.0E2	1.9E-13	4.7E2	77	0.23
	TCLP	2	100	2000	8.6E2	2.0E2	2.0E-13	4.2E2	72	0.23
Cloth coveralls (CC052985)	EP	1	100	2412	3.1E1	3.6E0	3.0E-15	3.1E1	112	0.12
	EP	2	100	2412	3.1E1	5.6E0	4.6E-15	2.8E1	109	0.18
	TCLP	1	100	2000	3.1E1	6.4E0	6.4E-15	1.1E1	56	0.21
	TCLP	2	100	2000	3.1E1	5.6E0	5.6E-15	1.0E1	49	0.18
Plastic shoe covers (PCS052985)	EP	1	100	2000	3.1E2	2.2E2	2.2E-13	1.8E2	129	0.71
	EP	2	100	2000	3.1E2	8.4E1	8.4E-14	1.7E2	82	0.27
	TCLP	1	100	2000	3.1E2	1.2E2	1.2E-13	1.2E2	77	0.38
	TCLP	2	100	2000	3.1E2	1.3E2	1.3E-13	1.1E2	77	0.43
Paper coveralls (PCC052985)	EP	1	75	2000	3.5E4	1.1E4	1.1E-11	1.7E4	80	0.33
	EP	2	75	2000	3.5E4	1.3E4	1.3E-11	1.3E4	75	0.38
	TCLP	1	100	2000	4.7E4	1.5E4	1.5E-11	2.1E5	652	0.32
	TCLP	2	100	2000	4.7E4	1.6E4	1.6E-11	2.0E4	102	0.35

Table B.2 ^{134}Cs leach results for samples from fission product utilization building low-level waste (Building 3517)

Waste sample[a]	Test conditions				Starting sample	Leachate		Residue	Element balance	Fraction leached
	Leach method	Test No.	Waste (g)	Leachate (mL)	(∑Bq)	(∑Bq)	mol/L	(∑Bq)	(%)	
Blotter paper (BP052985)	EP	1	100	2000	1.9E1	3.0E0	2.3E-16	8.8E0	62	0.16
	EP	2	100	2000	1.9E1	b	-	3.6E0	-	-
	TCLP	1	100	2000	1.9E1	5.4E0	4.2E-16	3.8E0	48	0.28
	TCLP	2	100	2000	1.9E1	6.4E0	5.0E-16	5.3E0	62	0.32
Paper coveralls (PCC052985)	EP	1	75	2000	1.4E1	b	-	9.5E0	-	-
	EP	2	75	2000	1.4E1	2.8E0	2.2E-16	b	-	-
	TCLP	1	100	2000	1.7E1	b	-	5.6E1	-	-
	TCLP	2	100	2000	1.7E1	7.8E0	6.1E-16	7.6E0	81	0.46

[a]Amounts of ^{134}Cs was below detection level in all other samples.

[b]No data.

Table B.3 ^{60}Co leach results for samples from fission product utilization building low-level waste (Building 3517)

Waste sample[a]	Test conditions				Starting sample	Leachate		Residue	Element balance	Fraction leached
	Leach method	Test No.	Waste (g)	Leachate (mL)	($\sum$Bq)	($\sum$Bq)	mol/L	($\sum$Bq)	(%)	
Blotter paper (BP052985)	EP	1	100	2000	3.1E1	3.2E0	6.3E-16	1.5E1	58	0.10
	EP	2	100	2000	3.1E1	<2.0E0	<3.9E-16	7.5E0	24	-
	TCLP	1	100	2000	3.1E1	6.8E0	1.3E-15	1.9E1	83	0.22
	TCLP	2	100	2000	3.1E1	5.0E0	9.9E-16	1.0E1	49	0.16
Coarse mop (CM052985)	EP	1	100	2683	7.0E2	1.4E2	2.0E-14	3.6E2	71	0.20
	EP	2	100	2675	7.0E2	1.5E2	2.2E-14	4.0E2	78	0.21
	TCLP	1	100	2000	7.0E2	1.4E2	2.8E-14	3.5E2	71	0.21
	TCLP	2	100	2000	7.0E2	1.3E2	2.6E-14	3.6E2	70	0.19
Fine mop (FM052985)	EP	1	100	2000	3.4E2	1.1E2	2.2E-14	1.1E2	66	0.33
	EP	2	100	2000	3.4E2	1.3E2	2.5E-14	1.1E2	72	0.38
	TCLP	1	100	2000	3.4E2	1.2E2	2.4E-14	1.3E2	73	0.35
	TCLP	2	100	2000	3.4E2	1.2E2	2.4E-14	1.3E2	75	0.35
Paper coveralls (PCC052985)	EP	1	75	2000	2.3E2	5.4E2	1.1E-13	4.2E1	259	0.24
	EP	2	75	2000	2.3E2	6.2E2	1.2E-13	4.9E1	296	0.28
	TCLP	1	100	2000	3.0E2	1.2E2	2.4E-14	1.2E3	423	0.40
	TCLP	2	100	2000	3.0E2	1.3E2	2.5E-14	4.8E1	58	0.42

[a] ^{60}Co was below detection limit in all other samples.

Table 8.4 ^{75}Se leach results for samples from fission product utilization building low-level waste (Building 3517)

Waste sample[a]	Test conditions				Starting sample	Leachate		Residue	Element balance	Fraction leached
	Leach method	Test No.	Waste (g)	Leachate (mL)	($\sum$Bq)	($\sum$Bq)	mol/L	($\sum$Bq)	(%)	
Coarse mop (CM052985)	EP	1	100	2683	1.5E3	4.6E2	4.2E-15	5.0E2	63	0.30
	EP	2	100	2678	1.5E3	4.6E2	2.1E-15	5.6E2	68	0.30
	TCLP	1	100	2000	1.5E3	4.4E2	5.5E-15	5.3E2	65	0.29
	TCLP	2	100	2000	1.5E3	4.4E2	5.5E-15	6.0E2	69	0.29
Fine mop (FM052985)	EP	1	100	2000	9.1E2	2.0E2	2.4E-15	5.0E2	76	0.22
	EP	2	100	2000	9.1E2	1.8E2	2.3E-15	5.2E2	77	0.20
	TCLP	1	100	2000	9.1E2	1.6E2	2.0E-15	6.3E2	87	0.18
	TCLP	2	100	2000	9.1E2	1.6E2	2.0E-15	5.9E2	82	0.17

[a] ^{75}Se was below detection limit in all other samples.

Table B.5 ^{152}Eu leach results for samples from fission product utilization building low-level waste (Building 3517)

Waste sample[a]	Test conditions				Starting sample	Leachate		Residue	Element balance	Fraction leached
	Leach method	Test No.	Waste (g)	Leachate (mL)	($\sum$Bq)	($\sum$Bq)	mol/L	($\sum$Bq)	(%)	
Coarse mop (CM052985)	EP	1	100	2683	9.4E2	2.0E1	7.3E-15	7.0E2	77	0.02
	EP	2	100	2675	9.4E2	1.6E1	5.8E-15	b		0.02
	TCLP	1	100	2000	9.4E2	4.4E1	2.2E-14	5.8E2	63	0.05
	TCLP	2	100	2000	9.4E2	3.8E1	1.8E-14	7.0E2	79	0.04
Fine mop (FM052985)	EP	1	100	2000	4.5E2	1.3E1	6.3E-15	3.1E2	71	0.03
	EP	2	100	2000	4.5E2	2.2E1	1.1E-14	2.9E2	70	0.05
	TCLP	1	100	2000	4.5E2	5.4E1	2.6E-14	3.5E2	90	0.12
	TCLP	2	100	2000	4.5E2	5.0E1	2.5E-14	2.6E2	70	0.11

[a] ^{152}Eu was below detection limit in all other samples.

[b] No data.

Table B.6 ^{154}Eu leach results for samples from Fission Product Utilization building low-level waste (Building 3517)

Waste sample[a]	Test conditions				Starting sample	Leachate		Residue	Element balance	Fraction leached
	Leach method	Test No.	Waste (g)	Leachate (mL)	($\sum$Bq)	($\sum$Bq)	mol/L	($\sum$Bq)	(%)	
Coarse mop (CM052985)	EP	1	100	2683	5.6E2	2.6E1	6.2E-15	5.3E2	100	0.05
	EP	2	100	2675	5.6E2	1.6E1	3.8E-15	4.9E2	90	0.03
	TCLP	1	100	2000	5.6E2	2.0E1	6.5E-15	3.9E2	74	0.04
	TCLP	2	100	2000	5.6E2	3.0E1	9.7E-15	4.9E2	93	0.05
Fine mop (FM052985)	EP	1	100	2000	2.9E2	b	-	1.9E2	-	-
	EP	2	100	2000	2.9E2	b	-	2.9E2	-	-
	TCLP	1	100	2000	2.9E2	3.2E1	1.6E-14	2.3E2	78	0.11
	TCLP	2	100	2000	2.9E2	2.8E1	9.1E-15	1.9E2	65	0.10

[a] ^{154}Eu was below detection limit in all other samples.

[b] No data.

Table B.7 ^{90}Sr leach results for samples from Fission Product Utilization building low-level waste (Building 3517)

Waste sample	Test conditions				Starting sample	Leachate		Residue	Element balance	Fraction leached
	Leach method	Test No.	Waste (g)	Leachate (mL)	(∑Bq)	(∑Bq)	mol/L	(∑Bq)	(%)	
Blotter paper (BP052985)	EP	1	100	2000	5.1E3	1.8E3	1.9E-12	5.6E2	47	0.36
	EP	2	100	2000	5.1E3	1.9E3	2.0E-12	a	---	0.37
	TCLP	1	100	2000	5.1E3	5.5E3	5.7E-12	8.8E2	125	1.08
	TCLP	2	100	2000	5.1E3	4.6E3	4.8E-12	1.4E4	365	0.90
Coarse mop (CM052985)	EP	1	100	2683	8.4E3	1.9E3	1.5E-12	1.4E3	39	0.23
	EP	2	100	2675	8.4E3	2.1E3	1.6E-12	6.2E3	99	0.25
	TCLP	1	100	2000	8.4E3	2.6E3	2.7E-12	1.3E3	46	0.31
	TCLP	2	100	2000	8.4E3	2.6E3	2.7E-12	3.1E3	68	0.31
Fine mop (FM052985)	EP	1	100	2000	4.2E2	3.2E2	3.3E-13	1.1E2	102	0.76
	EP	2	100	2000	4.2E2	3.2E2	3.3E-13	1.1E2	102	0.76
	TCLP	1	100	2000	4.2E2	3.6E2	3.8E-13	8.4E1	106	0.86
	TCLP	2	100	2000	4.2E2	3.6E2	3.8E-13	1.8E2	129	0.86
Cloth coveralls (CC052985)	EP	1	100	2412	3.5E3	2.3E3	2.0E-12	2.9E3	148	0.65
	EP	2	100	2412	3.5E3	2.7E3	2.3E-12	2.7E3	153	0.76
	TCLP	1	100	2000	3.5E3	3.8E3	4.0E-12	4.1E3	226	1.09
	TCLP	2	100	2000	3.5E3	4.0E3	4.2E-12	3.0E3	200	1.14
Plastic shoe covers (PSC052985)	EP	1	100	2000	5.8E2	4.0E2	4.2E-13	3.7E2	133	0.67
	EP	2	100	2000	5.8E2	4.8E2	5.0E-13	1.0E3	254	0.83
	TCLP	1	100	2000	5.8E2	1.5E2	1.6E-12	4.0E2	327	2.59
	TCLP	2	100	2000	5.8E2	5.2E2	5.4E-13	2.0E2	124	0.90
Paper coveralls (PCC052985)	EP	1	75	2000	1.4E4	5.6E3	5.8E-12	6.3E3	88	0.42
	EP	2	75	2000	1.4E4	6.4E3	6.7E-12	1.9E3	62	0.47
	TCLP	1	100	2000	1.8E4	1.1E4	1.1E-11	1.8E3	69	0.59
	TCLP	2	100	2000	1.8E4	1.2E4	1.3E-11	1.9E3	77	0.67

[a]No data.

Table B.8 Leach results for synthetic wipe samples from Buildings 3019, 7920, 4500N, 4501, 3074, and 3470

Building	Test conditions				Starting sample	Leachate		Residue	Element balance	Fraction leached
	Leach method	Test No.	Waste (g)	Leachate (mL)	(∑Bq)	(∑Bq)	mol/L	(∑Bq)	(%)	
Results for ^{137}Cs										
3019	EP	1	100	2801	8.6E1	4.8E1	3.4E-14	2.0E1	79	0.55
(W072385)	EP	2	100	2801	8.6E1	1.0E1	7.2E-15	9.7E0	23	0.12
	TCLP	1	100	2000	8.6E1	4.6E1	4.6E-14	a	--	0.53
	TCLP	2	100	2000	8.6E1	2.0E1	2.0E-14	2.3E1	50	0.23
7920	EP	1	100	2000	2.1E5	5.8E4	5.8E-11	8.1E3	32	0.28
(W081285)	EP	2	100	2000	2.1E5	6.6E4	6.6E-11	7.7E3	35	0.31
	TCLP	1	100	2000	2.1E5	6.4E4	6.4E-11	0	31	0.30
	TCLP	2	100	2000	2.1E5	7.0E4	7.0E-11	1.7E3	34	0.33
4501	EP	1	100	2000	2.3E5	1.2E5	1.3E-10	5.9E7	26,000	0.51
(W080585)	EP	2	100	2000	2.3E5	1.3E5	1.3E-10	6.0E7	26,000	0.56
	TCLP	1	100	2000	2.3E5	1.5E5	1.5E-10	1.6E4	71	0.64
	TCLP	2	100	2000	2.3E5	1.4E5	1.4E-10	1.4E4	67	0.61
3074	EP	1	100	2000	2.0E3	7.8E2	7.8E-13	6.4E2	71	0.39
(W080985)	EP	2	100	2000	2.0E3	6.8E2	6.8E-13	6.1E2	65	0.34
	TCLP	1	100	2000	2.0E3	9.4E2	9.4E-13	4.2E2	68	0.47
	TCLP	2	100	2000	2.0E3	1.3E3	1.3E-12	5.4E2	90	0.63
Results for ^{134}Cs										
7920	EP	1	100	2000	8.1E3	2.2E4	1.7E-12	2.7E3	304	2.71
(W081285)	EP	2	100	2000	8.1E3	2.4E4	1.9E-12	2.5E3	327	2.96
	TCLP	1	100	2000	8.1E3	2.4E4	1.9E-12	0	296	2.96
	TCLP	2	100	2000	8.1E3	2.6E4	2.0E-12	3.7E1	321	3.21
4501	EP	1	100	2000	4.1E4	2.0E4	1.6E-12	1.0E7	25,000	0.49
(W080585)	EP	2	100	2000	4.1E4	2.2E4	1.7E-12	1.0E7	25,000	0.54
	TCLP	1	100	2000	4.1E4	2.6E4	2.0E-12	2.7E3	70	0.63
	TCLP	2	100	2000	4.1E4	2.4E4	1.9E-12	2.4E3	64	0.59
3074	EP	1	100	2000	2.4E2	5.6E1	4.4E-15	3.7E1	39	0.23
(W080985)	EP	2	100	2000	2.4E2	9.6E1	7.5E-15	3.8E1	56	0.40
	TCLP	1	100	2000	2.4E2	1.1E2	8.6E-15	1.5E1	52	0.46
	TCLP	2	100	2000	2.4E2	1.2E2	9.2E-15	1.7E1	56	0.49

Table B.8 (continued)

Building	Test conditions: Leach method	Test No.	Waste (g)	Leachate (mL)	Starting sample (∑Bq)	Leachate (∑Bq)	Leachate mol/L	Residue (∑Bq)	Element balance (%)	Fraction leached
Results for ^{75}Se										
3047	EP	1	100	2005	8.1E5	1.7E5	2.1E-12	4.0E5	71	0.21
(W060685)	EP	2	100	2006	8.1E5	1.8E5	2.3E-12	4.9E5	83	0.23
	TCLP	1	100	2000	8.1E5	1.7E5	2.1E-12	3.1E5	59	0.21
	TCLP	2	100	2000	8.1E5	1.6E5	2.0E-12	4.1E5	70	0.20
3019	EP	1	100	2000	6.2E3	1.1E3	1.4E-14	9.8E2	34	0.18
(W072385)	EP	2	100	2000	6.2E3	1.2E3	1.5E-14	7.4E2	32	0.20
	TCLP	1	100	2000	6.2E3	1.3E3	1.6E-14	2.6E3	63	0.20
	TCLP	2	100	2000	6.2E3	1.4E3	1.8E-14	2.9E3	70	0.20
4501	EP	1	100	2000	a	5.8E2	7.2E-15	8.4E5	—	—
(W080585)	EP	2	100	2000	a	5.4E2	6.7E-15	1.1E6	—	—
	TCLP	1	100	2000	a	6.8E2	8.5E-15	4.4E2	—	—
	TCLP	2	100	2000	a	5.2E2	6.5E-15	5.1E2	—	—
3074	EP	1	100	2000	6.0E2	1.6E2	2.0E-15	2.7E2	73	0.27
(W080985)	EP	2	100	2000	6.0E2	1.3E2	1.6E-15	1.5E2	46	0.22
	TCLP	1	100	2000	6.0E2	1.6E2	2.0E-15	1.9E2	59	0.26
	TCLP	2	100	2000	6.0E2	1.5E2	1.8E-15	2.5E2	67	0.25
Results for ^{60}Co										
3047	EP	1	100	2005	2.4E4	2.0E3	3.9E-13	1.7E4	78	0.08
(W060685)	EP	2	100	2006	2.4E4	1.0E3	2.0E-13	1.6E4	69	0.04
	TCLP	1	100	2000	2.4E4	2.4E4	4.7E-12	3.5E3	110	1.00
	TCLP	2	100	2000	2.4E4	1.6E4	3.2E-12	2.2E3	76	0.67
3019	EP	1	100	2801	2.1E2	7.6E1	1.5E-14	4.7E1	58	0.36
(W072385)	EP	2	100	2801	2.1E2	4.5E1	8.9E-15	2.9E1	35	0.21
	TCLP	1	100	2000	2.1E2	6.8E1	1.3E-14	3.7E1	50	0.32
	TCLP	2	100	2000	2.1E2	5.6E1	1.1E-14	3.6E1	44	0.27
3074	EP	1	100	2000	6.6E1	2.4E1	4.7E-15	2.7E1	77	0.36
(W080985)	EP	2	100	2000	6.6E1	4.2E1	8.3E-15	4.2E1	127	0.63
	TCLP	1	100	2000	6.6E1	2.8E1	5.5E-15	3.4E1	94	0.42
	TCLP	2	100	2000	6.6E1	8.0E1	1.6E-14	3.7E1	177	1.21

Table B.8 (continued)

Building	Test conditions				Starting sample	Leachate		Residue	Element balance	Fraction leached
	Leach method	Test No.	Waste (g)	Leachate (mL)	($\sum$Bq)	($\sum$Bq)	mol/L	($\sum$Bq)	(%)	
Results for ^{90}Sr										
4501 (W080585)	EP	1	100	2000	4.6E2	5.5E2	5.7E-13	7.6E2	283	1.19
	EP	2	100	2000	4.6E2	2.1E2	2.2E-13	5.0E2	153	0.45
	TCLP	1	100	2000	4.6E2	5.2E2	5.4E-13	6.0E2	243	1.13
	TCLP	2	100	2000	4.6E2	5.0E2	5.2E-13	8.6E2	295	1.08
3074 (W080985)	EP	1	100	2000	1.2E3	5.6E2	5.8E-13	5.9E2	92	0.45
	EP	2	100	2000	1.2E3	4.4E2	4.6E-13	2.6E2	56	0.35
	TCLP	1	100	2000	1.2E3	8.2E2	8.5E-13	4.4E2	70	0.66
	TCLP	2	100	2000	1.2E3	1.6E3	1.7E-12	1.2E2	139	1.29
3047 (W060685)	EP	1	100	2005	7.8E2	3.3E2	3.5E-13	1.2E3	190	0.43
	EP	2	100	2006	7.8E2	2.9E2	3.0E-13	1.1E3	174	0.36
	TCLP	1	100	2000	7.8E2	9.2E3	9.6E-12	2.1E3	146	11.80
	TCLP	2	100	2000	7.8E2	4.1E2	4.3E-13	5.1E2	118	0.52
3019 (W072385)	EP	1	100	2801	4.1E2	1.9E1	1.4E-14	3.9E2	98	0.05
	EP	2	100	2801	4.1E2	2.5E1	1.8E-14	3.1E2	80	0.06
	TCLP	1	100	2000	4.1E2	4.8E1	5.0E-14	3.1E3	765	0.12
	TCLP	2	100	2000	4.1E2	3.0E1	3.1E-14	1.8E3	430	0.07

[a]No data.

Table B.9 Leach rate results for selected synthetic wipe samples

Building	Test conditions: Leach method	Waste (g)	Leachate (mL)	Sample time (h)	Starting sample (∑Bq)	Leachate (∑Bq)	Leachate (mol/L)	Residue (∑Bq)	Element balance (%)	Fraction leached
Results for ^{137}Cs										
7920	TCLP	100	2000	1	1.3E4	7.0E3	7.0E-12	7.2E2	59	0.54
(W081285)	TCLP	100	2000	3	1.3E4	6.8E3	6.8E-12	6.7E2	58	0.52
	TCLP	100	2000	5	1.3E4	7.0E3	7.0E-12	6.5E2	59	0.54
	TCLP	100	2000	24	1.3E4	7.2E3	7.2E-12	5.0E2	59	0.55
	TCLP	100	2000	48	1.3E4	6.8E3	6.8E-12	3.7E2	55	0.52
	TCLP	100	2000	96	1.3E4	6.6E3	6.6E-12	6.6E2	56	0.51
Results for ^{134}Cs										
7920	TCLP	100	2000	1	5.2E3	2.6E3	2.0E-13	3.0E2	56	0.50
(W081285)	TCLP	100	2000	3	5.2E3	2.6E3	2.0E-13	2.5E2	55	0.50
	TCLP	100	2000	5	5.2E3	2.6E3	2.0E-13	1.9E2	54	0.50
	TCLP	100	2000	24	5.2E3	2.6E3	2.0E-13	2.4E2	55	0.50
	TCLP	100	2000	48	5.2E3	2.6E3	2.0E-13	2.9E2	56	0.50
	TCLP	100	2000	96	5.2E3	2.6E3	2.0E-13	2.1E2	54	0.50
Results for ^{75}Se										
7920	TCLP	100	2000	1	2.8E2	4.4E1	5.5E-16	1.5E2	69	0.16
(W081285)	TCLP	100	2000	3	2.8E2	3.8E1	4.7E-16	1.4E2	63	0.14
	TCLP	100	2000	5	2.8E2	4.4E1	5.5E-16	1.1E2	56	0.16
	TCLP	100	2000	24	2.8E2	7.0E1	8.7E-16	1.5E2	79	0.25
	TCLP	100	2000	48	2.8E2	8.0E1	1.0E-15	1.7E2	89	0.29
	TCLP	100	2000	96	2.8E2	6.4E2	8.0E-16	1.5E2	76	0.23
Results for ^{144}Ce										
7920	TCLP	100	2000	1	4.9E4	1.9E3	5.5E-14	2.4E4	53	0.04
(W081285)	TCLP	100	2000	3	4.9E4	1.6E3	4.7E-14	2.4E4	52	0.03
	TCLP	100	2000	5	4.9E4	2.0E3	5.9E-14	2.1E4	47	0.04
	TCLP	100	2000	24	4.9E4	2.2E3	6.5E-14	2.3E4	52	0.05
	TCLP	100	2000	48	4.9E4	2.4E3	7.1E-14	3.2E4	71	0.05
	TCLP	100	2000	96	4.9E4	2.6E3	7.7E-14	2.8E4	63	0.05
Results for ^{99}Tc										
4500N	TCLP	100	2000	1	9.2E5	9.1E5	7.3E-6	0	99	0.99
(W082085)	TCLP	100	2000	3	9.2E5	9.0E5	7.2E-6	0	98	0.98
	TCLP	100	2000	5	9.2E5	8.9E5	7.2E-6	4.7E6	607	0.98
	TCLP	100	2000	24	9.2E5	9.1E5	7.3E-6	0	99	0.99
	TCLP	100	2000	48	9.2E5	9.0E5	7.2E-6	0	98	0.98
	TCLP	100	2000	96	9.2E5	8.7E5	7.0E-6	0	95	0.95
Results for ^{90}Sr										
7920	TCLP	100	2000	1	3.1E3	9.0E2	9.4E-13	9.0E2	58	0.29
(W081285)	TCLP	100	2000	3	3.1E3	1.0E3	2.0E-12	2.0E2	39	0.32
	TCLP	100	2000	5	3.1E3	7.6E2	7.9E-13	7.0E2	47	0.24
	TCLP	100	2000	24	3.1E3	8.4E2	8.8E-13	1.9E2	33	0.27
	TCLP	100	2000	48	3.1E3	1.0E3	1.1E-12	1.7E3	87	0.33

Table B.10 Leach results for used ion-exchange resin from Building 7900

Radionuclide	Test conditions				Starting sample	Leachate		Residue	Element balance	Fraction leached
	Leach method	Test No.	Waste (g)	Leachate (mL)	($\sum$Bq)	($\sum$Bq)	(mol/L)	($\sum$Bq)	(%)	
^{60}Co	EP	1	100	2000	8.9E6	1.9E2	3.7E-14	3.9E7	435	0.00002
	EP	2	100	2000	8.9E6	3.2E2	6.3E-14	3.7E6	42	0.00004
	TCLP	1	100	2000	8.9E6	1.3E4	2.6E-12	1.0E7	113	0.00015
	TCLP	2	100	2000	8.9E6	2.6E4	5.1E-12	1.7E7	195	0.00029

APPENDIX C - DATA FOR HAZARDOUS MATERIALS

The analytical data for the hazardous material elements are given in the following tables.

Table C.1 Analysis of waste samples[a]

Waste samples	Element (μg/g)														
	Ag	Al	As	B	Ba	Be	Ca	Cd	Co	Cr	Cu	Fe	Ga	Hg	Li
Fission product utilization (Bldg. 3517)															
Plastic shoe cover (052985)	<4.8	220	<9.6	<7.7	<1.9	1.2	12,000	890	9.7	780	<1.9	61	<29	<0.03	23
Cloth coverall (052985)	<4.9	800	<9.8	<7.8	<1.9	0.41	2,700	1.7	1.3	<3.9	7.1	180	<29	0.04	<20
Blotter paper (052985)	<5	91	<10	<8	<2	<0.2	660	<0.5	<1	<4	3	130	<30	<0.03	<20
Paper coverall (052985)	<4.5	23	<9	130	<1.8	<0.18	790	40	1.9	9.3	2.6	130	<27	<0.03	<18
Coarse mop (052985)	<4.8	<19	<9.7	<7.8	<1.9	0.2	1,800	1.8	1.5	10	75	550	<29	0.06	<19
Fine mop (052985)	<4.9	420	<9.8	<7.9	<2	0.71	5,100	13	3.4	70	350	2,300	<29	3.3	<20
Hot Cells (Bldg. 3019)															
Synthetic wipe (072385)	<7	1,100	<14	<11	<2.8	0.55	660	2.9	<1.4	9.6	8	780	<42	0.25	<28
Isotope production (Bldg. 3047)															
Synthetic wipe (060685)	<3.3	300	<6.7	<5.3	<1.3	0.42	29	<0.33	3.1	<2.7	1.3	37	<20	<0.03	15
Manipulator shop (Bldg. 3074)															
Synthetic wipe (080985)	<4.3	<17	<8.7	170	<1.7	0.3	580	<0.43	4.2	<3.5	2.5	3.8	<26	0.03	<17
HFIR (Bldg. 7900)															
IX resin (051685)	<4.4	650	<8.7	<7	<1.7	9	990	<0.44	3.1	14	<1.7	260	<26	<0.03	<17
TRU (Bldg. 7920)															
Synthetic wipe (081285)[a]	<3.8	280	<7.6	<6.1	<1.5	0.52	430	<0.38	3.4	6.9	<1.5	58	<23	<0.03	16
Synthetic wipe (081285)[a]	<3.5	300	<6.9	<5.6	<1.4	0.44	380	<0.35	2.9	31	<1.4	170	<21	0.04	15
Research laboratory (Bldg. 4501)															
Synthetic wipe (080585)	<3.8	<15	<7.7	13	<1.5	0.25	470	<0.38	3.6	<3.1	1.9	21	<23	1.3	<15
Research Laboratory (Bldg. 4500N)															
Synthetic wipe (082085)	<4.9	36	<9.8	<7.9	2.1	0.88	850	<0.49	6.7	5.3	2.7	34	<29	<0.03	<20

Table C.1 (continued)

Waste samples	Element (μg/g)															
	Mg	Mn	Mo	Na	Ni	P	Pb	Sb	Se	Si	Sn	Sr	Ti	V	Zn	Zr
Fission product utilization (Bldg. 3517)																
Plastic shoe cover (052985)	2600	2.4	<3.9	61	<5.8	590	110	80	<3	<19	<4.8	1.7	4,000	<0.96	120	2.9
Cloth coverall (052985)	300	4.7	<3.9	180	<5.8	1200	21	<20	<3	<20	9.2	6.3	120	<0.97	40	2.4
Blotter paper (052985)	86	2.9	<4	72	<6	<30	<20	<20	<3	<20	<5	1.4	27	<1	8.5	<2
Paper coverall (052985)	120	4.5	<3.6	190	<5.4	140	<18	<18	<3	96	<4.5	34	810	<0.9	120	<1.8
Coarse mop (052985)	460	16	<3.9	b	<5.8	330	36	27	<3	<19	<4.8	5.3	170	<0.97	100	<1.9
Fine mop (052985)	1,000	39	12	420	52	700	52	<20	<3	25	28	5.7	180	1.6	240	8.5
Hot cells (Bldg. 3019)																
Synthetic wipe (072385)	61	11	<5.6	220	<8.5	200	210	<28	<3	<28	<7	4.5	94	<1.4	94	<2.8
Isotope production (Bldg. 3047)																
Synthetic wipe (060685)	8.1	20	<2.7	210	<4	61	<13	64	<3	<13	<3.3	0.42	1,300	<0.67	3.9	<1.3
Manipulator shop (Bldg. 3074)																
Synthetic wipe (080985)	70	30	<3.5	200	<5.2	49	51	97	<3	<17	<4.3	1.1	2,000	0.98	<1.7	3
HFIR (Bldg. 7900)																
IX resin (051685)	240	7.7	<3.5	1100	10	58	<17	<17	<3	<17	<4.4	2.2	10	<0.87	9.2	<1.7
TRU (Bldg. 7920)																
Synthetic wipe (081285)[c]	64	24	<3.1	<38	<4.6	61	<15	65	<3	<15	<3.8	1.2	1,500	<0.76	3.3	<1.5
Synthetic wipe (081285)[c]	47	19	<2.8	<35	28	57	<14	49	<3	<14	<3.5	1	1,300	<0.69	15	<1.4
Research laboratory (Bldg. 4501)																
Synthetic wipe (080585)	58	23	<3.1	<38	<4.6	39	<15	73	<3	<15	<3.8	1	1,600	<0.77	2.1	95
Research laboratory (Bldg. 4500N)																
Synthetic wipe (082085)	100	36	<3.9	170	<5.9	33	<20	120	<3	<20	b	1.7	3,100	<0.98	53	23

[a]Se and Hg were analyzed by AA methods; all other elements were analyzed by ICP methods.

[b]No data.

[c]Duplication samples taken the same day.

Table C.2 Analyses of selected waste leach solutions and residues[a]
(all results in µg/g)

	Plastic shoe cover, Bldg. 3517 (PSC052985)							
	EP leach				TCLP leach			
Element	Leachate	Residue	Leachate	Residue	Leachate	Residue	Leachate	Residue
Ag	<0.07	<2.3	<0.07	<3.7	<0.07	<1.4	<0.07	<1.5
Al	<0.2	250	<0.2	150	<0.2	180	<0.2	150
As	<0.2	<4.6	<0.2	<7.4	<0.2	2.7	<0.2	<2.9
B	<0.1	<3.7	<0.1	<5.9	<0.1	<2.2	<0.1	<2.4
Ba	0.61	980	0.59	1,000	0.63	1,000	0.63	1,000
Be	<0.002	<0.092	<0.002	<0.15	<0.002	<0.054	<0.002	<0.059
Ca	34	9,900	33	10,000	45	9,100	45	8,700
Cd	0.58	670	0.56	720	0.54	680	0.45	680
Co	<0.02	1.1	<0.02	1.4	<0.02	0.97	<0.02	1.0
Cr	<0.02	700	<0.02	720	0.26	670	0.26	640
Cu	<0.02	1.4	<0.02	<1.5	0.023	<0.54	0.046	<0.59
Fe	0.41	150	0.33	83	0.48	94	0.52	85
Ga	<0.5	<14	<0.5	<22	<0.5	<8.1	<0.5	<8.8
Li	<0.2	<9.2	<0.2	<15	<0.2	<5.4	<0.2	<5.9
Mg	2.5	2,300	2.1	2,600	9.7	2,000	9.7	1,900
Mn	0.025	3.0	0.024	2.6	0.026	2.2	0.026	2.1
Mo	<0.02	1.9	<0.02	<2.9	<0.02	2.1	<0.02	2.1
Na	<0.5	110	<0.5	<37	b	170	b	170
Ni	<0.06	<2.8	<0.06	<4.4	<0.06	<1.6	<0.06	<1.8
P	0.47	480	0.46	480	0.64	480	0.66	480
Pb	<0.2	3,700	<0.2	3,800	1.7	3,500	1.7	3,400
Sb	<0.3	39	<0.3	37	<0.3	35	<0.3	35
Se	<0.4	<9.2	<0.4	<15	<0.4	5.6	<0.4	<5.9
Si	<0.08	<9.2	0.08	<15	<0.08	<5.4	0.082	<5.9
Sr	<0.013	25	0.013	27	0.014	27	0.013	26
Ti	<0.02	37	<0.02	17	<0.02	23	<0.02	21
V	<0.03	3.9	<0.03	4.0	<0.03	2.3	<0.03	2.4
Zn	0.13	98	0.17	98	0.14	97	0.21	97
Zr	<0.06	1.8	<0.06	<1.5	<0.06	1.3	<0.06	0.65

Table C.2 (continued)

Element	Paper coveralls, Bldg. 3517 (PCC052985)							
	EP leach				TCLP leach			
	Leachate	Residue	Leachate	Residue	Leachate	Residue	Leachate	Residue
Ag	<0.07	<0.32	<0.07	<0.32	<0.07	<0.35	<0.07	<0.32
Al	<0.2	60	<0.2	57	<0.2	37	<0.2	37
As	<0.2	<0.64	<0.2	<0.64	<0.2	<0.70	<0.2	<0.65
B	5.8	3.3	5.9	4.3	7.4	4.8	7.5	5.0
Ba	0.092	31	0.098	37	0.15	28	0.15	25
Be	0.002	<0.013	<0.002	<0.013	<0.002	<0.014	<0.002	<0.013
Ca	15	120	15	140	23	77	24	73
Cd	<0.009	19	0.014	23	0.038	16	0.044	14
Co	<0.02	0.089	<0.02	0.066	<0.02	<0.07	<0.02	0.072
Cr	<0.02	1.2	<0.02	1.1	<0.02	0.91	<0.02	1.1
Cu	<0.02	1.3	<0.02	1.6	<0.02	1.1	<0.02	1.1
Fe	0.15	42	0.2	55	0.54	35	0.53	35
Ga	<0.5	<1.9	<0.5	<1.9	<0.5	<2.1	<0.5	<1.9
Li	<0.2	<1.3	<0.2	<1.3	<0.2	<1.4	<0.2	<1.3
Mg	2.7	17	2.8	18	4	11	4	11
Mn	0.033	1.3	0.033	1.4	0.052	0.93	0.052	1.0
Mo	<0.02	0.94	<0.02	1.0	<0.02	1.0	<0.02	0.74
Na	9	20	9.2	18	1,500	1,100	1,500	1,200
Ni	<0.06	0.58	<0.06	0.56	<0.06	<0.42	<0.06	0.46
P	0.48	45	0.63	52	0.76	38	0.76	36
Pb	<0.2	4.8	<0.2	3.5	<0.2	3.6	<0.2	2.3
Sb	<0.3	<1.3	<0.3	<1.3	<0.3	<1.4	<0.3	1.5
Se	<0.2	<1.3	<0.4	<1.3	<0.4	<1.4	<0.4	<1.3
Si	0.28	1.6	0.29	2.6	0.35	2.5	0.38	3.0
Sr	1.1	5.2	1.1	5.8	1.7	2.5	1.7	2.6
Ti	<0.02	7.8	<0.02	9.9	<0.02	5.7	<0.02	5.6
V	<0.03	0.078	<0.03	<0.064	<0.03	<0.07	<0.03	<0.065
Zn	0.78	62	1.1	74	1.9	60	1.9	50
Zr	<0.06	<0.13	<0.06	0.15	<0.06	<0.14	<0.06	<0.13

Table C.2 (continued)

	Fine mop, Bldg. 3517 (FM052985)							
	EP leach				TCLP leach			
Element	Leachate	Residue	Leachate	Residue	Leachate	Residue	Leachate	Residue
Ag	<0.07	0.52	<0.07	1.6	<0.07	1.1	<0.07	1.2
Al	0.85	140	0.89	200	0.59	190	0.6	230
As	<0.2	<0.64	<0.2	<0.68	<0.2	<0.67	<0.2	<0.67
B	0.19	2.1	<0.19	2.9	0.19	2.8	0.19	3.1
Ba	0.19	5.9	0.2	7.1	0.18	6.9	0.18	8.1
Be	<0.002	<0.013	<0.002	<0.014	<0.002	<0.013	<0.002	<0.013
Ca	91	560	100	860	150	470	150	520
Cd	0.099	0.72	0.1	1.4	0.17	0.72	0.16	0.76
Co	<0.02	0.36	<0.02	0.63	<0.02	0.60	<0.02	0.68
Cr	<0.02	7.0	<0.02	11	0.026	11	0.025	13
Cu	0.32	52	0.33	38	0.28	180	0.29	140
Fe	0.2	570	0.32	570	1.6	610	2	850
Ga	<0.5	<1.9	<0.5	<2.0	<0.5	<2.0	<0.5	<2.0
Li	<0.2	<1.3	<0.2	<1.4	<0.2	<1.3	<0.2	<1.3
Mg	15	180	16	240	15	220	15	260
Mn	0.58	5.3	0.59	7.3	0.65	7.0	0.67	8.8
Mo	<0.02	1.4	<0.02	2.0	<0.02	4.6	<0.02	2.4
Na	37	28	37	34	b	970	1,600	960
Ni	0.07	5.1	0.067	8.6	0.093	8.3	0.098	10
P	4.7	110	4.5	120	1.2	180	0.94	190
Pb	<0.2	24	<0.2	31	0.36	26	0.34	33
Sb	<0.3	1.3	<0.3	1.7	<0.3	2.1	<0.3	1.9
Se	<0.4	<1.3	<0.4	1.7	<0.4	<1.3	<0.4	<1.3
Si	2.8	13	2.8	11	2.5	12	26	15
Sr	0.13	0.89	0.14	1.2	0.18	0.79	0.18	0.94
Ti	<0.02	4.4	<0.02	6.9	<0.02	6.3	<0.02	7.3
V	<0.03	0.54	<0.03	0.77	<0.03	0.78	<0.03	0.93
Zn	6.8	24	7	30	7.3	25	7.4	27
Zr	<0.06	2.0	<0.06	1.7	<0.06	2.1	<0.06	0.71

Table C.2 (continued)

Element	Wipe, Bldg. 7920 (W081285)							
	EP leach				TCLP leach			
	Leachate	Residue	Leachate	Residue	Leachate	Residue	Leachate	Residue
Ag	<0.07	<0.35	<0.07	<0.33	<0.07	<0.35	<0.07	0.54
Al	0.33	30	0.37	24	0.57	36	0.48	50
As	<0.2	<0.69	<0.2	<0.65	<0.2	<0.71	<0.2	<0.67
B	0.11	<0.56	0.11	0.52	0.14	0.71	0.13	0.58
Ba	0.08	5.2	0.081	4.5	0.14	5.2	0.14	4.6
Be	<0.002	<0.014	<0.002	<0.013	<0.002	<0.014	<0.002	<0.013
Ca	37	210	37	190	51	230	51	230
Cd	0.029	0.24	0.035	0.67	0.047	48	0.038	0.38
Co	<0.02	0.20	<0.02	0.19	<0.02	0.18	<0.02	0.21
Cr	<0.02	2.3	<0.02	2.2	<0.02	1.6	<0.02	1.6
Cu	0.23	120	0.23	96	0.25	35	0.25	96
Fe	0.24	160	0.35	170	0.61	180	0.53	180
Ga	<0.5	<2.1	<0.5	<2.0	<0.5	<2.1	<0.5	<2.0
Li	<0.2	<1.4	<0.2	<1.3	<0.2	<1.4	<0.2	<1.3
Mg	14	44	14	48	18	51	18	51
Mn	0.25	3.2	0.24	2.9	0.33	3.0	0.33	3.2
Mo	<0.02	0.60	<0.02	0.54	<0.02	0.58	<0.02	0.64
Na	b	62	b	69	b	1,300	1,700	1,400
Ni	<0.06	1.2	<0.06	1.2	<0.06	0.86	<0.06	0.85
P	6	69	6.1	60	8.2	49	8.1	74
Pb	0.65	68	0.73	210	3.1	140	3.5	130
Sb	<0.3	7.8	<0.3	6.9	<0.3	12	<0.3	7.8
Se	<0.4	<1.4	<0.4	<1.3	<0.4	<1.4	<0.4	<1.3
Si	1.4	2.7	1.5	3.2	2.1	4.4	1.9	2.5
Sr	0.14	0.87	0.14	0.78	0.21	0.84	0.21	0.92
Ti	<0.02	3.0	<0.02	2.6	0.042	3.8	0.03	4.6
V	<0.03	0.085	<0.03	0.089	0.032	0.15	0.033	0.12
Zn	1.7	22	1.6	20	2.1	22	2.2	24
Zr	<0.06	<0.14	<0.06	<0.13	<0.06	0.15	<0.06	0.16

Table C.2 (continued)

Element	Synthetic wipe, Bldg. 3019 (W060685)							
	EP leach				TCLP leach			
	Leachate	Residue	Leachate	Residue	Leachate	Residue	Leachate	Residue
Ag	<0.05	<0.35	<0.05	<0.32	<0.05	0.65	<0.05	<0.35
Al	<0.20	11	0.22	6.1	0.48	17	0.61	10
As	<0.10	<0.70	<0.10	<0.64	<0.10	<0.68	<0.10	<0.69
B	<0.08	<0.56	<0.08	0.82	<0.08	<0.54	<0.080	<0.55
Ba	<0.02	0.74	0.022	0.64	0.062	3.1	0.061	2.3
Be	<0.005	<0.014	<0.005	<0.013	<0.002	<0.014	<0.002	<0.014
Ca	0.24	41	14	31	23	52	22	45
Cd	0.005	0.22	0.038	0.18	0.086	0.22	0.088	0.22
Co	<0.01	<0.07	<0.010	<0.064	<0.010	0.083	<0.010	<0.069
Cr	<0.04	1.2	<0.040	1.1	<0.04	1.4	<0.040	1.9
Cu	0.048	0.65	0.20	0.63	0.26	0.94	0.25	1.7
Fe	0.032	90	0.17	83	0.99	130	1.3	150
Ga	<0.30	<2.1	<0.30	<1.9	<0.30	<2.0	<0.30	<2.1
Li	<0.20	<1.4	<0.02	<1.3	0.22	<1.4	0.23	<1.4
Mg	0.082	3.5	1.0	2.8	1.5	5.0	1.4	5.1
Mn	<0.005	0.39	0.081	0.35	0.12	0.47	0.11	0.56
Mo	<0.04	<0.28	<0.04	<0.26	0.043	<0.27	0.046	<0.28
Na	26	14	12	15	1,500	1,100	1,400	1,100
Ni	<0.06	<0.42	0.098	<0.38	0.14	0.52	0.14	0.45
P	<0.30	10	0.94	10	1.8	18	1.9	21
Pb	<0.20	37	0.51	31	3.9	46	3.9	52
Sb	<0.20	<1.4	<0.20	<1.3	<0.20	<1.4	<0.20	<1.4
Se	<0.20	<1.4	<0.20	<1.3	<0.20	<1.4	<0.20	<1.4
Si	<0.20	2.7	0.28	2.1	0.83	1.9	1.1	2.1
Sr	<0.005	0.28	0.12	0.24	0.19	0.25	0.18	0.29
Ti	<0.02	1.9	<0.02	1.3	0.021	2.5	0.038	2.3
V	<0.01	<0.07	0.01	<0.064	<0.010	0.090	<0.1	<0.69
Zn	0.026	5	1.7	3.9	2.8	4.9	2.7	6.0
Zr	<0.02	0.29	0.02	<0.13	<0.02	0.15	<0.02	<0.14

[a]Se and Hg were by AA methods; all other elements were by ICP methods.

[b]No data.

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