LOCKHEED MARTIN

**ENVIRONMENTAL
RESTORATION
PROGRAM**

RECEIVED

DEC 19 1997

ORNL/ER-425/V2

OSTI

**In Situ Vitrification Demonstration
at Pit 1, Oak Ridge National Laboratory**

**Volume 2. Site Characterization Report
of the Pit 1 Area**

This document has been approved by the
ORNL Technical Information Office
for release to the public. Date: 12/12/97

ENERGY SYSTEMS

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MANAGED BY
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

UCN-17580 (G 8-95)

dy

ER
»»»»»

MASTER

DISCLAIMER

**Portions of this document may be illegible
electronic image products. Images are
produced from the best available original
document.**

**In Situ Vitrification Demonstration
at Pit 1, Oak Ridge National Laboratory**

**Volume 2. Site Characterization Report
of the Pit 1 Area**

B. P. Spalding
M. A. Bogle
S. R. Cline
M. T. Naney
B. Gu

Date Issued—December 1997

Prepared for the
U.S. Department of Energy
Office of Environmental Management
under budget and reporting code EW 20

Environmental Management Activities at the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
managed by
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

PREFACE

In Situ Vitrification Demonstration at Pit 1, Oak Ridge National Laboratory Volume 1. Results of Treatability Study and Volume 2. Site Characterization Report of the Pit 1 Area (ORNL/ER-425/V1&V2) summarize the technical accomplishments, through September 1997, and status of the treatability study carried out on seepage Pit 1 to establish the field-scale technical performance of in situ vitrification (ISV).

CONTENTS

PREFACE	iii
FIGURES	vii
TABLES	xi
EXECUTIVE SUMMARY	xiii
1. SITE DESCRIPTION AND HISTORICAL BACKGROUND INFORMATION	1
2. PIT 1 CHARACTERIZATION	8
2.1 DEPTH OF PIT 1	8
2.2 LATERAL EXTENT OF PIT 1	11
2.3 DISTRIBUTION OF RADIOACTIVITY WITHIN PIT 1	20
2.4 VERTICAL DISTRIBUTION OF RADIOACTIVITY WITHIN AND AROUND PIT 1	23
2.5 WATER TABLE ELEVATION AND QUALITY WITHIN AND AROUND PIT 1 .	26
2.5.1 Pit 1 Geoprobe Well Installation	26
2.5.2 Water Level and Rainfall Monitoring	26
2.5.3 Comparison with Local Groundwater Data	27
2.5.4 Hydraulic Conductivity Estimation of Pit 1 Backfill Soil	28
2.5.5 Hydraulic Conductivity Estimation of Surrounding Undisturbed Soil	30
2.5.6 Perched Water Characteristics	34
2.6 DENSITY AND POROSITY OF PIT 1 FILL (SOIL) MATERIAL	45
2.7 CHEMICAL ANALYSES OF PIT 1 SOIL AND FILL	49
2.7.1 Pilot-Scale and Previous ISV Test Soils	49
2.7.2 Pit 1 Soil Elemental Composition and Its Spatial Distribution	50
2.8 RADIOCHEMICAL ANALYSES OF PIT 1 SOILS	64
2.9 GROUNDWATER SUSPENDED SOLIDS RADIOCHEMICAL COMPOSITION .	74
2.10 INVENTORY OF RADIONUCLIDES IN PIT 1	75
2.11 MELT PROPERTIES OF PIT 1 SOIL AND VOLATILIZATION OF ¹³⁷ CS	78
2.12 SOURCE SOIL LEACH PROPERTIES	84
2.12.1 Leaching Summary	84
2.12.2 Materials and Methods	85
2.12.3 Leaching Results	86
2.13 SITE PREPARATION FOR ISV	94
3. REFERENCES	99
APPENDIX A Project Procedures	A-1
APPENDIX B Bulk Densities and ¹³⁷ Cs Activities in Pit 1 Soil Cores	B-1

FIGURES

1. ORNL Waste Area Grouping 7, which contains the seven seepage pits and trenches, showing location of the pit 1 treatability study site (WAG7MAP.WPG).	3
2. ORNL seepage pit 1 dimensions showing the paving and grading plan for covering (PIT1PLAN.WPG).	4
3. Photograph of ORNL seepage pit 1 in 1955 showing the roof covering (PIT1PH55.WPG).	5
4. View of ORNL seepage pit 1 with asphalt cap in December 1988 (PIT1PH88.WPG).	6
5. Surface of ORNL Seepage Pit 1 in October 1993 exhibiting the many surface pipe penetrations resulting from site characterization activities (PIT1PH93.WPG).	7
6. Location of points in and around ORNL seepage pit 1 for penetration tests, AQ-rod insertions, water monitoring and sampling wells, and soil core sampling (PIT1LOCA.WPG).	9
7. Driving half-inch threaded rod into pit 1 fill material using electric vibratory hammer (DRIVPH93.WPG).	10
8. Penetration of 0.5-in. rod into pit 1 at point 14 (Fig. 6, H14TRPEN.WPG).	12
9. Velocity of 0.5-in. rod into pit 1 at penetration point 14 (Fig. 6, H14TRVEL.WPG).	12
10. Penetration of 0.5-in. rod into soil formation at point 12 (Fig. 6, H12TRPEN.WPG).	13
11. Velocity of 0.5-in. rod into soil formation at point 12 (Fig. 6, H12TRVEL.WPG).	13
12. Elevation of refusal depths of threaded rods within and around pit 1 (PT1TRPNF.WPG).	14
13. Refusal elevation of driven AQ drill rod casing within and around seepage pit 1 (PT1AQRDP.WPG).	14
14. Velocity of penetration of AQ rod into soil formation at point 71 (Fig. 6) near pit 1 (H71AQVEL.WPG).	15
15. Velocity of penetration of AQ rod into pit 1 at point 67 (Fig. 6) (H67AQVEL.WPG).	15
16. Penetration of AQ rod in soil formation near pit 1 at point 71 (Fig. 6) (H71AQPEN.WPG).	16
17. Penetration of pit 1 at point 67 (Fig. 6) with AQ rod (H67AQPEN.WPG).	16
18. Transects of AQ rod penetration points across seepage pit 1 used for Figs. 19, 20, 21, and 22 (PIT1TRAN.WPG).	17
19. AQ rod refusal depths and in situ beta/gamma radioactive readings of penetration points along the northern lateral transect of seepage pit 1 (see Fig. 18) (PIT1XS70.WPG).	18
20. AQ rod refusal depths and in situ beta/gamma radioactive readings of penetration points along the middle lateral transect of seepage pit 1 (see Fig. 18) (PIT1XSMD.WPG).	18
21. AQ rod refusal depths and in situ beta/gamma radioactive readings of penetration points along the southern lateral transect of seepage pit 1 (see Fig. 18) (PIT1XS90.WPG).	19
22. AQ rod refusal depths and gross beta/gamma activity versus hole depth within and along the length of ORNL seepage pit 1 (PIT1XSCN.WPG).	19
23. In situ logging of beta/gamma activity within AQ rods and pipe within seepage pit 1 using Geiger-Mueller probe and scaler (LOGPHT93.WPG).	21
24. Correlation of in situ Geiger-Mueller readings with activities of ¹³⁷ Cs in retrieved soil samples from Hole 120, Pit 1 (HOLE120R.WPG).	22
25. Distribution of maximum Geiger-Mueller readings in AQ rods driven to various depths within and around pit 1 (PIT1ISVT.WPG).	24
26. Distribution of maximum Geiger-Mueller readings among AQ rods within and around pit 1 (MAX3DCPM.WPG).	25

27. Elevations of maximally contaminated in situ radiation readings in AQ rods within pit 1 relative to historical reference elevations (PIT1MAXI.WPG).	25
28. Elevation of groundwater within seepage pit 1 and relation to precipitation (PIT1WATB.WPG).	28
29. Groundwater elevations in and around seepage pit 1 and relation to precipitation (PIT1WTGD.WPG).	29
30. Equation used to calculate the hydraulic conductivity from measured water elevations during a well slug test (HCEQUAT.WPG).	31
31. Configuration of groundwater in and around ORNL pit 1 used for analysis of recharge following the pit dewatering after the ISV melt expulsion of April 21, 1996 (PIT1XSEC.PLT).	32
32. Watertable elevations within and around ORNL pit 1 and precipitation during and after ISV operations in March-April 1996 (MELTH20.WPG).	33
33. Bulk density of soil core segments recovered from hole 113 on the eastern side of seepage pit 1 (CH113BD.WPG).	46
34. Bulk density of soil core segments from fill material in the center of seepage pit 1 (CH120BD.WPG).	47
35. Bulk density of soil core segments from hole 114 (Fig. 6) on west side of seepage pit 1 (CH114BD.WPG).	48
36. Correlations and linear regressions of ^{137}Cs activity in samples of pit 1 soils with activities of ^{90}Sr , ^{239}Pu , and ^{238}U (PT1RNCOR.WPG).	70
37. Relationship between the determination of ^{90}Sr by Cerenkov radiation detection and by the standard method (EPA 905.0) in soil samples dissolved in nitric acid/lithium borate (PT1SR90C.WPG).	71
38. The vertical distribution of ^{137}Cs in soil core from sampling point 114 (Fig. 6) west of seepage pit 1 (CH114RN.WPG).	73
39. Vertical distribution of ^{137}Cs in soil core 119 (Fig. 6) from the center of seepage pit 1 (CH119RN.WPG).	73
40. Activity of ^{137}Cs in maximally contaminated soil core segments of the three sampling locations penetrating the bottom of pit 1 (PIT1TIPS.WPG).	74
41. Retention of ^{137}Cs in soil samples from ORNL pit 1 following sequential thermal treatment to the indicated temperature (PIT1CSVO.WPG).	79
42. Limestone addition versus ISV operating temperature, i.e., temperature of 100 poise viscosity, calculated using quadratic Scheffe mixture model of Shade and Piepel (1990) (ISVT100P.WPG).	81
43. Sequential leaching of ^{137}Cs from ORNL pit 1 soils and pulverized laboratory vitrified product (CSLEACH.WPG).	87
44. Sequential leaching of ^{90}Sr from ORNL pit 1 soils and pulverized laboratory vitrified product (SRLEACH.WPG).	87
45. TCLP leaching of ^{137}Cs and ^{90}Sr from ORNL pit 1 soils and pulverized laboratory vitrified product (CSSRTCLP.WPG).	90
46. Fraction of ^{90}Sr and Ca^{2+} leached from ORNL pit 1 soils and pulverized laboratory vitrified product by TCLP test (SRCATCLP.WPG).	91
47. Product Consistency Test (PCT) leaching of ^{137}Cs and ^{90}Sr from ORNL pit 1 soils and pulverized laboratory vitrified product (CSSRPCT.WPG).	92
48. Fractions of ^{90}Sr and Ca^{2+} leached from ORNL pit 1 soils and pulverized laboratory vitrified product by the PCT procedure (SRCAPCT.WPG).	93

49. Cross-section of possible ISV melt at seepage pit 1 with startup in a straight-walled, 10-ft deep excavation (PIT1ISV3.WPG).	96
50. Plan view of pit 1 ISV melt setting using a 50-ft square hood and a 32-ft wide startup trench (PIT1ISVO.WPG).	96
51. Potential ISV scenario at seepage pit 1 using 32-ft wide straight-walled startup trench (PIT1ISV2.WPG).	97
52. Potential ISV scenario at seepage pit 1 using a startup trench with walls tapered from 40 to 32 ft (PIT1ISV1.WPG).	97

TABLES

1. Summary characteristics of ORNL seepage pits and trenches in Waste Area Grouping 7. . .	2
2. Installation information for Geoprobe and ORNL groundwater wells.	27
3. Summary of Aquifer Characteristics for Soil/Rock In and Around Pit 1.	33
4. Water quality characteristics of perched water sampled March 7, 1994, from three wells driven into contaminated strata in seepage pit 1.	36
5. Dissolved elements in three samples of perched water in seepage pit 1 on March 7, 1994.	37
6. Volatile organic analyses performed on three samples of perched water in seepage pit 1 on March 7, 1994.	38
7. Semivolatile organic analyses performed on three samples of perched water in seepage pit 1 on March 7, 1994.	39
8. Water quality characteristics of perched water sampled August 22, 1994, from three wells driven into contaminated strata in seepage pit 1.	40
9. Dissolved elements in perched groundwater from seepage pit 1 sampled on August 22, 1994.	41
10. Volatile organic analyses performed on perched water sampled on August 22, 1994, from ORNL seepage pit 1.	42
11. Volatile organic quality control analyses performed with perched water sampled on August 22, 1994, from ORNL seepage pit 1.	43
12. Semivolatile organic analyses performed on perched water sampled on August 22, 1994, from ORNL seepage pit 1.	44
13. Elemental composition of pit 1 bulk soil and soils and limestones used for previous ORNL ISV tests.	50
14. Elemental oxide composition of pit 1 soils in three cores taken at penetration refusal. ...	52
15. Trace element composition (ppm) of pit 1 soils from three cores.	54
16. Elemental oxide composition (%) of pit 1 soils from various depths and locations.	55
17. Trace element composition (ppm) of pit 1 soils from various depths and locations.	57
18. Average elemental composition of pit 1 unweathered bottom and fill soils.	58
19. Elemental oxide (%) and trace element (ppm) composition of materials potentially included in the pit 1 in situ vitrification product.	59
20. Typical reagent blank and matrix-spiked analyses and typical concentrations in lithium borate/nitric acid dissolutions of pit 1 soils analyzed by inductively coupled plasma emission spectroscopy.	62
21. Comparison of observed and known gross and trace elemental composition of geological standards using lithium borate fusion/nitric acid dissolution with inductively coupled plasma emission spectroscopic analyses.	63
22. Rare earth element composition, as determined by neutron activation analyses, for selected pit 1 soil samples, ISV materials, Oak Ridge Reservation soils, and standards. ...	65
23. Radionuclide activities (Bq/g) determined for selected soil samples from ORNL pit 1. ...	68
24. Linear correlation coefficients among radionuclide activities in soils from ORNL pit 1. ...	69
25. Activity ratios of ⁹⁰ Sr, ²³⁸ U, and ²³⁹ Pu to ¹³⁷ Cs determined in soil samples from maximally contaminated depths of ORNL pit 1.	71
26. Radiochemical characteristics of maximally contaminated soil solids collected with water samples on February 14, 1994, from pit 1.	75

27. Retention of ^{137}Cs in ORNL pit 1 soil with limestone amendment after sequential heating to various temperatures.	82
28. Retention of ^{137}Cs in pit 1 soil with limestone amendment after heating to 1500 and 1700°C.	83
29. Normalized leachate elemental composition (mg/g) from TCLP test (numbers in parentheses are fractions of total element extracted).	91
30. Normalized leachate elemental composition (mg/g) from Product Consistency Tests (numbers in parentheses are fractions of total element extracted).	93

EXECUTIVE SUMMARY

A treatability study was initiated in October 1993, initially encompassing the application of in situ vitrification (ISV) to at least two segments of Oak Ridge National Laboratory (ORNL) seepage pit 1 by the end of fiscal year (FY) 1995. This treatability study was to have supported a possible Interim Record of Decision (IROD) or removal action for closure of one or more of the seepage pits and trenches as early as FY 1997. The Remedial Investigation/Feasibility Study for Waste Area Grouping (WAG) 7, which contains these seven seepage pits and trenches, will probably not begin until after the year 2000. This treatability study will establish the field-scale technical performance of ISV for (1) attaining the required depth, nominally 15 ft, to incorporate source contamination within and beneath the pits; (2) demonstrating field capability to overlap melt settings that are necessary to achieve fused, melted segments of the source contamination; (3) demonstrating off-gas handling technology for accommodating and minimizing the volatilization of ^{137}Cs ; (4) demonstrating adequate site characterization techniques to predict ISV melting kinetics, processing temperatures, and product durability; and (5) promoting public acceptance of ISV technology by demonstrating its safety, implementability, site impacts, and air emissions and by coordinating the treatability study within the regulatory closure process. This report summarizes the site characterization information gathered through the end of September 1996 which supports the planning and assessment of ISV for pit 1 (objective 4 above).

In situ vitrification is a promising technology that could be applied to the pits and trenches on the Oak Ridge Reservation (other candidate technologies would include grouting and ground densification). ISV, developed and patented for the U. S. Department of Energy by Battelle Pacific Northwest Laboratory (PNL), involves placing electrodes in an array above a contaminated volume of soil, applying power to the electrodes, and melting the entire mass of soil into a chemically homogeneous and durable glassy-to-microcrystalline waste form (*Handbook vitrification technologies for treatment of hazardous and radioactive waste*, EPA/625/R-92/002, U.S. Environmental Protection Agency, 1992). The array of vertical electrodes is inserted into the soil to a nominal depth (about two electrode diameters) above the waste site, and, because dry soil is not electrically conductive, a conductive material (typically glass frit and graphite flake) is placed in paths between the electrodes to act as the initial resistive heating element. The soil-melting process is initiated when an electric potential applied to the electrodes establishes a current in the path, in turn heating the path and the surrounding soil to temperatures above the melting point. Once molten, the soil becomes electrically conductive and its ambient resistance can be used to generate heat in situ. Power to the melt is controlled as the process continues and the molten soil mass grows downward and outward (typically maintaining temperatures between 1400°C and 2000°C). The melt dissolves and/or incorporates radionuclides and nonvolatile hazardous elements, such as heavy metals, and destroys organic components by pyrolysis. Semivolatile metals are largely retained in the melt, but the small quantity of material that does escape from the melt is captured and treated by an off-gas processing system. The fate and disposition of various materials during ISV processing has been determined in previous studies; organics are pyrolyzed and combusted, metals are melted and, because of their density, sink to the bottom of the ISV melt. Most other inorganic components are incorporated into the ISV glassy or crystalline product.

The initial step of this treatability study was to gather the required site characterization data about pit 1 so that its in situ vitrification could be effectively and safely planned. This

characterization phase is critical, not only for the ISV of pit 1, but, more importantly, as a demonstration of what information is needed for ISV planning and how it can be gathered efficiently for the remedial investigation of all the ORNL seepage pits and trenches. The characterization techniques and resulting information should also support alternative remediation techniques in WAG 7, and the characterization approach should provide useful methods for characterization tasks in other WAGs. Using in situ radioactivity logging within pipes and AQ-sized drill rod casing, driven into pit 1, the three-dimensional distribution of radioactive contamination in the pit 1 environs was determined so that depth and lateral targets for ISV could be set. Additionally a variety of other pit 1 soil characteristics, which will affect vitrification operations, have been determined, including its bulk density profile, chemical composition, presence and amounts of groundwater, and absence of hazardous nonradioactive ambient contaminants.

The major finding of this characterization effort was that the maximally contaminated strata, which contained ^{137}Cs at a maximum activity of 135,000 Bq/g and is the target for ISV processing, actually resides between 24 and 26 ft below the original asphalt cap over pit 1 rather than at the 15-ft depth presumed prior to site characterization. Apparently, clean soil was imported not only to fill pit 1, but also to cover residual peripheral surface contamination during its 1981 capping operation. Unfortunately, the proven ISV depth capability was only 19 ft when the treatability study was initiated. Thus, by a combination of site grading and ISV startup within an excavated trench, the target depth for pit 1 ISV can be kept within this current capability. Pit 1 also has perched groundwater at a seasonally varying depth of 7 to 10 ft below the surface; the groundwater, sampled from the maximally contaminated depth, averaged ^{137}Cs and ^{90}Sr activities of 1300 and 2140 Bq/L. Tritium was very low at 610 Bq/L (below the drinking water standard). Other than the dissolved radionuclides, this perched groundwater appeared rather typical of uncontaminated groundwater with only background concentrations in all organic and inorganic constituents. The hydraulic conductivity of the loose soil backfill in pit 1 was determined to be 1.9×10^{-4} cm/sec (0.54 ft/day) and was significantly larger than that of the surrounding undisturbed soil/rock (1.1×10^{-5} cm/sec or 0.031 ft/day) in which the pit had been excavated. This condition leads to the accumulation or perching of water within pit 1 throughout the year, a condition commonly referred to as "bath tubbing".

Elemental composition of the fill soil within pit was comparatively low in alkali metal (Na and K) and alkaline earth elements (Ca and Mg) and, thus, exhibited a relatively high ISV processing temperature of over 1700°C. The inventory of ^{137}Cs found in pit 1 was calculated at 38.8 Ci which is consistent with the decay-corrected and greatly interpreted disposal record estimate of 71 Ci. In addition the inventory of ^{90}Sr was calculated at only 0.31 Ci while the inventories of ^{238}U and ^{239}Pu were determined to be 0.012 and 0.088 Ci, respectively. The ^{90}Sr in untreated pit 1 soil was observed to be quantitatively leached by a sequential combination of dilute salt and acid solutions indicative of the environmentally mobile nature of this most hazardous contaminant radionuclide. The conversion of the ^{90}Sr from its ambient cation-exchangeable and leachable form in soil to an unleachable and insoluble form in the ISV product is one of the major benefits of the ISV technology. Melting of laboratory specimens of pit 1 soil yielded a simulated ISV product which, even when ground to a fine powder, exhibited a two order-of-magnitude lowering in the ^{90}Sr leaching behavior. The leaching of ^{137}Cs was also improved by soil melting although its strong and specific adsorption to soil renders its environmentally immobile even without vitrification. Amendment of pit 1 soil with up to 20% limestone in laboratory crucibles showed no effect on the fraction of ^{137}Cs volatilized when the specimens were melted. Limestone amendments of 10 to 20% lowered the melting point of pit 1 soil from >1700°C to <1500°C. The use of limestone amendment

during pit 1 ISV is thus projected to reduce ISV processing temperatures and, thereby, improve the thermal efficiency of the process and minimize the volatilization of ^{137}Cs .

Pit 1 dimensions were found to be approximately 22 ft wide and 90 ft long presenting a roughly rectangular ISV target of 1,990 ft² for the entire pit. The planned three large-scale melt settings should result in vitrification of all of this maximally contaminated soil within pit 1. Scenarios for performing these ISV melts within pit 1 are discussed; selection of an appropriate starting geometry for pit 1 ISV depends on excavation slope stability analyses as inferred from soil strength measurements.

1. SITE DESCRIPTION AND HISTORICAL BACKGROUND INFORMATION

ORNL has many sites that have significantly contaminated soils with mixed fission products and transuranic isotopes. From 1951 through 1966, ORNL disposed of more than a million curies (Table 1) via liquid waste seepage into seven shallow pits and trenches which are contained in WAG 7 (Fig. 1). Presently the pits and trenches are covered with asphalt and require regular maintenance. However, this inventory of radioactivity is situated within 20 ft of the seasonally high water table while all the pits and trenches have perched groundwater in them; in places only 100 ft separates the contaminant source from perennial surface streams. The present and potential mobility of radionuclides, particularly ^{90}Sr , into shallow groundwater and streams represents one of the most significant long-term risks posed by ORNL waste management units. The levels of radioactivity in the ORNL seepage pits and trenches would restrict any direct contact by remediation workers or machine operators. Radiation fields at contact with exhumed waste would probably fall in the range of 200 to 1000 R/hr. In addition to such potentially lethal radiation fields, from which shielding may provide some protection, containment of contamination would be extremely important to prevent ingestion or inhalation of contamination by operating personnel. Any exhumation approach entails a large risk for environmental releases because of the proximity to surface water and the generally wet climate of the area. Such hazards, coupled with the lack of any credible alternative disposal site or treatment method for exhumed waste, have focused consideration on in situ stabilization and closure techniques, particularly for high-radiation-hazard sites like the ORNL seepage pits and trenches.

Pit 1 was constructed in August 1951 by digging an assumed 30- by 115-ft trench (Fig. 2) into weathered shale residuum to a maximum nominal depth of 15 ft. During the following 3 months, pit 1 is estimated to have received about 389 Ci of mixed fission products, 200 kg of depleted uranium (0.0678 Ci if ^{238}U), and 266 mg of plutonium (0.017 Ci if ^{239}Pu), as sludge suspended in highly alkaline liquid waste (approximately 123,000 gal). The exact mixture of fission product isotopes was not reported in the disposal records for pit 1. If it is assumed that the pit 1 fission product waste is similar to the sludge from ORNL pit 2, which was analyzed and used in the 1991 radioactive ISV test (Spalding et al. 1992), then 80.2% of the present activity would be composed of ^{137}Cs and 19.8% would be composed of ^{90}Sr while ^{106}Ru , with its 367 day half-life, would have decayed completely in the 42 years since pit 1 use. Disposal records estimated that total beta emitters, disposed in pit 1, were 60% ^{137}Cs and 40% ^{106}Ru . If it is assumed that the recorded beta activity of " ^{137}Cs " was actually a mixture of ^{137}Cs and ^{90}Sr , as found for the pit 2 sludge, and correcting for decay to 1993, then the estimates of ^{137}Cs and ^{90}Sr presently in pit 1 would be 71.0 and 17.5 Ci, respectively. However, these must be viewed as working estimates based on the number of assumptions and the disposal record quality. Thus, a significant part of the present treatability study will center on a better characterization of the present pit 1 radioisotopic inventory. This pit was a proof-of-principle operation, and, although it leaked into a nearby drainage, a larger pit 2 was constructed in 1952, becoming the operational disposal unit for liquid radioactive waste at ORNL.

Although not used for routine liquid waste disposal after 1951, pit 1 received discharges via a buried pipeline from drains in the nearby decontamination building (7819) between 1962 and 1970. These discharges of acids, soaps, and chelating agents were not measured, but this contact-handled

Table 1. Summary characteristics of ORNL seepage pits and trenches in Waste Area Grouping 7

Waste Unit	Size (l × w × d - ft)	Dates Used	Volume Disposed (gal)	Activity ^a (Ci)	Isotopes
Pit 1 ^b	115 × 30 × 10+	1951 (leak)	120,000	389	Cs, Sr, Ru ^c
Pits 2, 3, 4	200 × 100 × 15	1952-1962	24,000,000	480,000	Cs, Sr, Ru
Pit 4 only, additional disposal	200 × 100 × 15	1956-1976	9,000/week	undetermined	Sludge from Process Water Treatment Plant
Trench 5	300 × 10 × 15	1960-1966	9,500,000	308,500	Cs, Sr, TRU
Trench 6	450 × 10 × 15	1961 (leak)	130,000	1,335	Cs, Sr, TRU
Trench 7	200 × 10 × 15	1962-1966	9,500,000	283,900	Cs, Sr, TRU

^a Activity at the time of disposal as stated in operations records exclusive of U and transuranic (TRU) elements.

^b Pit 1 also received drain discharges from a decontamination building from 1962-1976, but there was probably no significant change in radionuclide inventory.

^c Exact radioisotopic composition is not available in disposal records. See text for discussion and assumptions.

Source: Spalding 1987.

equipment decontamination facility probably did not add significantly to the inventory of radioactivity in pit 1. During this and previous operations, pit 1 was spanned by a wooden roof with asphalt-coated corrugated metal sheeting to prevent infiltration of precipitation (Fig. 3). In 1981, the pit was filled with soil and capped with asphaltic concrete. Since that time the pavement has been resealed occasionally with various asphaltic coatings and the site surrounded by a 4-ft-high barbed-wire fence with appropriate hazard warning signs (Fig. 4). In 1993, the pit remains covered with asphalt although numerous penetrations of the asphalt have been made as part of the present site characterization and sampling activities (Fig. 5).

Fig. 1. ORNL Waste Area Grouping 7, which contains the seven seepage pits and trenches, showing location of the pit 1 treatability study site.

Fig. 2. ORNL seepage pit 1 dimensions showing the paving and grading plan for covering. Taken from Energy Systems Engineering drawing C3D20929A001 (1981). Scale is indicated by the 100-ft administrative grid tick marks.

Fig. 3. Photograph of ORNL seepage pit 1 in 1955 showing the roof covering.

Fig. 4. View of ORNL seepage pit 1 with asphalt cap in December 1988.

Fig. 5. Surface of ORNL seepage pit 1 in October 1993 exhibiting the many surface pipe penetrations resulting from site characterization activities.

2. PIT 1 CHARACTERIZATION

The initial step of this treatability study will be to gather the required site characterization data about pit 1 so that its ISV can be effectively and safely planned. This characterization phase is critical not only for the ISV of pit 1 but, more importantly, as a demonstration of what information is needed for ISV planning and how it can be gathered efficiently for the remedial investigation of all ORNL seepage pits and trenches. The characterization techniques and information should also support alternative remediation techniques in WAG 7, and the characterization approach should provide a useful method for other site characterization activities.

Basically, the three-dimensional distribution of radioactive contamination in the pit 1 environs was determined so that depth and lateral targets for ISV can be set. Additionally, a variety of other parameters that will affect vitrification operations were determined, including bulk density, chemical composition, presence and amounts of groundwater, and ambient contaminant leach properties. The required characterization information and the proposed method of obtaining it is described in the following sections.

Procedures for performing the various characterization measurements were developed early in the project and are contained in Appendix A. The locations of various test points in and around pit 1 are depicted in Fig. 6; all test points are depicted including penetration tests with half-inch diameter threaded rods, AQ-size drill rods, Geoprobe driven well screens, and soil core samples.

2.1 DEPTH OF PIT 1

The actual depth of excavation of pit 1 was unknown prior to this study but was presumed to be approximately 15 ft, which would be similar to the other pits and trenches; however, given the width and length dimensions of pit 1 and its stated liquid holding capacity of 200,000 gal, it was considered possible that the pit may have been less than 10 ft deep. Obviously, the depth of pit 1 is a critical characteristic needed to set a target depth for this ISV treatability study. The depth of pit 1 was planned to be determined by measuring the average depth at which increased resistance to penetration of a driven threaded rod (half-inch diameter) was experienced.

Backfill within pit 1 should have lower bulk density than the surrounding and underlying host soil formation and, hence, should offer considerably less resistance to penetration than the undisturbed peripheral soil. Such penetration tests (Fig. 7) were performed at various intervals on linear transects within the asphalt pad. Previous penetration testing techniques used for buried waste trenches and surrounding soil at ORNL SWSA 6 (Spalding et al. 1989) employed a retractable and reusable AW-size drill rod (1.75 in. diameter). However, because of the higher activities of radionuclides likely to exist in pit 1, rod withdrawal was not planned for penetration testing and expendable 0.5-in. diameter threaded rod was employed to minimize costs and potential metal addition to the pit. The smaller diameter also facilitated driving the rod with an electric vibratory hammer and improved the safety and speed of field operations compared with conventional drill rig operations. The presence of residual steel rods within pit 1 will not affect ISV operations, because molten metals will pool at the bottom of the melt.

The penetration rate of threaded rod into pit 1 proved difficult to interpret in terms of an obvious bottom to the pit. Initially, threaded rods were routinely driven to a depth of 18 ft at points well within the edges of the asphalt pad. Several rods were then tested for actual refusal depth

Fig. 6. Location of points in and around ORNL seepage pit 1 for penetration tests, AQ-rod insertions, water monitoring and sampling wells, and soil core sampling.

Fig. 7. Driving half-inch threaded rod into pit 1 fill material using electric vibratory hammer.

and were driven to 39 ft below the asphalt pad without refusal (Fig. 8 and Fig. 9). Although the pit was obviously not 39 ft deep, it did become apparent that it was more than 15 ft deep. In contrast, threaded rod driven at points around the perimeter of the asphalt pad and within 5 ft of its edge generally encountered refusal within 10 to 15 ft below the surface; this strongly indicated a contrast between areas within and outside the pit (Figs. 10 and 11). Fig. 12 depicts the refusal depth of threaded rod except that all non-refusal penetration points were limited to a 30-ft maximum depth for graphic contouring purposes. Apparently, driven rod within the pit was penetrating either a dense, undisturbed, underlying soil formation or thinly layered residual rock strata beneath the pit. Thus, a clear contrast between host formation and fill materials was not possible using the small diameter threaded rod.

The depth of refusal of AQ rods provided a much more obvious contrast between host formation and imported fill materials (Fig. 13). AQ rod (1.75-in. diameter) was driven with the same electric vibratory hammer that was used for driving the narrower threaded rod; obviously the driving times were considerably greater (Fig. 17 and Fig. 15). With a ground surface elevation of about 826 ft, the outlines of a pit can be seen with an elevation of 801 ft or 25 ft deep. A lot of the irregularity in Fig. 13 is due to the contouring interpolation graphics program. Unlike the case using threaded 0.5-in. rod, the larger diameter AQ rod was always driven to a definite refusal depth even in the peripheral soil formation (Fig. 16 and Fig. 14). Efforts to drive AQ rod deeper, after refusal using the electric vibratory hammer, were unsuccessful; both an air-powered 140-lb vibratory hammer and a 140-lb cathead-driven safety hammer (i.e., the hammer used for the standard penetration tests and split spoon sampling) failed to produce further penetration on several AQ rods tested. Thus, the present driving technique yielded a refusal criteria similar to that of the standard penetration test.

2.2 LATERAL EXTENT OF PIT 1

Although the recorded dimensions of pit 1 (30 x 115 ft) are consistent with both the paving and grading plot plan dimensions (Fig. 2) and the photograph of pit 1 during its operations (Fig. 3), the exact field locations were confirmed by penetration testing with AQ rods at about 5-ft intervals on each of three transects perpendicular to each side of pit 1 and a central transect through the long axis of the pit 1 (Fig. 18). Decisions about withdrawal, partial or complete, of any or all penetration test rods prior to ISV operations will be made after the completion of in situ radioactivity logs, which will allow estimates of their degree of contamination to be made, as well as plans for their handling and disposal. Even if the rods cannot be withdrawn, the presence of the additional steel will not affect ISV operations; such materials have already been determined not to affect the volatility of ^{137}Cs . The presence of so many rods may improve the soil stability and enhance the safety of planned excavation for ISV startup in pit 1.

The transect of refusal depths along the long axis of the pit is depicted in Fig. 22. Although the asphalt pad is 120 ft long, the underlying pit is between 90 and 100 ft with relatively steep slopes at either end. The refusal within the pit was 25-27 ft beneath the asphalt pad while a ledge of host soil around it yielded refusal depths between 8-10 ft. This pit depth estimate is supported by the depicted in situ radioactivity logs, coplotted in Fig. 22, which will be discussed subsequently. The original pit bottom would be expected to exhibit the maximum radiation readings due the strong soil adsorption of the dominant contaminant, ^{137}Cs , during disposal of liquid waste. Thus, the coincidence of refusal and maximum in situ radiation supports the conclusion that this is the original pit 1 depth. Actually, refusal depth appeared 1-2 ft below the maxima in radiation readings presumably because the AQ rods were able to penetrate that additional depth before sufficient resistance to further penetration was accumulated.

Hole # 14 - Threaded Rod

Fig. 8. Penetration of 0.5-in. rod into pit 1 at point 14.

Hole # 14 - Threaded Rod

Fig. 9. Velocity of 0.5-in. rod into pit 1 at penetration point 14.

Hole # 12 - Threaded Rod

Fig. 10. Penetration of 0.5-in. rod into soil formation at point 12.

Hole # 12 - Threaded Rod

Fig. 11. Velocity of 0.5-in. rod into soil formation at point 12.

Fig. 14. Velocity of penetration of AQ rod into soil formation at point 71.

Fig. 15. Velocity of penetration of AQ rod into pit 1 at point 67.

Hole # 71 - AQ Rod

Fig. 16. Penetration of AQ rod in soil formation near pit 1 at point 71.

Hole # 67 - AQ Rod

Fig. 17. Penetration of pit 1 at point 67 (Fig. 6) with AQ rod.

Fig. 18. Transects of AQ rod penetration points across seepage pit 1 used for Figs. 19, 20, 21, and 22.

Obviously, the original assumption that pit 1 was 15 ft below grade was not correct. However, the original pit was probably operated as a 15-ft deep pit. Subsequent filling and capping appears to have imported 8-10 ft of fill soil to level the area and probably to cover residual surface contamination prior to paving the area. Regardless, the target depth for ISV, to include the maximally contaminated pit bottom, resides between 23 and 26 ft beneath the present ground surface. Unfortunately, this target depth for ISV is greater than the currently proven depth of 19 ft; approaches to the obvious challenge to ISV limitations are discussed subsequently.

Three refusal depth transects are depicted in Fig. 19, Fig. 20, and Fig. 21. As with the transect along the central long axis of pit 1 (Fig. 22), maximum radiation reading and refusal occurred between 23 and 26 ft with relatively steep slopes for the original pit walls on both sides. The pit appeared to be between 20 and 25 ft wide being slightly wider in the northern end (Fig. 19) than in the southern end (Fig. 21).

Fig. 19. AQ rod refusal depths and in situ beta/gamma radioactive readings of penetration points along the northern lateral transect of seepage pit 1 (see Fig. 18).

Fig. 20. AQ rod refusal depths and in situ beta/gamma radioactive readings of penetration points along the middle lateral transect of seepage pit 1 (see Fig. 18).

Fig. 21. AQ rod refusal depths and in situ beta/gamma radioactive readings of penetration points along the southern lateral transect of seepage pit 1 (see Fig. 18).

Fig. 22. AQ rod refusal depths and gross beta/gamma activity versus hole depth within and along the length of ORNL seepage pit 1.

2.3 DISTRIBUTION OF RADIOACTIVITY WITHIN PIT 1

Anecdotal information from personnel present during the filling and paving of pit 1 in 1981 indicated that the pit was filled by pushing imported soil from the north to the south (Fig. 2). This activity apparently resulted in pushing liquid within the pit to the south end. Thus, it seemed possible that most of the pit 1 radioactive inventory would be concentrated in the south end of the trench, which, if confirmed during this site characterization, would present the best target for limited ISV operations. Thus, the lateral or plot plan distribution of radioactivity within pit 1 needed to be determined.

To accomplish this spatial distribution characterization without producing significant amounts of radioactive sample material, in situ beta/gamma logging will be employed. Initially, capped pipes (1.25 in. inside diameter) were driven into pit 1 to an apparent pit bottom or refusal at selected locations. However, at or before the refusal depth, as determined subsequently using AQ drill rod, many of the 5-ft coupled pipe trains collapsed or buckled at their couplings; these collapse problems were encountered using either the routine schedule 80 galvanized or stainless-steel 1.25-in. pipe with NPT fittings. However, two pipe trains remained open to about 24 ft below the surface and preliminary logging activities indicated maximum radiation readings at their bottom. However, because it was desired to log beneath peak radiation readings, to demonstrate the sharp decline in radioactive contamination beneath the pit, a much more sturdy 'pipe' was required. AQ drill rod casing was selected because of its high strength and its outside diameter being approximately equivalent to that of standard 1.25-in. pipe. Although AQ rod costs approximately ten times as much as standard pipe, it can be hammered to and well beyond refusal without damage; no AQ rod stems were damaged during the various penetration tests in pit 1. In addition, the flush-wall couplings and custom-fabricated flush-wall drive points provided a smooth wall over the entire rod stem (no couplings). The couplings have also proved water-tight in over one year of residence within pit 1 and, therefore, have facilitated repeated in situ radiation logs without any leakage or contamination of logging probes.

Each driven pipe and rod was originally planned to be logged in situ with both a Geiger-Mueller detector for gross beta/gamma activity and a sodium-iodide scintillation crystal detector for specific gamma emitters (i.e., ^{137}Cs). However, the sodium-iodide detector was often saturated (>80% dead time) in the higher activity regions of pipes and rods within pit 1; thus, most of the planned in situ logs using NaI were not attempted. Geiger-Mueller probes of different sensitivities (1000, 150, and 20 cpm/mR/hr for ^{137}Cs gamma) were employed to determine if the linear range of the most sensitive probe (1000 cpm/mR/hr for ^{137}Cs gamma) has been exceeded by some of the highest readings; but most sensitive probe proved to exhibit a linear response over the range of in situ readings encountered.

Typically, a given G-M probe was connected to a scaler, adjusted to the optimal high voltage, and lowered down a pipe (Fig. 23). Routinely, probe backgrounds and responses to ^{137}Cs standards were performed before and after logging each hole. Later, soil cores were taken proximate to existing in situ logging rods, so that more precise calibrations were made with laboratory-determined activities of various depth samples; additional AQ rods were driven into several residual holes from soil sampling points and were subsequently logged for radioactivity in situ; these coupled series of in situ and retrieved sample readings provided a correlation or calibration factor by which to convert the in situ readings into activities per unit soil weight of ^{137}Cs ; as an example, the paired series of reading in sampling hole 120, which is in the center of pit 1, are depicted in Fig. 24 with additional correlations within other core holes listed in Appendix B.

Fig. 23. In situ logging of beta/gamma activity within AQ rods and pipe within seepage pit 1 using Geiger-Mueller probe and scaler.

Pit 1 - Core 120

Fig. 24. Correlation of in situ Geiger-Mueller readings with activities of ^{137}Cs in retrieved soil samples from hole 120, pit 1.

The distribution of radioactivity within and around pit 1 can be gleaned from the in situ radiation readings within the 40 AQ rods placed in and around pit 1. **Fig. 25** depicts the spatial distribution of maximum readings for the G-M probe at any depth within the various AQ rods. In this picture, the outline of the original pit can be seen by the area which circumscribes all access points with readings above 100,000 cpm; this 1,992-ft² area is considerably smaller than the 4,888-ft² asphalt pad over the original pit. This projected target area for ISV was constructed by dividing the spacing between readings above and below 100,000 cpm. It appears to be a rounded rectangle of about 93 ft long and 23 ft wide.

Although G-M readings approximating background rates were observed on both the eastern and southern perimeters of pit 1, maximum reading in rods on the northern and western sides were markedly elevated but below what is being considered "source" contamination, i.e., readings above 100,000 cpm. This peripheral contamination around the original pit is likely due to overflow of liquids from the pit during its operation and/or the period before it was filled. This peripheral contamination was also found at much shallower depth probably on the original land surface which was presumably the downslope area for overflow and runoff from pit 1. This extensive peripheral contamination was the likely reason why so much fill was imported to the site during pit filling and capping; filling, excavation, and paving equipment would need to operate on a clean surface to avoid contamination. Although **Fig. 25** is an accurate representation of the various in situ radioactivity measurements, **Fig. 26** depicts the same information using a three-dimensional graph; it is even more apparent from **Fig. 26** that the "source" contamination appears to be only slightly more concentrated in the northern region of pit 1.

2.4 VERTICAL DISTRIBUTION OF RADIOACTIVITY WITHIN AND AROUND PIT 1

Given the assumed method of backfilling pit 1 prior to its paving (i.e., pushing clean fill soil into the excavation while working off a clean surface to the east), it would seem likely that radioactivity would remain concentrated near the bottom of the original pit. The many AQ rods were logged for in situ radioactivity as depicted in **Fig. 22**, **Fig. 19**, **Fig. 20**, and **Fig. 21**. In this manner, the three-dimensional distribution of the radioactive contaminants in pit 1 was determined without any intrusive sampling or exposure of field personnel to significant doses. However, this integration has not been completely finished; further interpolation of in situ readings and correlation with the retrieved soil ¹³⁷Cs and ⁹⁰Sr needs to be completed. However, it is apparent from the in situ logs, contained in these figures, that the vast majority of the "source" contamination is still retained at or near the original excavated soil surface of the pit. Actually, the rationale for the demarcation of "source" contamination at those readings above 100,000 cpm has substantial support when one observes the absolute elevations of the maximally contaminated strata (**Fig. 27**); all the readings above 100,000 cpm occurred at elevations below 805 ft above NGVD which is more than 20 ft below the present asphalt pad. The three historical reference elevations annotated on **Fig. 27** were obtained from a 1963 MMES Engineering Drawing D-54730 which contains an elevation profile of the drainage line from the decontamination facility (Building 7819) to pit 1. The elevation of the original land surface at the point where the drainage line entered pit is indicated as well as an approximate water level in the pit at that time which has been termed operational water elevation in **Fig. 27**. As discussed in the review of historical information about pit 1, the discharges from the decontamination facility were probably not sufficient to alter the inventory of radionuclides within pit 1 which were dominated by those placed during its operation as a disposal pit in 1951. These 1951 discharges to pit 1, with their particle-reactive ¹³⁷Cs, compose most of the radioactive inventory and still resides in the original pit bottom.

Fig. 25. Distribution of maximum Geiger-Mueller readings in AQ rods driven to various depths within and around pit 1.

Fig. 26. Distribution of maximum Geiger-Mueller readings in AQ rods driven to various depths within and around pit 1.

Fig. 27. Elevations of maximally contaminated in situ radiation readings in AQ rods within pit 1 relative to historical reference elevations.

2.5 WATER TABLE ELEVATION AND QUALITY WITHIN AND AROUND PIT 1

Prior to the start of this study, the elevation of the permanent water table within or around pit 1 or even the presence of perched water within pit 1 during wet seasons had not been determined. Although the presence of a true or perched water table within pit 1 will not affect the feasibility of its vitrification, it may affect the rate of vitrification and, hence, the cost of its vitrification. Any moisture in the targeted region of pit 1 would be boiled away during ISV. If perched water were present and the pit's backfill were quite permeable, then the entire pit may be dried during its ISV. In addition, large amounts of boiling water beneath the ISV melt may lead to excessive bubbling of steam through the melt during ISV operations. Although this scenario seems unlikely, given the expected high permeability of the pit backfill, the degree of permeability needs to be established prior to ISV operations as part of run planning.

2.5.1 Pit 1 Geoprobe Well Installation

Due to difficulties encountered in driving pipe and/or AQ rod to a maximum depth of 25 ft during installation of the in situ logging holes, a commonly used flush-joint well screen (24 in. long x 1.25 in. diameter) could not be used. Instead, Geoprobe Screen Point Ground Water Samplers were used at three locations (Fig. 6), which had a much smaller diameter (o.d. = 1 in.). The tool was equipped with a 19 in. screen encased in a perforated stainless steel sleeve. The screen and sleeve is held in the first section of Geoprobe that is driven into the subsurface, using an electric jack hammer. The remaining Geoprobe sections were each 3 ft in length, and the joints were sealed with Teflon tape. After the entire assembly was driven to its maximum desired depth or refusal, the assembly was withdrawn approximately 20 to 25 in. During the jacking activity, the expendable drive point separated from the assembly and remained at its final driven depth. A ram rod was then inserted through the top of the Geoprobe to push the outer sleeve and screen down into the 20 in. subsurface cavity. All three Geoprobos were successfully driven into the saturated zone. Installation Data for the three Geoprobe wells and the existing groundwater wells is presented in Table 2.

2.5.2 Water Level and Rainfall Monitoring

Since installation of the wells, fluctuations in the elevation of the Pit 1 groundwater have been periodically measured and recorded. Water levels were determined using a Solinst water level meter (0.01 ft. accuracy). Measurements were recorded in the field as the depth of water from the top of the Geoprobe casing. These values were later converted to elevations using survey data and the height of casing above the ground surface.

A Tru-Chek wedge rain gauge (0.05 in. accuracy) was also installed at Pit 1 and was placed greater than 50 ft from any trees that might affect its radius of influence (N 18830.56, E 26871.91). The rain gauge was emptied after each reading. Water levels within Pit 1 and rainfall data for the same period are presented in Fig. 28. Since rainfall data was not collected daily, the data is presented so that the rainfall between two consecutive readings is cumulative; however, the data is a result of a distinct rainfall event(s). The data suggests that the water present in each of the wells is interconnected since there is little variation among water levels readings at any point in time (i.e., there are no localized region(s) having significantly different water table elevations than those presented in Fig. 28).

Table 2. Installation information for Geoprobe and ORNL groundwater wells

Well I.D.	Installation Date	Depth of well (ft)	Height of Casing (ft)	ORNL Grid Coordinates:		Top of Casing (ft)
				North (ft)	East (ft)	
North Geoprobe (No. 105)	2/07/94	24.0	2.10	18867.16	26847.72	826.19
Middle Geoprobe (No. 107)	2/14/94	26.5	2.25	18836.51	26855.89	826.07
South Geoprobe (No. 106)	2/07/94	22.0	0.95	18800.36	26865.51	825.96
Well No. 676	4/17/86	27.0	%0.10	18796.93	26804.92	817.84
Well No. 718	4/21/86	35.0	%0.10	18863.69	26783.93	816.97
Well No. 719	4/18/86	34.5	%0.10	18848.69	26915.45	827.27

During the 20-month monitoring period to date, (2/94-11/95) the water table elevation in Pit 1 has averaged 817.5 ft or approximately 8.5 ft below the asphalt surface of Pit 1. However, fluctuations in the water levels did occur, with the maximum and minimum water levels of 819 ft and 814.2 ft, respectively. This 4.8-ft maximum fluctuation in water elevation appears to correspond to seasonal variation in rainfall. The maximum water levels occurred in mid April 1994 after a couple of very significant rainfall events; water levels approached this maximum again in April 1995. The lowest water levels were recorded during the drier autumn 1994 period. A large delay response between rainfall events and pit 1 water level changes is not apparent. Since pit 1 has an asphaltic cover, it is assumed that the rainfall is reaching the pit via its connection to the local groundwater system. In March 1995, the asphalt cap over pit 1 was removed as part of site preparation for receipt of large-scale ISV equipment; an average of about 4 ft of soil underlying the asphalt cap was also removed at that time and used as fill on the western or downslope edge of pit 1 to expand the leveled area for eventual off-gas hood maneuvering.

2.5.3 Comparison with Local Groundwater Data

From the limited data available to this point, the water level in pit 1 does not appear to be "perched." The elevation of the pit 1 water is between that of the upslope groundwater well (No. 719) and the two downslope wells (No.'s 676 and 718). Figure 29 presents recent water level measurements for the nearby ORNL groundwater wells. For comparison, water level readings for the "North Geoprobe" are also presented. However, because the water level within pit 1 is constant, following no gradient within the pit, the water table can be considered perched or terraced within the region.

There appears to be a slight delay in the groundwater response to precipitation events (e.g., the increase in groundwater elevation resulting from the August 19 and 22, 1994, rainfall was still observed on August 26). Furthermore, the change in pit 1 water levels appears to "track" well with that of the other wells in the area, indicating that the difference in bulk density between the original soil and the fill material currently in pit 1 does not appear to significantly affect the rate of groundwater migration through the region.

Fig. 28. Elevation of groundwater within seepage pit 1 and relation to precipitation.

2.5.4 Hydraulic Conductivity Estimation of Pit 1 Backfill Soil

Slug tests were performed using the screened Geoprobe wells to obtain an estimate of the hydraulic conductivity of the Pit 1 material. (Such information will help aid in the prediction of drying rates during the ISV operations in Phase III.) Approximately 1 gal of groundwater was collected from each Geoprobe well (start and stop times were recorded). After sample collection, the water level in each Geoprobe was measured at approximately 1 minute intervals for 15 min. The data obtained during recharge of the screened wells was used to estimate the hydraulic conductivity of the saturated Pit 1 soil according to the piezometer method (Luthin and Kirkham 1949). The governing equation for this determination is presented in Fig. 30. The slug tests were performed on 3/7/94 for each Geoprobe.

Some assumptions were made in the use of the above equation. The radius was chosen as 0.5 in, the gross radius of the cavity, since the radius of the screened section was not the same as that of the Geoprobe or the cavity created by it. (Use of the larger, more conservative cavity diameter estimated the maximum hydraulic conductivity of the fill material.) The shape factor was based on a cavity length of 20 in. (length of screen). Estimates using this equation should be correct to better than $\pm 4\%$ (since $d \geq 2X$ cavity length and depth to impermeable layer $\geq 2X$ cavity length). The average hydraulic conductivities for the north, middle, and south Geoprobe well regions were determined to be 1.78×10^{-4} , 1.47×10^{-4} , and 2.5×10^{-4} cm/sec, respectively. Each value is the average of at least 7 time intervals. Also, as was noted in the water level section, the lower hydraulic conductivity value for the Middle Geoprobe is probably due to screen clogging during the purge test.

Fig. 29. Groundwater elevations in and around seepage pit 1 and relation to precipitation.

2.5.5 Hydraulic Conductivity Estimation of Surrounding Undisturbed Soil

The technical approach to gaining these aquifer characteristics of the soil formation around pit 1 was to use the observed watertable elevation monitoring data within pit 1 as it recharged following the melt expulsion incident of April 21, 1996. It was not technically feasible to perform such a massive dewatering test as part of the pre-ISV characterization effort; but this valuable and useful characteristic can be readily estimated from simple calculations based on the water table response after the melt expulsion incident. This data is contained in Figures 10 and 16 of the report of the incident (ORNL/ER-374/R1, November 1996). The calculation of formation hydraulic conductivity from the water level data is not particularly complicated, using the basic Darcy equation for saturated hydraulic conductivity (K_s):

$$K_s = \frac{\text{Water seepage rate}}{\text{Area through which seepage occurs} \times \text{hydraulic gradient}}$$

where:

Water seepage rate = flow rate of water (volume/time, e.g. gal/day)

Area = area (length x length, e.g., ft²) through which the flow occurs, (i.e., the area of pit wall and floor beneath the water level).

Hydraulic Gradient = difference between water levels inside the pit and water level outside the pit divided by the distance between the two points (dimensionless).

The configuration around pit 1 used for this analysis is depicted in Fig. 31. Water level data from well 719 was used for the water level in the surrounding upgradient area while water levels from wells 105 and 106, inside pit 1, were used for the level within pit 1 (Fig. 32, from original Figure 16, ORNL/ER-374/R1). This water level was assumed to extend to within 10 ft of the pit 1 eastern wall. The analysis is basically that of a shallow-well pump-out technique where the recovery of water level within the borehole is used to calculate K_s of the surrounding formation. To use the above equation, an interval of time was selected (i.e., May 13-15, 1996) in which no rainfall occurred in addition to little preceding rainfall; selection of this interval precludes the possibility of recharge from the surface influencing the water level recovery. Selection of this short finite interval, in which the water elevation rose only 1 ft, allows direct application of the above equation under constant-head rather than falling-head conditions.

The three input parameters to the above equation need some explanation so that their selection is fully justified and documented. The hydraulic gradient estimation seems pretty straight forward. The difference in water levels between the pit and the recharge area of the aquifer (as measured at well 719) was simply divided by an assumed 10-ft distance between the pit edge and zone of undisturbed water table. The average computed hydraulic gradient used in this analysis was 0.95. The seepage area was simply calculated as the sum of pit floor plus the saturated portion of pit sidewall area. The pit is a rounded rectangle, roughly 22 x 93 ft and contained an average depth of 6 ft of water at the start of the May 13-15 interval during which this depth decreased by 1 ft. Thus, the total seepage area was 3,423 ft² which increased to 3,656 ft² (7% increase) as the water elevation in the pit rose over the selected 48-hr interval. The smaller starting area was used in the calculation, rather than the 7%-larger final area, so that the calculated hydraulic conductivity would be conservative, i.e., as large as reasonably possible. The third input parameter to the equation is the seepage rate into the pit during the selected interval.

$$K(\text{cm/sec}) = \frac{\pi R^2 [\ln(d - y_1) / (d - y_2)]}{A(t_2 - t_1)}$$

Where:

K = hydraulic conductivity

R = inside radius of pipe

d = depth of Geoprobe below water table

y_1 = depth below water table of H_2O at time t_1

y_2 = depth below water table of H_2O at time t_2

$t_2 - t_1$ = time for water to rise from y_1 to y_2

A = shape factor

Fig. 30. Equation used to calculate the hydraulic conductivity from measured water elevations during a well slug test.

This was calculated as the volume of water divided by the time interval, i.e., 48 hours. The volume was computed as the fraction of the 1-ft volume slice of pit 1 which gravitational water could fill [i.e., the difference in volumetric water content at complete saturation (43%) and at field capacity (33%) where all freely drainable water has been removed]. These two moisture states of the pit 1 backfill soil were determined during site characterization and are discussed subsequently. The percentage of drainable and, therefore, fillable water is 10% (i.e., 43 to 33%). A 1-ft depth interval of pit 1 ($93 \times 22 \times 1$ ft) has a total volume of 2,046 ft^3 and, therefore, can be filled by 204.6 ft^3 (1,530 gal) of water seeping into the pit in the 48-hr interval. Thus, the seepage rate into the pit was approximately 765 gal/day during this selected interval. As an independent validation of this estimate, the disposal operation records for pit 1 were examined. When the pit was maintained near capacity in 1951, "the volume of waste in the chemical waste storage pit is decreasing at a rate of 500 to 600 gal per day .." (ORNL-1156, p. 9, 1951). Thus, the rate of seepage discharge from pit 1 in 1951 is almost identical to the rate of near-empty seepage recharge in 1996 under presumably similar, but opposite, hydraulic gradient. Thus, all of the input parameters to the above formula seem reasonable and the calculated hydraulic conductivity should be quite accurate.

As indicated in Table 3, the calculated hydraulic conductivity was $1.11\text{E-}05$ cm/s. The very slow recharge of water into pit 1 following the ISV melt expulsion (Fig. 31) can be interpreted as a direct result of this relatively low K_s . This relatively low K_s has several consequences affecting concepts for water table suppression in and around pit 1.

But before highlighting the impacts of this much lower K_s on watertable suppression design, it would be useful to point out that a formation $K_s = \text{E-}05$ probably would be representative of the other pits and trenches in WAG 7. All of the other pits and trenches were situated on the tops of hills. Such placement has two consequences: 1) these pits and trenches were well above the

Fig. 31. Configuration of groundwater in and around ORNL pit 1 used for analysis of recharge following the pit dewatering after the ISV melt expulsion of April 21, 1996.

Fig. 32. Watertable elevations within and around ORNL pit 1 and precipitation during and after ISV operations in March–April 1996.

Table 3. Summary of Aquifer Characteristics for Soil/Rock In and Around Pit 1

Material	Hydraulic Conductivity (K_s) (cm/s)	Bulk Density (g/cm ³)	Total Porosity (fraction)	Functional Porosity (fraction)
Within Pit 1	1.92E-04	1.5	0.43	0.10
Undisturbed Outside Soil	1.11E-05	2.2	0.17	0.015

seasonally high watertable and, thus, 2) were in more weathered strata with its lower bulk density and greater K_s . Operational records for trenches 5 and 7, which were similar in total seepage area to pit 1, recorded seepage rates around 4,000 to 5,000 gal/day (i.e., an order-of-magnitude greater than pit 1); these higher seepage rates are consistent with a similar soil formation but with an order-of-magnitude greater hydraulic gradient. Thus, most of the concepts for watertable suppression, developed in the previous team assessment, will be directly applicable to conditions around the other pits and trenches in WAG 7. However, area watertable suppression in the soil formation surrounding the other pits and trenches will probably not be required during their ISV because they are situated above the permanent watertable. Nevertheless, all of the pits and trenches in WAG 7 appear to contain perched water which can and should be drained prior to their ISV.

Pit 1 is unique among the seven seepage pits and trenches in WAG 7 because it is positioned, at least partially, within the watertable and, thus, in a portion of the soil/rock formation with the low $K_s = E-05$ cm/s. Several consequences of this low K_s impact the potential strategies for watertable suppression. First, one can expect only a very low yield from any well placed into such a formation. The formation K_s was used to compute the yield of a 6-in. diameter well placed 30 ft into the watertable; the water level in this well was maintained 28.5 ft below the watertable to provide a strong hydraulic gradient to a hypothetical pump in its bottom.

A shallow-well pump out analysis method (Amoozegar and Warrick 1986) was used to compute the water flow under such hydraulic gradient, aquifer K_s , and well geometry. The predicted initial yield from such a well is only 167 gal/day; this yield or pumpable rate will, of course, decrease significantly as stored water is depleted and the hydraulic gradient declines. Ten such wells placed around but outside pit 1 would yield only 1670 gal/day. The total amount of potentially pumpable water in such a formation was estimated for a 100-ft radius around pit 1 to a depth of 30 ft below the water table. A functional porosity or coefficient of aquifer storativity of 0.015 was assumed for this tight formation and is consistent with aquifer parameters in Melton Valley (Moore and Toran 1992; Solomon et al. 1992). This assumption of aquifer porosity does not affect the prediction of well yields but only the amount of stored water which can be pumped. Such an assumed porosity results in a total of 106,000 gal of pumpable water which, at the above calculated well yields, would take over 63 days to remove, assuming no recharge from precipitation or lateral inflow in that interval. In addition, one can use the well yield equation to determine the influence of varying well diameter (or depth) on overall yields; one finds very little change (167 to 234 gal/day/well) as well diameter is increased from 6 to 24 in. Thus, there is no practical way to overcome the tightness of the formation through selection of well diameter or depth.

It is important to realize that such a tight formation, in addition to meaning that it will be difficult to design a watertable suppression system using pumpable wells, also means that, once pit 1 itself is drained, recharge to it will be very slow; recharge of 500-600 gal/day is the maximum initial recharge. As the surrounding soil formation discharges to the pit, the hydraulic gradient falls and the inward seepage rate will fall much farther.

In contrast, the soil backfill within pit 1 has a much higher $K_s = 1.92E-04$ cm/s and coefficient of aquifer storativity (i.e., 0.10) and a lower bulk density (i.e., 1.5 g/cm³) as was determined in the site characterization activities (page 34) through slug tests in the three wells placed to the bottom of pit 1.

The same type of well and yield analysis in this backfill material to a depth of 17 ft below the level of water in pit 1 predicts a yield of 1030 gal/day/well; two such wells would require approximately 12.6 days to pump the total of 26,018 gal of pumpable water in the pit (see attached worksheet). Given such well yields, durations, and pumpable volumes, reducing water levels within the pit is very reasonable to consider prior to and during ISV.

2.5.6 Perched Water Characteristics

Water was sampled from the three Geoprobe driven well screens on March 7, 1994, and again on August 22, 1994. Following processing, handling, and preservation via various methods, as defined in the project quality assurance plan, analyses were requested from ORNL Analytical Services Division for ICP elements (EPA Method 200.7), mercury (EPA Method 245.1), inorganic anions (EPA Method 300.0), volatile organic analytes (EPA Method 8240), semivolatile organic analytes (EPA Method 8270), and radionuclides including gamma emitters (EPA Method 901.1),

gross alpha and beta (EPA Method 900.0), ^{90}Sr (EPA Method 905.0), ^3H (EPA Method 906.0); in addition, project methods (Appendix A) were employed to determine electrical conductivity, pH, hardness, alkalinity, dissolved solids, ^{137}Cs , ^{90}Sr , and ^3H .

During the sampling of these wells, whose screened intervals were positioned in the depth interval of maximum in situ radioactive contamination, large amounts of suspended solids were also included in the samples; during sample filtration, these entrained solids were collected, dried, and saved. They were analyzed for ^{137}Cs before and after fusion with lithium metaborate (ASTM Method D4503-86) and for ^{90}Sr in the fusion dissolved solutions; results of the analyses of these radioactive solids are described subsequently. Results of the water quality characteristics of the March 7, 1994, sampling date are given in Table 3, Table 4, Table 5, and Table 6; results of the August 22, 1994, sampling date are presented in Tables 7, 8, 9, 10, and 11.

The sampling of perched groundwater from pit 1 on August 22, 1994, was carried out under the proscriptions of the phase II quality assurance project plan (Spalding 1994). Because of the quality control samples included in this sampling effort, a high degree of confidence is warranted in the findings with actual water samples. Particular emphasis was placed on the various organic analyses because the previous analyses on March 7, 1994 indicated that there were virtually no organic contaminants present in pit 1 water.

Because of the potential for degradation during processing and storage and potential for volatilization of organics during the vacuum sampling, standard spiked solutions for both the volatile organic analyses and semivolatile analyses were employed (Supelco Cat. No. 4-8959, TCL Volatiles Mix 4 and Cat. No. 4-7377, EPA 8270 Phenols Mix); these certified standards were dissolved in 2 L of distilled water (also used for the blanks) on the day preceding field sampling to yield final concentration of each analyte of 1000 $\mu\text{g/L}$. The measured concentration of all analytes was in excellent agreement with the spiked concentrations for both volatile (Table 11) and semivolatile (Table 12) components. This indicates that, had organic contaminants been present in pit 1 water, neither the vacuum sampling technique nor biodegradation during storage and processing would have resulted in a failure to detect them. In addition, the processing of various sampling equipment rinse blanks did not detect any artifactual contributions in these samples. Thus, the conclusion that organic contaminants are not present in pit 1 is strongly supported by these quality control analyses. The various rinse blanks for inorganic anion, ICP elements, and radionuclides all indicated no contamination by the distilled water used for sampling equipment cleaning or from the polyethylene tubing used for sample removal from the wells. Duplicate samples were also highly reproducible yielding confidence in the precision of the analyses. Because there were only three wells placed in pit 1 for perched water sampling, all analyses were duplicated for each class of analyses and their related differences in sampling technique for each class. No unusual concentrations of heavy metals or other inorganic contaminants were detected in any of these samples.

In summary, the perched water in pit 1 did not contain any hazardous inorganic or organic species; it did however contain quite significant activities of both ^{137}Cs and ^{90}Sr with only minor activities of ^3H . The water quality was dominated by Ca and Mg bicarbonates with a significant contribution from dissolved Fe due to anoxic condition of the perched water. Inorganic anions were characteristically dominated by bicarbonate (alkalinity), sulfate, and chloride; fortunately, chloride concentrations seem rather typical of groundwater in the Conasauga formation and, thus, are not elevated to a degree which might pose a problem for volatilization of ^{137}Cs during the pit 1 vitrification. It was very encouraging that project methods for both ^{137}Cs and, particularly, for ^{90}Sr via Cerenkov radiation measurement, were in close agreement with the standard methods; these

findings validate the use of these project methods for routine analyses during planned leaching studies and ISV product characterization.

Table 4. Water quality characteristics of perched water sampled March 7, 1994, from three wells driven into contaminated strata in seepage pit 1

	Well 105	Well 106	Well 107
Radionuclides:			
⁶⁰ Co (Bq/L)	0.16	0.90	0.49
¹³⁷ Cs (Bq/L)	1000	1000	1600
⁹⁰ Sr (Bq/L)	2200	1000	3200
³ H (Bq/L)	110	430	130
Gross α (Bq/L)	1.0	-0.5	1.0
Gross β (Bq/L)	5100	2900	6900
Project Method Parameters:			
Electrical conductivity (mS/m)	457	699	406
Alkalinity (mg CaCO ₃ /L)	254	229	195
Hardness (mg CaCO ₃ /L)	198	314	158
pH	5.6	5.5	5.5
Dissolved Solids (mg/L)	220	570	210
Suspended Solids (mg/L)	8160	165	1050
⁹⁰ Sr (Bq/L)	2270	980	3170
¹³⁷ Cs (Bq/L)	1090	1070	1740
³ H (Bq/L)	<100	380	<100
Inorganic Anions:			
bromide (mg/L)	0.1	0.22	0.15
chloride (mg/L)	16	24	14
fluoride (mg/L)	<0.1	<0.1	<0.1
nitrate (mg/L)	0.27	0.22	0.24
phosphate (mg/L)	<0.5	<0.5	<0.5
sulfate (mg/L)	12	160	29

Table 5. Dissolved elements in three samples of perched water in seepage pit 1 on March 7, 1994

Inorganic Elements:	Well 105 (mg/L)	Well 106 (mg/L)	Well 107 (mg/L)
Ag	<0.005	<0.005	<0.005
Al	0.26	0.70	0.36
As	<0.050	<0.050	<0.050
B	<0.08	<0.08	<0.08
Ba	0.12	0.032	0.077
Be	<0.001	<0.001	<0.001
Ca	61	61	38
Cd	<0.005	<0.005	<0.005
Co	0.010	0.011	0.013
Cr	<0.004	<0.004	<0.004
Cu	<0.007	<0.007	<0.007
Fe	18	47	24
Hg	<0.00005	<0.00005	<0.00005
K	2.8	2.4	2.3
Li	<0.005	0.029	<0.005
Mg	12	47	14
Mn	7.9	2.9	3.6
Mo	<0.04	<0.04	0.049
Na	22	19	16
Ni	0.035	0.012	<0.010
P	1.6	3.3	1.6
Pb	0.077	<0.050	<0.050
Sb	<0.050	<0.050	<0.050
Se	<0.050	<0.050	<0.050
Si	14	16	8.3
Sn	<0.050	<0.050	<0.050
Sr	0.10	0.14	0.086
Ti	<0.020	<0.020	<0.020
V	0.0071	0.015	0.007
Zn	0.032	0.011	0.016
Zr	<0.020	<0.020	<0.020

Table 6. Volatile organic analyses performed on three samples of perched water in seepage pit 1 on March 7, 1994

	Well 105	Well 106	Well 107
Volatile Organic Analytes:	(mg/L)	(mg/L)	(mg/L)
chloromethane	<0.10	<0.10	<0.10
bromomethane	<0.10	<0.10	<0.10
vinyl chloride	<0.10	<0.10	<0.10
chloroethane	<0.10	<0.10	<0.10
methylene chloride	<0.05	<0.05	<0.05
acetone	<0.10	<0.10	<0.10
carbon disulfide	<0.05	<0.05	<0.05
1,1-dichloroethene	<0.05	<0.05	<0.05
1,1-dichloroethane	<0.05	<0.05	<0.05
1,2-dichloroethene (trans)	<0.05	<0.05	<0.05
1,2-dichloroethene (cis)	<0.05	<0.05	<0.05
chloroform	<0.05	<0.05	<0.05
1,2-dichloroethane	<0.05	<0.05	<0.05
2-butanone	<0.10	<0.10	<0.10
1,1,1-trichloroethane	<0.05	<0.05	<0.05
carbon tetrachloride	<0.05	<0.05	<0.05
vinyl acetate	<0.10	<0.10	<0.10
bromodichloromethane	<0.05	<0.05	<0.05
1,2-dichloropropane	<0.05	<0.05	<0.05
cis-1,2-dichloropropene	<0.05	<0.05	<0.05
trichloroethene	<0.05	<0.05	<0.05
dibromochloromethane	<0.05	<0.05	<0.05
1,1,2-trichloroethane	<0.05	<0.05	<0.05
benzene	<0.05	<0.05	<0.05
trans-1,3-dichloropropene	<0.05	<0.05	<0.05
bromoform	<0.05	<0.05	<0.05
4-methyl-2-pentanone	<0.10	<0.10	<0.10
2-hexanone	<0.10	<0.10	<0.10
tetrachloroethene	<0.05	<0.05	<0.05
1,1,2,2-tetrachloroethane	<0.05	<0.05	<0.05
toluene	<0.05	<0.05	<0.05
chlorobenzene	<0.05	<0.05	<0.05
ethylbenzene	<0.05	<0.05	<0.05
styrene	<0.05	<0.05	<0.05
xylene (m-&p-)	<0.05	<0.05	<0.05
xylene (o-)	<0.05	<0.05	<0.05
1,3-dichlorobenzene	<0.05	<0.05	<0.05
1,4-dichlorobenzene	<0.05	<0.05	<0.05
1,2-dichlorobenzene	<0.05	<0.05	<0.05
1,2-dichloroethene (total)	<0.05	<0.05	<0.05
xylene (total)	<0.05	<0.05	<0.05

Table 7. Semivolatile organic analyses performed on three samples of perched water in seepage pit 1 on March 7, 1994

Semivolatile Organic Analytes:	Well 105 (mg/L)	Well 106 (mg/L)	Well 107 (mg/L)
phenol	<0.011	<0.011	<0.011
bis(2-chloroethyl)ether	<0.011	<0.011	<0.011
2-chlorophenol	<0.011	<0.011	<0.011
1,3-dichlorobenzene	<0.011	<0.011	<0.011
1,4-dichlorobenzene	<0.011	<0.011	<0.011
benzyl alcohol	<0.011	<0.011	<0.011
1,2-dichlorobenzene	<0.011	<0.011	<0.011
2-methylphenol	<0.011	<0.011	<0.011
bis(2-chloroisopropyl)ether	<0.011	<0.011	<0.011
4-methylphenol	<0.011	<0.011	<0.011
N-nitroso-di-N-propylamine	<0.011	<0.011	<0.011
hexachloroethane	<0.011	<0.011	<0.011
nitrobenzene	<0.011	<0.011	<0.011
isophorone	<0.011	<0.011	<0.011
2-nitrophenol	<0.011	<0.011	<0.011
2,4-dimethylphenol	<0.011	<0.011	<0.011
carbazole	<0.011	<0.011	<0.011
bis(2-chloroethoxy)methane	<0.011	<0.011	<0.011
2,4-dichlorophenol	<0.011	<0.011	<0.011
1,2,4-trichlorobenzene	<0.011	<0.011	<0.011
naphthalene	<0.011	<0.011	<0.011
4-chloroaniline	<0.011	<0.011	<0.011
hexachlorobutadiene	<0.011	<0.011	<0.011
4-chloro-3-methylphenol	<0.011	<0.011	<0.011
2-methylnaphthalene	<0.011	<0.011	<0.011
hexachlorocyclopentadiene	<0.011	<0.011	<0.011
2,4,6-trichlorophenol	<0.011	<0.011	<0.011
2,4,5-trichlorophenol	<0.028	<0.028	<0.028
2-chloronaphthalene	<0.011	<0.011	<0.011
2-nitroaniline	<0.028	<0.028	<0.028
dimethylphthalate	<0.011	<0.011	<0.011
acenaphthylene	<0.011	<0.011	<0.011
2,6-dinitrotoluene	<0.011	<0.011	<0.011
3-nitroaniline	<0.028	<0.028	<0.028
acenaphthene	<0.011	<0.011	<0.011
2,4-dinitrophenol	<0.028	<0.028	<0.028
4-nitrophenol	<0.028	<0.028	<0.028
dibenzofuran	<0.011	<0.011	<0.011
2,4-dinitrotoluene	<0.011	<0.011	<0.011
diethylphthalate	<0.011	<0.011	<0.011
4-chlorophenyl-phenylether	<0.011	<0.011	<0.011
fluorene	<0.011	<0.011	<0.011
4-nitroaniline	<0.028	<0.028	<0.028
4,6-dinitro-2-methylphenol	<0.028	<0.028	<0.028
N-nitrosodiphenylamine (1)	<0.011	<0.011	<0.011
4-bromophenyl-phenylether	<0.011	<0.011	<0.011
hexachlorobenzene	<0.011	<0.011	<0.011
pentachlorophenol	<0.028	<0.028	<0.028
phenanthrene	<0.011	<0.011	<0.011
anthracene	<0.011	<0.011	<0.011
di-n-butylphthalate	<0.011	<0.011	<0.011
fluoranthene	<0.011	<0.011	<0.011
pyrene	<0.011	<0.011	<0.011
butylbenzylphthalate	<0.011	<0.011	<0.011
3,3'-dichlorobenzidine	<0.011	<0.011	<0.011
benzo(a)anthracene	<0.011	<0.011	<0.011
chrysene	<0.011	<0.011	<0.011
bis(2-ethylhexyl)phthalate	<0.011	<0.011	<0.011
di-n-octylphthalate	<0.011	<0.011	<0.011
benzo(b)fluoranthene	<0.011	<0.011	<0.011
benzo(k)fluoranthene	<0.011	<0.011	<0.011
benzo(a)pyrene	<0.011	<0.011	<0.011
indeno(1,2,3-cd)pyrene	<0.011	<0.011	<0.011
dibenz(a,h)anthracene	<0.011	<0.011	<0.011
benzo(g,h,i)perylene	<0.011	<0.011	<0.011

Table 8. Water quality characteristics of perched water sampled August 22, 1994, from three wells driven into contaminated strata in seepage pit 1

	Well 105A	Well 105B	Well 106A	Well 106B	Well 107A	Well 107B	Rinse Blank-A	Rinse Blank-B
Radionuclides:								
⁶⁰ Co (Bq/L)	0.18	0.34	0.57	0.56	0.40	0.39	0.14	0.04
¹³⁷ Cs (Bq/L)	1500	1500	3200	3300	460	470	-0.04	-0.07
⁹⁰ Sr (Bq/L)	2300	2500	900	800	1800	1500	-0.012	0.17
³ H (Bq/L)	150	140	290	280	150	170	21	15
⁹⁹ Tc (Bq/L)	0.9	0.2	-0.22	0.3	0.8	0.4	0.27	0.01
Gross α (Bq/L)	1.2	1.2	4.3	5.0	5.1	7.4	0.066	0.051
Gross β (Bq/L)	5200	5200	4400	4300	3600	3600	0.24	0.05
Project Method Parameters:								
Elect. conduct. (mS/m)	471	465	667	665	422	419	7	7
Alkalinity (mg CaCO ₃ /L)	215	210	226	214	173	171	4	0
Hardness (mg CaCO ₃ /L)	212	210	338	336	152	168	0	0
pH	5.7	5.8	6.0	6.0	6.0	6.0	6.9	6.7
Dissolved Solids (mg/L)	460	360	740	860	360	320	0	0
Suspended Solids (mg/L)	2395	2559	251	245	257	290	20	0
⁹⁰ Sr (Bq/L)	2200	2200	810	800	1910	1900	nd	nd
¹³⁷ Cs (Bq/L)	1520	1480	3950	3910	710	740	38	36
Inorganic Anions:								
bromide (mg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
chloride (mg/L)	13	13	19	18	14	14	0.10	0.11
fluoride (mg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	0.57	<0.1	<0.1
nitrate (mg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
phosphate (mg/L)	<0.5	<0.5	5.0	6.0	<0.5	<0.5	<0.5	<0.5
sulfate (mg/L)	19	19	140	140	34	33	<0.2	<0.2

Table 9. Dissolved elements in perched groundwater from seepage pit 1 sampled on August 22, 1994

[illegible]

Table 10. Volatile organic analyses performed on perched water sampled on August 22, 1994, from ORNL seepage pit 1

Volatiles Organic Analytes:	Well 105-A (µg/L)	Well 105-B (µg/L)	Well 106-A (µg/L)	Well 106-B (µg/L)	Well 107-A (µg/L)	Well 107-B (µg/L)	Rinse Blank-A (µg/L)	Rinse Blank-B (µg/L)
chloromethane	<10	<10	<10	<10	<10	<10	<10	<10
bromomethane	<10	<10	<10	<10	<10	<10	<10	<10
vinyl chloride	<10	<10	<10	<10	<10	<10	<10	<10
chloroethane	<10	<10	<10	<10	<10	<10	<10	<10
methylene chloride	<5	<5	<5	<5	<5	<5	<5	<5
acetone	3J	3J	2J	<10	<10	<10	43	41
carbon disulfide	<5	<5	<5	<5	<5	<5	<5	<5
1,1-dichloroethene	<5	<5	<5	<5	<5	<5	<5	<5
1,1-dichloroethane	<5	<5	<5	<5	<5	<5	<5	<5
1,2-dichloroethene (trans)	<5	<5	<5	<5	<5	<5	<5	<5
1,2-dichloroethene (cis)	<5	<5	<5	<5	<5	<5	<5	<5
chloroform	<5	<5	<5	<5	<5	<5	1J	9J
1,2-dichloroethane	<5	<5	<5	<5	<5	<5	<5	<5
2-butanone	3J	<10	<10	3J	2J	3J	8J	<10
1,1,1-trichloroethane	<5	<5	<5	<5	<5	<5	<5	<5
carbon tetrachloride	<5	<5	<5	<5	<5	<5	<5	<5
vinyl acetate	<10	<10	<10	<10	<10	<10	<10	<10
bromodichloromethane	<5	<5	<5	<5	<5	<5	<5	<5
1,2-dichloropropane	<5	<5	<5	<5	<5	<5	<5	<5
cis-1,2-dichloropropene	<5	<5	<5	<5	<5	<5	<5	<5
trichloroethene	<5	<5	<5	<5	<5	<5	<5	<5
dibromochloromethane	<5	<5	<5	<5	<5	<5	<5	<5
1,1,2-trichloroethane	<5	<5	<5	<5	<5	<5	<5	<5
benzene	<5	<5	<5	<5	<5	<5	<5	<5
trans-1,3-dichloropropene	<5	<5	<5	<5	<5	<5	<5	<5
bromoform	<5	<5	<5	<5	<5	<5	<5	<5
4-methyl-2-pentanone	<10	<10	<10	<10	<10	<10	<10	<10
2-hexanone	<10	<10	0.10	<10	<10	<10	<10	<10
tetrachloroethene	<5	<5	<5	<5	<5	<5	<5	<5
1,1,2,2-tetrachloroethane	<5	<5	<5	<5	<5	<5	<5	<5
toluene	<5	<5	<5	<5	<5	5J	<5	<5
chlorobenzene	<5	<5	<5	<5	<5	<5	<5	<5
ethylbenzene	<5	<5	<5	<5	<5	<5	<5	<5
styrene	<5	<5	<5	<5	<5	<5	<5	<5
xylene (m-&p-)	<5	<5	<5	<5	2J	2J	<5	<5
xylene (o-)	<5	<5	<5	<5	<5	<5	<5	<5
1,3-dichlorobenzene	<5	<5	<5	<5	<5	<5	<5	<5
1,4-dichlorobenzene	<5	<5	<5	<5	<5	<5	<5	<5
1,2-dichlorobenzene	<5	<5	<5	<5	<5	<5	<5	<5
1,2-dichloroethene (total)	<5	<5	<5	<5	<5	<5	<5	<5
xylene (total)	<5	<5	<5	<5	2J	2J	<5	<5

J is a data qualifier which indicates that the quantitative value is estimated. Usually this qualifier will appear after a value that is below the quantitation limit, i.e., the compound was detected at some level below the quantitation limit.

Table 11. Volatile organic quality control analyses performed with perched water sampled on August 22, 1994, from ORNL seepage pit 1

Volatile Organic Analytes:	Pit1 Std-4 (µg/L)	Pit1 Std-5 (µg/L)	VOA Std-1 (µg/L)	VOA Std-2 (µg/L)	Trip Blank-1 (µg/L)	Trip Blank-2 (µg/L)	Trip Std-1 (µg/L)	Trip Std-2 (µg/L)
chloromethane	<100	<100	<100	<100	<10	<10	<100	<100
bromomethane	<100	<100	<100	<100	<10	<10	<100	<100
vinyl chloride	<100	<100	<100	<100	<10	<10	<100	<100
chloroethane	<100	<100	<100	<100	<10	<10	<100	<100
methylene chloride	<50	<50	<50	<50	<5	<5	<50	<50
acetone	<100	<100	2J	<100	56	28	<100	<100
carbon disulfide	<50	<50	<50	<50	<5	3J	<50	<50
1,1-dichloroethene	<50	<50	<50	<50	<5	<5	<50	<50
1,1-dichloroethane	<50	<50	<50	<50	<5	<5	<50	<50
1,2-dichloroethene (trans)	<50	<50	<50	<50	<5	<5	<50	<50
1,2-dichloroethene (cis)	<50	<50	<50	<50	<5	<5	<50	<50
chloroform	<50	<50	<50	<50	<5	<5	<50	<50
1,2-dichloroethane	<50	<50	<50	<50	<5	<5	<50	<50
2-butanone	23J	31J	<100	21J	8J	190B	16J	28J
1,1,1-trichloroethane	<50	<50	<50	<50	<5	<5	23J	<50
carbon tetrachloride	<50	<50	<50	<50	<5	<5	<50	<50
vinyl acetate	<100	<100	<100	<100	<10	<10	<100	<100
bromodichloromethane	<50	<50	<50	<50	<5	<5	<50	<50
1,2-dichloropropane	1000	990	1000	990	<5	<5	1100	1000
cis-1,2-dichloropropene	<50	<50	<50	<50	<5	<5	<50	<50
trichloroethene	16J	<50	15J	<50	<5	<5	<50	51
dibromochloromethane	<50	<50	<50	<50	<5	<5	<50	<50
1,1,2-trichloroethane	<50	<50	<50	<50	<5	<5	<50	<50
benzene	880	860	920	900	<5	<5	980	940
trans-1,3-dichloropropene	<50	<50	<50	<50	<5	<5	<50	<50
bromoform	<50	<50	<50	<50	<5	<5	<50	<50
4-methyl-2-pentanone	<100	<100	<100	<100	<10	<10	<100	<100
2-hexanone	<100	<100	0.100	<100	<10	<10	<100	<100
tetrachloroethene	<50	<50	<50	<50	<5	<5	<50	<50
1,1,2,2-tetrachloroethane	1200	1100	1200	1100	<5	<5	1200	1200
toluene	21J	730	920	970	<5	<5	910	850
chlorobenzene	1000	900	1200	1100	<5	<5	1100	1100
ethylbenzene	<50	<50	<50	<50	<5	<5	<50	<50
styrene	980	860	1100	1100	<5	<5	1100	1000
xylene (m-&p-)	850	720	950	900	<5	<5	950	910
xylene (o-)	920	800	1100	1000	<5	<5	960	970
1,3-dichlorobenzene	<50	<50	<50	<50	<5	<5	<50	<50
1,4-dichlorobenzene	<50	<50	<50	<50	<5	<5	<50	<50
1,2-dichlorobenzene	<50	<50	<50	<50	<5	<5	<50	<50
1,2-dichloroethene (total)	<50	<50	<50	<50	<5	<5	<50	<50
xylene (total)	1770	1520	2050	1990	<5	<5	1910	1880

J is a data qualifier which indicates that the quantitative value is estimated. Usually this qualifier will appear after a value that is below the quantitation limit, i.e., the compound was detected at some level below the quantitation limit.

B is a data qualifier which appears for a compound that was detected in both the sample and its associated blank.

Pit1 Std-4 and Std-5 were standards in distilled water which were carried to the field sampling site and processed through the field sampling equipment and containers.

VOA Std-1 and Std-2 were standards in distilled water prepared in the laboratory the day before sampling, stored under refrigeration, and submitted with the field samples and other quality control samples.

Trip Blank-1 and Blank-2 were distilled water blanks which were carried to the field sampling site, stored unopened in the sample cooler, and submitted with the other samples.

Trip Std-1 and Std-2 were standards in distilled water which were carried to the field, stored unopened in the sample cooler, and submitted for analyses with the other samples.

Table 12. Semivolatile organic analyses performed on perched water sampled on August 22, 1994, from ORNL seepage pit 1

Semivolatile Organic Analytes:	Well 105-A (µg/L)	Well 105-B (µg/L)	Well 106-A (µg/L)	Well 106-B (µg/L)	Well 107-A (µg/L)	Well 107-B (µg/L)	Rinse Blank-A (µg/L)	Rinse Blank-B (µg/L)	Pit1 Std-6 (µg/L)
phenol	<11	<11	<11	<11	<11	<11	<11	<11	990Y
bis(2-chloroethyl)ether	<11	<11	<11	<11	<11	<11	<11	<11	<110
2-chlorophenol	<11	<11	<11	<11	<11	<11	<11	<11	920Y
1,3-dichlorobenzene	<11	<11	<11	<11	<11	<11	<11	<11	<110
1,4-dichlorobenzene	<11	<11	<11	<11	<11	<11	<11	<11	<110
benzyl alcohol	<11	<11	<11	<11	<11	<11	<11	<11	<110
1,2-dichlorobenzene	<11	<11	<11	<11	<11	<11	<11	<11	<110
2-methylphenol	<11	<11	<11	<11	<11	<11	<11	<11	1000Y
bis(2-chloroisopropyl)ether	<11	<11	<11	<11	<11	<11	<11	<11	<110
4-methylphenol	<11	<11	<11	<11	<11	<11	<11	<11	2300Y
N-nitroso-di-N-propylamine	<11	<11	<11	<11	<11	<11	<11	<11	<110
hexachloroethane	<11	<11	<11	<11	<11	<11	<11	<11	<110
nitrobenzene	<11	<11	<11	<11	<11	<11	<11	<11	<110
isophorone	<11	<11	<11	<11	<11	<11	<11	<11	<110
2-nitrophenol	<11	<11	<11	<11	<11	<11	<11	<11	1200Y
2,4-dimethylphenol	<11	<11	<11	<11	<11	<11	<11	<11	1200Y
carbazole	<11	<11	<11	<11	3J	3J	<11	<11	<110
bis(2-chloroethoxy)methane	<11	<11	<11	<11	<11	<11	<11	<11	<110
2,4-dichlorophenol	<11	<11	<11	<11	<11	<11	<11	<11	1100Y
1,2,4-trichlorobenzene	<11	<11	<11	<11	<11	<11	<11	<11	<110
naphthalene	1J	<11	<11	<11	6J	6J	<11	<11	<110
4-chloroaniline	<11	<11	<11	<11	<11	<11	<11	<11	<110
hexachlorobutadiene	<11	<11	<11	<11	<11	<11	<11	<11	<110
4-chloro-3-methylphenol	<11	<11	<11	<11	<11	<11	<11	<11	890Y
2-methylnaphthalene	<11	<11	<11	<11	9J	9J	<11	<11	<110
hexachlorocyclopentadiene	<11	<11	<11	<11	<11	<11	<11	<11	<110
2,4,6-trichlorophenol	<11	<11	<11	<11	<11	<11	<11	<11	730Y
2,4,5-trichlorophenol	<28	<28	<28	<28	<28	<28	<28	<28	810Y
2-chloronaphthalene	<11	<11	<11	<11	<11	<11	<11	<11	<110
2-nitroaniline	<28	<28	<28	<28	<28	<28	<28	<28	<280
dimethylphthalate	<11	<11	<11	<11	<11	<11	<11	<11	<110
acenaphthylene	<11	<11	<11	<11	<11	<11	<11	<11	<110
2,6-dinitrotoluene	<11	<11	<11	<11	<11	<11	<11	<11	<110
3-nitroaniline	<28	<28	<28	<28	<28	<28	<28	<28	<280
acenaphthene	1J	1J	<11	<11	19	21	<11	<11	<110
2,4-dinitrophenol	<28	<28	<28	<28	<28	<28	<28	<28	990Y
4-nitrophenol	<28	<28	<28	<28	<28	1J	<28	<28	940Y
dibenzofuran	8J	7J	<11	<11	20	20	<11	<11	<110
2,4-dinitrotoluene	<11	<11	<11	<11	<11	<11	<11	<11	<110
diethylphthalate	<11	<11	<11	<11	<11	<11	<11	<11	<110
4-chlorophenyl-phenylether	<11	<11	<11	<11	<11	<11	<11	<11	<110
fluorene	2J	2J	<11	<11	13	13	<11	<11	130
4-nitroaniline	<28	<28	<28	<28	<28	<28	<28	<28	<280
4,6-dinitro-2-methylphenol	<28	<28	<28	<28	<28	<28	<28	<28	1100Y
N-nitrosodiphenylamine (1)	<11	<11	<11	<11	<11	<11	<11	<11	<110
4-bromophenyl-phenylether	<11	<11	<11	<11	<11	<11	<11	<11	<110
hexachlorobenzene	<11	<11	<11	<11	<11	<11	<11	<11	<110
pentachlorophenol	<28	<28	<28	<28	<28	<28	<28	<28	920Y
phenanthrene	<11	<11	<11	<11	2J	2J	<11	<11	<110
anthracene	<11	<11	<11	<11	1J	2J	<11	<11	<110
di-n-butylphthalate	<11	<11	<11	<11	<11	<11	<11	<11	<110
fluoranthene	<11	<11	<11	<11	1J	2J	<11	<11	<110
pyrene	<11	<11	<11	<11	<11	<11	<11	<11	<110
butylbenzylphthalate	<11	<11	<11	<11	<11	<11	<11	<11	<110
3,3'-dichlorobenzidine	<11	<11	<11	<11	<11	<11	<11	<11	<110
benzo(a)anthracene	<11	<11	<11	<11	<11	<11	<11	<11	<110
chrysene	<11	<11	<11	<11	<11	<11	<11	<11	<110
bis(2-ethylhexyl)phthalate	<11	<11	<11	<11	<11	2J	<11	<11	<110
di-n-octylphthalate	<11	<11	<11	<11	<11	<11	<11	<11	<110
benzo(b)fluoranthene	<11	<11	<11	<11	<11	<11	<11	<11	<110
benzo(k)fluoranthene	<11	<11	<11	<11	<11	<11	<11	<11	<110
benzo(a)pyrene	<11	<11	<11	<11	<11	<11	<11	<11	<110
indeno(1,2,3-cd)pyrene	<11	<11	<11	<11	<11	<11	<11	<11	<110
dibenz(a,h)anthracene	<11	<11	<11	<11	<11	<11	<11	<11	<110
benzo(g,h,i)perylene	<11	<11	<11	<11	<11	<11	<11	<11	<110

J is a data qualifier which indicates that the quantitative value is estimated. Usually this qualifier will appear after a value that is below the quantitation limit, i.e., the compound was detected at some level below the quantitation limit. Y is a data qualifier which indicates that the quantitative value was obtained after dilution of the sample.

2.6 DENSITY AND POROSITY OF PIT 1 FILL (SOIL) MATERIAL

The bulk density and porosity of pit 1 backfill and surrounding soil needed to be determined to assess the permeability of the pit material to heated gases generated during ISV and to calculate the degree of subsidence expected when melting the fill material. After completing the in situ radioactivity logging of pit 1, 14 representative regions in and around pit 1 were sampled to retrieve undisturbed soil cores over the entire depth interval to refusal. One-in. diameter core tube (i.e., JMC Environmentalist's Sub-Soil Probe, Appendix A) was used. The recovered soil core was sealed in the plastic field sampling tubes and returned to the laboratory for determination of weight and moisture content; from the sample dry weight and core dimensions, bulk density of pit backfill and surrounding soil formation was calculated. Three nearly complete soil core profiles were collected within the pit and six from outside the pit (three upslope and three downslope); in addition, soil cores were collected at the four corners of the asphalt pad to a depth of 6 ft to determine their degree of radioactive contamination should site grading in these areas prove necessary. Selected sections of these soil samples will also be used for elemental analyses of the pit backfill, which will determine the melting range and other properties of the molten ISV material.

Considering the nature of the soil fill material, the average core recovery of between 75 and 80% of driven depth interval, seems excellent. When the 3-ft long core sections were cut into smaller segments for determination of soil weights, moisture content, and radionuclide assays, rock fragments were frequently encountered ranging in size up to completely filling the sampling tube diameter; the rocks appear to be chert or sandstone (but not limestone) as might be expected from the routine soil borrow area near SWSA 3 which was in use in 1981 when pit 1 was filled. Because the residual core holes were measured for open depth before and after taking each 3-ft soil segment, the less than complete core recovery appears to derive from blockage of the cutting shoe tip of the corer for various intervals as the corer was driven into the soil. Although continued vibration from the drive hammer would eventually result in a rock fragment being forced into the core sampler or into the surrounding soil, during that interval no core could enter the sampler as it was driven deeper into the soil. Such vibration probably caused many artefactually low soil bulk densities observed in the upper parts of a given core; such vibration is the likely cause of many of the apparent discontinuities in soil bulk density within a series of soil core sections. Although the soil core recovery was generally less than complete for each soil section, the actual measured soil bulk densities were depicted over the whole known sampling interval because the exact missing locations within the depth interval cannot be determined. Representative soil bulk density profiles for eastern (upslope) side of the pit, the pit middle, and the western side of the pit are presented in Fig. 33, Fig. 34, and Fig. 35, respectively. The average bulk density of the imported fill material appeared to be about 1.5 g/cm³ whether the fill was on the east or west sides of the pit or within the pit. However, sampling refusal was usually coincident with a marked increase in bulk density; for the samples from within the pit, bulk density of the bottom segments actually were greater than 2 g/cm³ indicating the presence of hard rock (likely limestone although this has yet to be determined via chemical analyses of these segments). A bulk density of 1.5 g/cm³ corresponds to a porosity of 43% in this soil fill material to be melted during ISV. Thus, approximately 43% subsidence of the fill material would be expected during ISV.

Pit 1 - Core 113
Bulk Density vs Depth

Fig. 33. Bulk density of soil core segments recovered from hole 113 on the eastern side of seepage pit 1.

Pit 1- Core 120
Bulk Density vs Depth

Fig. 34. Bulk density of soil core segments from fill material in the center of seepage pit 1.

Pit 1- Core 114
Bulk Density vs Depth

Fig. 35. Bulk density of soil core segments from hole 114 (Fig. 6) on west side of seepage pit 1.

2.7 CHEMICAL ANALYSES OF PIT 1 SOIL AND FILL

Selected samples of pit 1 backfill and surrounding soil, obtained for bulk density determination, were analyzed for elemental composition. The bulk elemental composition is an important characteristic because it determines the temperature of melting and other melt parameters, such as electrical resistance and viscosity, during ISV. Of critical interest is the amount, if any, of limestone or dolomite present in the materials or soil to be vitrified. Such alkaline earth-containing materials could well have been placed in pit 1 during operation or backfilling (as is known to have been used in trenches 5, 6, and 7 of WAG 7; such materials may also be present in the surrounding slightly weathered strata of the Conasauga Group from which the soil material formed. These calcium- and/or magnesium-rich materials form lower-melting-temperature products when mixed with the more highly siliceous soil material.

Also important is the trace element (i.e., rare earth elements) composition of the pit 1 material, because trace elements of low background concentrations needed to be selected for addition to the ISV melts for subsequent determination of the mass of ISV product. For the soil and limestone used in the 1991 radioactive test, elements such as Eu, Hf, Lu, Sm, Tb, Ta, and Yb were found at <10 mg/kg and, thus, represent potential candidates for use as tracers. Pit 1 backfill and surrounding soil may also have required analyses for chloride and bromide content to determine if concentrations of these elements are different from the naturally low background concentrations.

As discussed previously, chloride presence during ISV can induce significant increases in the volatility of ^{137}Cs ; if significant levels of chloride are found (due to either residuals from the waste sludge or from discharges to pit 1 from the decontamination facility drainage), then plans for handling the volatilization of ^{137}Cs must be developed or identification of chloride-mitigating additives assessed. However, because both chloride and bromide were near expected background concentrations in all samples of groundwater (pages 36 and 40), analyses of these mostly soluble species in the soils was not considered necessary and, therefore, not attempted.

2.7.1 Pilot-Scale and Previous ISV Test Soils

To prepare materials for a bench-scale ISV melt test of pit 1 soil to determine melt operating temperatures, a bulk sample (two 55-gal drums) of pit 1 soil was collected on the east side of pit 1 just next to the barbed-wire fence (close to penetration point 81 and soil sampling point 112, Fig. 6). A 2- x 6-ft hole was excavated by hand shovel to a depth of 6-8 in. to remove soil material containing numerous grass roots; the sample was collected between 8 and 18 in.. However, rock fragments greater than 2-3 in. were not included although these were frequent within the excavated volume. Several kg of the fresh soil was retained for elemental analyses and reference while the bulk soil was shipped to Battelle for use in the bench-scale ISV test.

The soil was subjected to preparation for lithium borate fusion (ASTM Method D4503-86) as the technique for elemental analyses via inductively-coupled plasma atomic emission spectroscopy. This preparation involved oven-drying at 110°C and ashing at 550°C with determination of respective weight losses. In addition, the ashed soil was subjected to loss-on-ignition analyses by heating for 16 hr at 1000°C as a measure of carbonate (limestone) content. Since the lithium borate fusion technique had not been applied previously in ORNL ISV studies, samples of the soils and limestones used in both the 1987 and 1991 ISV field tests were also analyzed via this method; complete details of the sample preparation methods are given on page 63. A sample of the Richland soil, which was used in the engineering-scale ISV test of off-gas handling equipment, was also

Table 13. Elemental composition of pit 1 bulk soil and soils and limestones used for previous ORNL ISV tests

Oxide	Pit 1 Soil (%)	Richland Soil (%)	1991 Soil (%)	1987 Soil (%)	1991 Limestone (%)	1987 Limestone (%)
Al ₂ O ₃	13.45	13.03	16.01	17.15	1.59	2.49
BaO	0.05	0.08	0.05	0.06	0.01	0.01
CaO	0.74	4.03	1.82	2.60	54.05	73.78
Fe ₂ O ₃	5.91	7.04	5.83	5.84	0.97	1.15
K ₂ O	2.28	2.52	3.01	4.06	0.69	1.43
MgO	0.73	2.09	1.95	1.66	24.91	4.83
MnO ₂	0.05	0.14	0.25	0.14	0.11	0.04
Na ₂ O	0.10	2.64	0.48	0.95	0	0.02
SiO ₂	69.13	64.09	64.95	60.21	9.03	8.02
TiO ₂	0.89	1.30	0.79	0.89	0.06	0.10
Loss-on-Ignition	1.67	0.83	10.31	9.07	42.66	40.53
Oxide Sum	93.45	97.10	95.30	93.69	91.59	91.96

analyzed via this method. Results of these elemental analyses, expressed on an element oxide basis, are presented in **Table 13**.

The bulk pit 1 soil (**Table 13**) was the lowest in alkali metals (Na and K) and alkaline earth elements (Ca and Mg) of any of the four soils. This result forces the conclusion that the pit 1 soil would be rather high melting during ISV processing; indeed, the average melt temperature during the recent bench-scale test was approximately 1700°C. This ISV operating temperature for the pit 1 melt will be considerably higher than the ca. 1500°C operating temperature during the 1987 and 1991 ORNL ISV field tests. Both the 1987 and 1991 tests used a mixture of limestone and soil to simulate seepage trenches 5, 6, and 7 which include limestone as a fill material; the mixture of soil and limestone results in a molten ISV material of considerably lower operating temperature. However, as discussed subsequently, pit 1 does not appear to have limestone as a fill material and, thus, would have its vitrification operating at the higher temperature. The rock fragments, frequently encountered and included during the taking of this bulk soil fill sample, were apparently not limestone because the elemental analyses showed less than 1% CaO.

2.7.2 Pit 1 Soil Elemental Composition and Its Spatial Distribution

As discussed previously, numerous samples of soil were obtained from within and around pit 1 using driven soil sampling tubes. Only selected samples were subjected to the lithium borate fusion method (ASTM Method D4503-86) prior to elemental analyses. In addition to the complete dissolution of all soil and rock forming elements, this technique has the advantage of bringing all the major composition elements (Si, Al, Fe, Mn, Ca, Mg, K, and Na) into solution in a single step. Because the soil, rock, or, after melting, the ISV product can be completely dissolved, the resulting dissolved sample can also be analyzed for the radionuclides of interest in pit 1: ¹³⁷Cs, ⁹⁰Sr, U, and Pu. Alternately, these radionuclides are assayed on acid-dissolution of the solid material with some correction for recovery using various spiked tracers. Thus, this single dissolution technique can prepare a sample for all necessary analyses; details of the sample handling methodology are given in the section on radiochemical analyses (page 63).

The only soil characteristic, which must be determined separately, is the carbonate content which is measured as the loss-on-ignition (LOI) of the material when heated to 1000°C after previous drying at 100°C. The sample LOI was found to be an accurate measure of carbonate content of the two limestone samples (Table 13) used previously and the new limestone material to be used in pit 1.

During soil sampling and probe driving, refusal to further penetration was frequently encountered and was interpreted as the contact between loose fill soil and the underlying relatively unweathered and undisturbed rock. After retrieval, three significant contrasts between the fill soil and the underlying residuum were apparent: 1) the fill was colored brown in contrast to the gray color of the underlying rock, 2) the bulk density of the fill (1.5 g/cm³) was considerably lower than that of the denser underlying rock (2.11 g/cm³), and 3) the apparent absence of radioactive contaminants in the denser underlying rock. Both the color and hardness/density contrast hinted of a contact between soil and limestone.

Actually, the soil sampling tube only penetrated 1-2 in. into the rock layer and, thus, only minimal amounts of this material were available. If this unweathered material were limestone, contact by a growing ISV melt body would have considerably different effects than if its elemental composition were more typical of shale or the overlying soil. Thus, the elemental composition of the dense underlying rock was identified as a critical characteristic for measurement in the overall site characterization effort.

The bottom core segment, retrieved from each of the three sampling location along the pit 1 center line, was divided into 1-in. depth increments. The bottom two 1-in. segments from each core, which were both dense and gray-colored, and two additional 1-in. segments from at least 12-18 in. above the core bottom, which were both less dense and brown-colored, were analyzed for bulk elemental composition (Table 14).

Although the six samples of rock were significantly different in both density and color from the overlying fill soil, there was little evidence of any limestone or carbonate present. Both the loss-on-ignition and the CaO content were similar for the brown and gray materials. Indeed, the highest LOI and CaO content was observed in one of the overlying soil samples (119-8-10); this may be an artifact resulting from the inadvertent inclusion of a small piece of limestone gravel from the sampling surface during the many sample tube drivings and retrievals in each hole. The dense underlying rock, thus, is mostly shale, not limestone, and of similar composition to the overlying soil. The low degree of weathering of this dense shale is also apparent in its slightly higher content of both CaO and Na₂O as would be expected of slightly weathered shale in the Conasauga formation.

The confidence in the accuracy of these measured elemental compositions is supported by the general quality control check that the sum of the major elemental oxides and LOI is at least 85% of the weighed material and not more than 110% of the weighed material (Table 14). All of these analyses tended to sum significantly below 100% (the average compositional sum was 90.4%), i.e., less material was accounted for by analytical results than was weighed out for fusion with LiBO₂. Probable sources of this error include incomplete fusion of the soil with lithium borate (due to inadequate mixing prior to fusion or large soil particles failing to completely fuse during the 20 minute heating interval) or spillage during transfer of the molten lithium borate into the dilute nitric acid solution. All of these errors would result in systematically low analytical values for all elements. Such low recovery is a standard argument to "normalize" the elemental compositions, i.e., proportionally increase all elemental oxide values until the total sums to 100%. Such normalization

Table 14. Elemental oxide composition of pit 1 soils in three cores taken at penetration refusal

Soil	118-8-1	118-8-2	118-8-17	118-8-18	119-8-1	119-8-2
Color	gray	gray	brown	brown	gray	gray
Depth (in.)	0-1	1-2	16-17	17-18	0-1	1-2
from bottom						
Bulk density	1.97	2.25	1.19	1.28	1.85	1.96
(g/cm ³)						
Al ₂ O ₃	18.85	20.47	18.42	19.97	20.67	20.61
CaO	1.49	1.39	0.54	1.46	2.83	2.06
Fe ₂ O ₃	6.47	6.19	6.15	7.09	6.14	6.23
K ₂ O	3.42	3.92	3.13	3.33	4.71	4.32
MgO	2.16	2.18	1.13	1.20	2.85	2.71
MnO ₂	0.05	0.04	0.05	0.05	0.09	0.07
Na ₂ O	0.95	0.61	0.10	0.08	0.22	0.22
P ₂ O ₃	0.21	0.46	0.09	0.07	0.03	0.02
SiO ₂	50.87	46.33	50.37	46.94	41.76	43.31
TiO ₂	0.66	0.72	0.77	0.73	0.76	0.80
Loss@100°C	1.39	1.67	2.44	2.62	1.73	1.73
Loss@1000°C	5.34	5.49	6.35	7.44	7.62	6.78
Total	91.86	89.47	89.54	90.98	89.41	88.86
Soil	119-8-10	119-8-11	120-8-1	120-8-2	120-8-11	120-8-12
Color	brown	brown	gray	gray	brown	brown
Depth (in.)	9-10	10-11	0-1	1-2	10-11	11-12
from bottom						
Bulk density	0.76*	0.18*	1.08*	2.13	1.72	1.57
(g/cm ³)						
Al ₂ O ₃	12.69	19.51	17.12	17.52	21.65	20.48
CaO	10.50	0.60	6.90	5.29	0.36	0.37
Fe ₂ O ₃	4.29	6.13	4.23	6.51	6.90	7.52
K ₂ O	2.10	3.83	3.18	3.35	3.85	2.99
MgO	1.21	1.31	1.77	1.92	1.76	1.41
MnO ₂	0.05	0.05	0.17	0.13	0.03	0.03
Na ₂ O	0.06	0.08	0.86	0.71	0.46	0.30
P ₂ O ₃	0.00	0.06	0.30	0.27	0.08	0.14
SiO ₂	43.94	49.25	42.27	42.96	47.23	51.33
TiO ₂	0.55	0.82	0.67	0.67	0.72	0.72
Loss@100°C	1.64	2.48	1.29	1.44	2.15	2.33
Loss@1000°C	12.84	6.30	9.42	8.16	5.95	6.34
Total	89.87	90.40	88.18	88.93	91.13	93.97

* Loose core or poor recovery in core sampler; thus, bulk density is low due to poor estimate of sample volume.

of results is quite convenient and legitimate to employ in reporting elemental compositions of soil and rock. However, normalization inadvertently masks ready quality assurance checks by informed readers and, thus, is not employed in this characterization report.

In addition to the major element composition, the analytical results by ICPAES provide information on trace element composition of the soils (**Table 15**). This provides a method to determine if hazardous elements were disposed in pit 1 during its use for liquid radioactive waste disposal or when later used as a drain field for the decontamination facility. Perhaps, the most facile method to determine whether pit 1 was impacted by hazardous elements is to compare the trace element content of the radiologically uncontaminated underlying rock with the strongly radiologically contaminated soil fill. For all 12 of the potentially hazardous elements in **Table 15**, no significant differences were observed between the unweathered rock and fill soil. Concentrations for the elements Ag, Mo, Pb, Sb, Se, and Sn were not detected in any of these samples and are reported at their detection limits in a footnote in **Table 15**. Obviously, these elemental analyses, with sample preparation via fusion with LiBO_2 , could not be employed to detect volatile or combustible organic hazardous constituents or even volatile elements like Hg. The analyses of perched groundwater samples, discussed previously, failed to detect any of these other hazardous constituents. Thus, there is no evidence that hazardous materials, other than radionuclides, were disposed in pit 1.

Also reported in **Table 15** are some "background" or expected concentrations for these 12 elements in Oak Ridge Reservation soil derived from shale (Watkins et al. 1993). Elements including Be and Co exhibited concentrations in pit 1 soil typical of those reported by Watkins et al. (1993). However, elements including As, Ba, Cr, Cu, Ni, Sr, V, and Zn exhibited values significantly elevated over those reported by Watkins et al. (1993). However, because all these elements exhibited similar concentrations in the pristine unweathered shale and in the contaminated soil fill within pit 1, the higher values result from elevated background concentrations within the particular shale material in and around pit 1. There are also considerable differences in the analytical techniques (neutron activation) employed by Watkins et al. (1993) and the LiBO_2 fusion/ICPAES used herein. The only particular artifact of the LiBO_2 fusion/ICPAES technique appeared to be the consistently higher than expected values for As; this is a probable analytical matrix effect of the LiBO_2 during ICPAES and is discussed subsequently. In summary, the background concentrations for these twelve potentially hazardous elements in pit 1 soils should be those reported in **Table 15**.

Although the elemental compositions of soil and rock in **Table 14** support the important conclusion that there is little difference in composition between the backfill soil in pit 1 and the underlying rock in which pit 1 was excavated, these compositions would not necessarily be the most representative of those to be vitrified in pit 1. Much of the mass of ISV product would originate from soil fill above the contact with the underlying rock. Thus, ten additional soil samples were selected for elemental analyses (**Table 16**) from various depths in soil cores from within pit 1 and soil core immediately surrounding pit 1. The specific locations of the soil cores, corresponding to the soil cores in **Table 16**, can be found on the pit 1 site sampling plan view (**Fig. 6**). The depth interval and bulk density of each sample is also given in the table to indicate the representative range of these characteristics employed. In general, these elemental compositions are not much different than those of the soils at the pit bottom and those of the underlying rock (**Table 14**). In only two samples (116-5-4 and 120-1-6) was there clear evidence for the presence of some limestone; the LOI of these samples was above 10% and the CaO content was well above 1% (i.e., 9.97 and 8.72%, respectively). The sample from west of pit 1 (116-5-4) was taken at refusal and is interpreted to contain significant limestone because of these characteristics and its relatively high bulk density.

Table 15. Trace element composition (ppm) of pit 1 soils from three cores

Soil	118-8-1	118-8-2	118-8-17	118-8-18	119-8-1	119-8-2	119-8-10
As	284	217	244	260	203	250	87
Ba	259	269	323	315	303	325	607
Be	2	2.2	1.8	2.0	2.3	2.3	1.3
Cd	0.8	0.8	1.6	2.4	0.8	2.3	<0.1
Co	16	17	11	18	21	22	10
Cr	81	90	86	86	99	98	50
Cu	5.4	8.5	29	37	13	24	11
Ni	56	47	31	34	52	37	119
Sr	100	124	63	68	102	94	103
V	56	64	59	68	81	80	44
Zn	115	93	98	114	94	94	61
Zr	138	147	179	155	94	101	111
Soil	119-8-11	120-8-1	120-8-2	120-8-11	120-8-12	ORR* Surface	ORR* Subsoil
As	262	165	232	221	248	9	13
Ba	324	311	292	284	308	75	56
Be	2.1	1.7	1.7	1.9	1.8	0.7	1.1
Cd	2.4	0.8	<31	<33	1.5	nd	nd
Co	14	17	18	16	14	14	9
Cr	92	145	159	95	90	23	35
Cu	31	71	41	87	98	10	25
Ni	517	124	50	31	26	13	23
Sr	70	115	108	82	70	5	2.4
V	66	55	72	68	64	33	51
Zn	87	107	108	107	171	42	82
Zr	175	115	124	115	132	na	na

All samples were <33 ppm Ag, <26 ppm Mo, <419 ppm Pb, <330 ppm Sb, <330 ppm Se, and <330 ppm Sn.

Table 16. Elemental oxide composition (%) of pit 1 soils from various depths and locations

Soil	117-5-5	118-1-5	118-4-7	118-6-9	119-4-4
Depth below surface (in.)	120-123	25-27	136-139	188-191	133-135
Bulk density (g/cm ³)	1.64	1.31	1.55	1.51	1.53
Al ₂ O ₃	16.55	14.15	14.49	15.66	16.50
CaO	0.23	0.42	0.21	0.34	0.32
Fe ₂ O ₃	5.90	6.24	5.12	5.36	6.00
K ₂ O	3.47	2.81	2.72	3.22	3.06
MgO	1.24	0.79	0.77	1.03	1.11
MnO ₂	0.03	0.14	0.18	0.06	0.06
Na ₂ O	0.31	0.05	0.11	0.36	0.31
P ₂ O ₃	0.05	0.14	0.05	0.06	0.04
SiO ₂	58.01	62.30	62.43	59.70	57.82
TiO ₂	0.72	0.8	0.81	0.71	0.75
Loss@100°C	1.46	1.37	1.13	1.19	1.29
Loss@1000°C	7.56	7.08	7.57	7.37	7.58
Total	95.53	96.29	95.59	95.06	94.84
Soil	119-7-7	120-5-8	116-3-7	116-5-4	120-1-6
Depth below surface (in.)	255-258	155-159	93-96	107-109	34-37
Bulk density (g/cm ³)	1.45	1.65	1.66	1.80	1.69
Al ₂ O ₃	16.53	18.88	8.09	9.66	12.12
CaO	1.37	0.79	0.09	9.97	8.72
Fe ₂ O ₃	5.60	6.31	5.29	4.16	4.88
K ₂ O	2.97	3.41	0.90	1.75	2.51
MgO	1.04	1.23	0.44	1.72	1.12
MnO ₂	0.03	0.03	0.04	0.07	0.14
Na ₂ O	0.16	0.20	0.07	0.09	0.02
P ₂ O ₃	0.04	0.09	0.06	0.03	0.03
SiO ₂	56.15	54.31	76.59	52.48	49.91
TiO ₂	0.67	0.70	0.77	0.68	0.62
Loss@100°C	1.35	1.45	0.81	1.07	1.29
Loss@1000°C	8.89	8.58	5.53	15.49	14.50

This soil-rock material, however, would not be in a zone to be melted during ISV. The other limestone-bearing sample was from the near-surface (34-37 in. depth interval) soil directly in the center of the proposed melting zone. However, this is probably a sampling artifact from including a piece of limestone gravel in the core during the initial core barrel driving or a small piece of limestone gravel included in the pit 1 fill material when it was emplaced. In general, limestone is not present in the pit 1 soil material to be vitrified. The trace element composition of these same samples is presented in **Table 17**. The concentrations of these trace elements is similar to those in the pit bottom soil and underlying rock samples (**Table 14**).

The average soil composition in pit 1 is presented in **Table 18** which includes the average composition of the unweathered gray underlying rock, the soils at the bottom of pit 1, and the ten other soil samples from within and around pit 1. This average is the elemental composition which should be used to predict melt characteristics. Fortunately, this elemental composition is quite similar to the bulk pit 1 soil sample collected for the pilot-scale ISV melting test (**Table 13**). The effects of this composition on melting characteristic is discussed in the section on melt properties and volatilization of ^{137}Cs . In general, the lack of limestone (low CaO and/or MgO) and the low Na_2O content of the unamended pit 1 soil will result in a relatively high melting range (ca. 1750°C) for ISV processing compared to previous ORNL pilot-scale tests where significant inclusion of limestone resulted in operating temperatures for ISV which were considerably lower (ca. 1500°C).

A number of additional materials could possibly be included in the pit 1 melt through either indirect or planned amendments to the melt body. There is the potential that these materials may significantly affect the operating and final elemental composition of the melt body depending on the actual amounts incorporated. These potential materials include limestone gravel (as an ISV processing temperature lowering amendment), feldspar sand (as a low-temperature melt starter material), Cer-Wool® blanket (as a mineral insulating material to cover the starter path material and the ground surface inside the off-gas collection hood), and Firelite® insulating aggregate (as high-temperature floating insulation over the melt surface to aid in filtering ^{137}Cs which might volatilize from the melt body). Samples of these materials were prepared for analyses by the lithium borate fusion technique prior to ICP/AES.

In addition to their possible effects on melt composition and ISV processing temperature, these materials needed to be checked as potential sources of rare earth elements which might affect the melt mass measurements employing these rare earth tracers. The limestone was obtained as a washed 3/4-in. gravel from Rodgers Group, Inc. (Oak Ridge, Tennessee), a local gravel and cement company, by the site preparation construction contractor (MK-Ferguson). Approximately, 80 tons of this gravel were stockpiled at the pit 1 site along its northern edge just west of the Melton Valley access gate. This quantity was selected as sufficient to amend up to 800 tons of ISV molten product to 10% limestone; a pit 1 soil amended to 10% CaCO_3 would lower the ISV processing temperature to under 1600°C , as discussed subsequently. The composition of this limestone exhibited excellent sum of oxides and LOI (**Table 19**). This limestone was also overwhelmingly calcitic as evidenced by the more than 10:1 ratio of $\text{CaO}:\text{MgO}$. Thus, it is anticipated that, if this limestone were used to amend pit 1 melts, the ISV product may be more similar to the 1987 ORNL pilot-scale ISV product (i.e., mostly vitreous) in contrast to the 1991 ORNL pilot-scale ISV product which was largely crystalline due to the use of a magnesian or dolomitic limestone (Spalding et al. 1992).

The Cer-Wool® blanket material was manufactured by and procured from Premier Refractories and Chemicals Inc, King of Prussia, Pennsylvania (Grade RT with an operating temperature rating of 1260°C and a melting point of 1760°C); this is a high temperature mineral fiber insulating blanket,

Table 17. Trace element composition (ppm) of pit 1 soils from various depths and locations

Soil	117-5-5	118-1-5	118-4-7	118-6-9	119-4-4
As	150	154	150	167	171
Ba	320	390	345	273	265
Be	2.3	1.9	1.8	2.1	2.1
Cd	<0.1	0.8	2.5	3.3	2.5
Co	15	15	14	11	15
Cr	86	69	78	82	82
Cu	14	16	7.9	18	13
Ni	42	23	15	23	27
Sr	56	65	53	54	53
V	73	73	62	65	71
Zn	99	53	62	74	64
Zr	129	271	259	163	196
Soil	119-7-7	120-5-8	116-3-7	116-5-4	120-1-6
As	183	192	79	83	142
Ba	311	344	202	206	253
Be	2.0	2.4	0.9	0.8	1.8
Cd	0.8	2.5	<0.1	<0.1	<0.1
Co	10.1	12	12.5	8.3	16
Cr	78	95	54	57	70
Cu	13	15	12	17	17
Ni	18	25	15	40	7.1
Sr	63	65	30	89	102
V	65	77	45	52	55
Zn	58	67	53	37	57
Zr	138	125	392	216	142

Table 18. Average elemental oxide composition of pit 1 unweathered bottom and fill soils

	Unweathered Gray Bottom Rock	Weathered Bottom Backfill Soils	Other Backfill Soils	Average Overall Pit 1 Soil
Number of samples	6	6	10	22
Elemental oxide	(%)	(%)	(%)	(%)
Al ₂ O ₃	19.1	18.8	14.3	16.8
CaO	3.2	2.3	2.2	2.5
Fe ₂ O ₃	6.1	6.3	5.5	5.8
K ₂ O	3.7	3.2	2.7	3.1
MgO	2.0	1.3	1.0	1.5
MnO ₂	0.1	0.0	0.1	0.1
Na ₂ O	0.6	0.2	0.2	0.3
P ₂ O ₅	0.2	0.1	0.1	0.1
SiO ₂	45.2	48.2	59.0	52.1
TiO ₂	0.7	0.7	0.7	0.7
Loss@100°C	1.7	2.3	1.2	1.6
Loss@1000°C	7.2	7.5	9.0	8.1
Total	89.8	91.0	95.9	92.8

Table 19. Elemental oxide (%) and trace element (ppm) composition of materials potentially included in the pit 1 in situ vitrification product

Material	Limestone	Firelite®	Feldspar	Cer-Wool®
	gravel	aggregate	sand	blanket
Oxide				
Al ₂ O ₃	1.01	62.32	18.25	40.53
CaO	49.77	0.36	1.86	0.10
Fe ₂ O ₃	0.54	0.44	0.05	0.82
K ₂ O	0.68	0.07	3.01	0.00
MgO	3.31	0.6	0.02	0.05
MnO ₂	0.02	0.00	0.01	0.00
Na ₂ O	0.04	0.22	8.04	0.05
P ₂ O ₃	0.00	0.00	0.00	0.00
SiO ₂	3.09	34.27	65.40	49.23
TiO ₂	0.03	1.17	0.00	1.81
Loss@100°C	0.26	0.11	0.09	0.06
Loss@1000°C	41.91	0.02	0.18	0.00
Total	100.66	99.58	96.91	92.65
Trace element				
Ba	45	201	842	68
Be	0.9	2.0	3.5	1.6
Co	<65	3.2	<65	0.8
Cr	4.4	101	nd	158
Ni	5.1	16.6	<165	22
Sb	<817	<810	386	391
Se	<817	24	<823	<830
Sr	372	72	391	50
V	7.7	84	<33	170
Zn	<82	<81	34	53
Zr	<327	93	<329	53

All materials were <83 ppm Ag, <817 ppm As, <83 ppm Cd, <115 ppm Cu, <663 ppm Mo, <829 ppm Pb, and <829 ppm Sn.

virtually identical to Kaowool® used in previous ISV applications. Its main function is to conserve heat within the melt particularly during start up when heat losses are largest relative to size of the melt. It is eventually incorporated into the melt, at least those areas directly over the melt body, in a few days. Residual Cer-Wool® blanket surrounding the ISV subsidence crater at the termination of the melt, functions to protect the ground surface from contamination by radioactive particles emitted or splattered from the melt body; the blanket can then be rolled up into the subsidence crater prior to backfilling with clean soil. The material was found to be within its chemical composition specifications and composed mostly of aluminum and silicon oxides. Such a potential material, if amended to an ISV melt, would be expected to raise its general operating temperature due to its lack of Na, K, Ca, and Mg; absence of these elements is the reason for its high melting point. Cer-Wool® did not exhibit any unusual concentration of hazardous trace elements (Table 19). Thus, its use would not introduce any change in ISV product hazard classification. However, even at its specified bulk density of 8 lb/ft³, an estimated 40 ft³ of 1-in.-thick blanket, covering the melt area and eventually being fully incorporated, would add only 320 lb to a typical melt mass of over 400 tons. Thus, Cer-Wool® would not be expected to alter the melt body characteristics or the chemical composition of the final ISV product.

The Firelite® Aggregates 2855LI (BNZ Materials Inc, Zellenople, Pennsylvania) was found to conform to its elemental composition specification. It is a high aluminum oxide-silicon oxide aggregate with high melting point (operating temperature to 1500°C) and low bulk density (55 lb/ft³) and can be fairly characterized as "crushed fire brick." Approximately 50,000 lb of this material was procured and delivered in 80 lb plastic-lined paper bags. The low density and high melting point of this material make it likely to float on the surface of an ISV melt body, thus, aiding in retaining heat as well as functioning as a filter layer for any ¹³⁷Cs volatilized from the melt body. Although the Firelite® Aggregate would eventually be incorporated into the melt body, its addition to the melt surface would not be attempted until the latter stages of a melt at pit 1 when the molten body had grown to contact the deep ¹³⁷Cs contamination. Thus, its life as a filtering layer over the melt would need to be maintained for only a few days. Its elemental composition (Table 19) is similar to Cer-Wool® in being low in Na, K, Ca, and Mg. It was also found to be low in hazardous trace elements and would, thus, not change the hazardous characteristic of the ISV product. Like Cer-Wool®, incorporation of significant amounts of Firelite® aggregates into the melt would be expected to raise the ISV processing temperature. However, even the full incorporation of a 6-in.-thick layer over a 500-ft² melt body surface, would add about 13,750 lb to a planned melt body of 800,000 lb (400 tons). Such an addition would not likely exert much effect on ISV product composition.

During the pilot-scale test using pit 1 soil, significant difficulty was encountered initiating and maintaining the early melt body due to its high melting point and the very coarse nature of the soil aggregates or clods. To overcome this difficulty, a low-melting starter material of fine and uniform texture was desired to initiate the melt in moist pit 1 soil avoiding the need to reestablish starter path materials (a labor intensive task). A potassium feldspar sand (Minspar 1®, K-T Feldspar Corp., Spruce Pine, North Carolina) was selected for this purpose. This material begins to melt (fuse) at 1065°C (product specification) due to its high Na and K content. Approximately 20 tons of this sand were procured and delivered in bulk and stockpiled at the pit 1 site. The material was tested in laboratory crucibles, heated to 1100°C, and was fully melted after less than one hour. Its elemental composition (Table 19) exhibited both high Na and K oxide values (3 and 8%, respectively); no unusual concentrations of hazardous trace elements were observed. A nominal 8-in.-thick layer over a planned approximately 500 ft² of melt start surface would add 31,600 lb to the melt mass if poured at its free-fall bulk density of 95 lb/ft³. In addition to significantly lowering the startup and early operating temperature of the pit 1 melt, this total quantity of feldspar could add an additional 2,500

lb of sodium oxide to a total melt mass of 800,000 lb (400 tons) which otherwise would contain only 2,400 lb of sodium oxide (i.e., 0.3% Na₂O) from pit 1 soil. This potential doubling of the Na₂O content of the ISV product can represent a significant increase in molten electrical conductivity and a decrease in melt viscosity and operating temperature. In addition, this amendment could have an effect on ISV product quality.

To verify the accuracy of the ICP/AES analyses using the LiBO₂-fusion HNO₃-dissolution sample preparation technique, reagent blank samples were spiked with known amounts of various standard element solutions and the observed concentrations compared to those calculated from known dilution of the standards. In addition, reagent blank samples (i.e., samples carried through the entire LiBO₂-fusion HNO₃-dissolution sample preparation but without any added soil) provide a quantitation of background elemental concentrations inherent in the reagents themselves and/or matrix interferences in the ICP/AES analyses arising from the significant background of both Li and B in these samples. Spiked reagent blanks (**Table 20**), at two different concentrations, were prepared by addition of either 0.500 or 1.000 mL of elemental standard solutions (Alpha Aesar, Ward Hill, Massachusetts, Stock # 35419, Solutions A and B [21 ICP elements], Stock # 38723 [Si standard]) to a final volume of 100 mL of reagent blank solution in volumetric flasks. The acceptance criteria for these spiked reagent blank standards was that the observed concentration be within $\pm 10\%$ of the expected values.

As can be seen in **Table 20**, all elements except Ag, in both spikes, and Sb, in the more dilute sample, were found to attain this acceptance criteria and, thus, the analytical technique was deemed accurate. The Ag detection problem was not deemed important to any analytical need and, therefore, was not pursued. The presence of LiBO₂ in the ICP/AES sample matrix did introduce some interferences which elevated many of the normal detection limits for some elements as can be seen in the reagent blank analyses in **Table 20**. These blank values posed no interference in the typical concentrations observed in soil samples (see average soil matrix values in **Table 20**) for the major compositional elements (Na, K, Ca, Mg, Al, Si, Fe, Mn, Ti, or P). The spikes and reagent blank analyses provide a high level of confidence in the ICP/AES analytical results of the soil analyses based on the LiBO₂-fusion HNO₃-dissolution sample preparation method. The variable and often low recoveries, based on the sum of elemental oxides and LOI being less than the weighed quantity of soil, must result from either sample losses during fusion and handling or incomplete fusion during heating or dissolution rather than from analytical method errors.

The consistently low recovery of sample elemental oxides was observed when "standard" soil samples were analyzed by LiBO₂-fusion HNO₃-dissolution sample preparation technique. Two standard rock samples (Cody Shale and Mica Schist from the 272 Geostandards, reported in Govindaraju (1989)) were selected for their compositional similarity to pit 1 soil, procured, and subjected to the same analyses. The known or standard values of the Cody Shale and Mica Schist are listed in **Table 21** along with the values found by ICP/AES analyses of the LiBO₂-fusion HNO₃-dissolution samples. The observed values were typically lower than the standard values particularly for the major compositional elements. As discussed previously, this is probably due to poor sample fusion and/or recovery as most of the major elements, particularly the mineral structural elements, including Al, Si, and Fe, were systematically and proportionally low. Among the trace elements, only As exhibited a significant problem where the observed values were more than an order-of-magnitude greater than the standard value. The relatively high As concentrations observed in the pit 1 soil samples can be assumed to be a similar analytical artifact rather than true As contamination above background levels. This undoubtedly is a sample matrix problem with the ICP/AES of LiBO₂-fusion HNO₃-dissolution samples. However, rather than invest significant resources in solving this

Table 20. Typical reagent blank and matrix-spiked analyses and typical concentrations in lithium borate/nitric acid dissolutions of pit 1 soils analyzed by inductively-coupled plasma emission spectroscopy

Element	Reagent Blank (mg/L)	Spike-A Expected (mg/L)	Spike-A Found (mg/L)	Spike-B Expected (mg/L)	Spike-B Found (mg/L)	Average Soil Matrix (mg/L)
Ag	<0.010	1.0	0.12	0.5	0.048	<0.01
Al	0.16	5.0	5.2	2.5	2.5	127
As	<0.10	5.0	5.1	2.5	2.4	0.38
Ba	<0.0020	5.0	4.9	2.5	2.2	0.41
Be	0.005	2.0	2.0	1.0	1.0	0.007
Ca	0.7	50	48	25	23	26
Cd	<0.010	2.5	2.4	1.25	1.2	0.01
Co	<0.0080	5.0	4.8	2.5	2.5	0.03
Cr	0.013	5.0	4.9	2.5	2.3	0.14
Cu	<0.014	5.0	4.7	2.5	2.3	0.06
Fe	1.6	5.0	4.9	2.5	2.4	55
K	<4.0	50	51	25	22	39
Mg	0.14	50	47	25	23	14
Mn	0.008	5.0	4.7	2.5	2.4	0.5
Mo	<0.080	0	<0.20	0	<0.40	<0.008
Na	0.26	50	49	25	27	5.4
Ni	0.02	5.0	4.8	2.5	2.3	0.14
P	<0.60	0	<1.5	0	<3.0	1.4
Pb	<0.10	5.0	4.6	2.5	2.4	0.4
Sb	0.59	5.0	4.5	2.5	1.8	<0.10
Se	<0.10	5.0	5.0	2.5	2.7	<0.10
Si	<0.40	0	<1.0	50	49	274
Sn	<0.10	0	<0.25	0	<0.05	<0.10
Sr	<0.010	0	<0.025	0	<0.025	0.13
Ti	<0.040	0	<0.10	0	<0.20	5.5
V	<0.0040	5.0	4.7	2.5	2.2	0.11
Zn	0.058	5.0	4.6	2.5	2.4	0.14
Zr	<0.040	0	<0.10	0	<0.20	0.21

Table 21. Comparison of observed and known gross and trace elemental composition of geological standards using lithium borate fusion/nitric acid dissolution with inductively coupled plasma emission spectroscopic analyses

Material	Cody Shale	Cody Shale	Mica Schist	Mica Schist
	Found	Known	Known	Found
Oxide	(%)	(%)	(%)	(%)
Al ₂ O ₃	12.25	13.67	15.75	14.24
CaO	2.35	2.62	1.40	1.31
FeO	4.34	4.62	6.21	5.77
K ₂ O	2.71	2.77	3.28	3.21
MgO	2.34	2.72	1.69	1.45
MnO	0.06	0.05	0.11	0.13
Na ₂ O	0.96	0.90	2.05	2.08
P ₂ O ₃	0.13	0.21	0.16	0.08
SiO ₂	60.48	62.78	65.85	54.35*
TiO ₂	0.51	0.63	1.01	0.88
Loss@100°C	2.15	2.11	0.10	2.33
Loss@1000°C	5.95	6.66	1.91	6.34
Total	94.19	99.74	99.52	92.14
Trace element	(ppm)	(ppm)	(ppm)	(ppm)
Ag	<34	0.13	0.041	<34
As	108	12	0.22	146
Ba	514	570	830	569
Be	1.7	1.8	3	2.5
Cd	0	0.14	0.080	0.4
Co	9.2	10.5	17.9	12.5
Cr	62	68	64	50.8
Cu	15	28.7	3	12.1
Mo	<267	1.37	0.25	<267
Ni	13.3	27	38	12.5
Pb	<334	3	25	<334
Sb	<334	2.5	0.54	<334
Se	<334	0.89	0.032	<334
Sn	<334	3.7	3	<334
Sr	148	174	183	156
V	108	131	102	79
Zn	78	103	103	81
Zr	100	160	290	225

* Average of a low value (44.54) and realistic value (64.16).

tangential interference problem, the As analytical anomaly was ignored as unimportant to the objectives of the ISV treatability study. The data in Table 21 can be used to evaluate the accuracy of trace element values in all the pit 1 samples; when the known and found values agree within $\pm 10\%$ in Table 21, then confidence can be placed in the reported trace element concentrations for pit 1 soil analyses. For all the major compositional elements, this confidence is well supported by these findings. Presumably, use of the LiBO_2 -fusion HNO_3 -dissolution technique for analyses of ISV product will prove equally accurate and reliable.

The background concentrations of rare earth elements, of potential use as melt body spike tracers for measurement of the final mass of ISV product, were also determined for pit 1 soils and the other materials potentially included in the ISV melt body (Table 22). These samples were analyzed by neutron activation analysis at ORNL's High Flux Isotope Reactor using an ORNL Analytical Chemistry Division standard analytical method (Procedure No. AC-MM-222003, April 15, 1993).

A standard reference material (NIST Standard 2709) was analyzed with this suite of samples as a quality control sample and the standard and observed values reported in Table 22. Also reported in Table 22 are the background levels of some of these rare earth elements previously observed in Oak Ridge Reservation soils (Watkins et al. 1993). The group of elements including La, Ce, Nd, Sm were observed to exhibit significant background concentrations in pit 1 soils making their use as tracer spikes for ISV melts too insensitive for accurate melt mass calculation. The elements Tb, Ho, Tm, Yb, and Lu were all found in sufficiently low concentrations in pit 1 soils (all < 3 ppm) to allow spiking with reasonable quantities (< 10 kg), into soil zones to be vitrified. The accurate analyses of these same elements in standards and their very low concentrations in other materials which might be incorporated in the melt body (limestone, feldspar sand, and Firelite® aggregates) provides confidence in their selection as tracers for ISV product mass measurements.

2.8 RADIOCHEMICAL ANALYSES OF PIT 1 SOILS

Nondestructive assays of gamma emitters in the undisturbed soil cores from pit 1 were completed for all core material by the project methods (ISV-TS-P04, Appendix A). These nondestructive procedures appeared to work well for assay of ^{137}Cs which was the dominant source of radioactivity in pit 1 soil samples. Cobalt-60 was detected only infrequently and, then, only at levels close to background and detection limits; thus, it was concluded that ^{60}Co was not present in pit 1 soil. The assay of ^{90}Sr via determination of bremsstrahlung in excess of that attributable to the independently measured activity of ^{137}Cs was interpreted as a qualitative method only and results indicated the need for a quantitative assay. In addition, validation of the nondestructive ^{137}Cs method was also desirable; an uncertainty in this assay was inherent due to the unknown distribution of ^{137}Cs within the standard 3-in. length of soil core and resulting effects on counting geometry and efficiency. In addition, selected samples needed to be assayed for the α -emitting isotopes, ^{239}Pu and ^{238}U , which disposal records indicated had been placed in pit 1. Assays for α -emitting radioisotopes necessitate destructive analyses to dissolve soil so that the desired isotopes can be radiochemically fractionated. All of the soil samples within and surrounding the maximally contaminated section of the three soil cores, sampled from within pit 1, were subjected to lithium borate (LiBO_2) fusion and dissolution in dilute nitric acid (ASTM Method D4503-86). In addition, selected samples from other less-contaminated sections of these cores, as well as from selected perimeter core, were also subjected to lithium borate dissolution. This selection of samples provided a population of pit 1 soils with a wide variance in ^{137}Cs activity; the resulting dissolved samples could then be assayed for

Table 22. Rare earth element composition, as determined by neutron activation analyses, for selected pit 1 soil samples, ISV materials, Oak Ridge Reservation soils, and standards

Element	Soil	Soil	Soil	Soil	Soil	Feldspar
	116-5-4	116-3-7	117-5-5	119-7-7	120-1-6	sand
	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
La	33.6	28.3	50.6	48.3	37.9	1.77
Ce	63.7	192	91.6	94.5	79.5	2.39
Nd	29.1	nd	39.2	33.4	nd	0.69
Sm	3.86	3.43	5.46	5.96	5.79	0.37
Eu	0.76	0.61	1.08	1.31	1.24	0.58
Tb	nd	nd	nd	0.64	nd	0.12
Ho	1.10	0.93	0.98	1.06	1.00	nd
Tm	1.91	2.71	2.22	2.65	1.13	0.062
Yb	2.04	3.09	2.31	2.28	2.04	0.10
Lu	0.39	0.51	0.37	0.40	0.34	0.015
	Firelite®	Limestone	NIST	NIST	ORR*	ORR*
	aggregate	gravel	Std 2709	Std 2709	Surface	Sub-
			Found	Actual	Soil	Soil
La	23.2	3.69	21.8	23.0	15.2	17.0
Ce	53.8	6.88	41.0	42.0	35.6	21.0
Nd	28.2	nd	nd		nd	nd
Sm	6.85	0.55	3.91	3.80	nd	nd
Eu	1.60	0.13	0.83	0.90	0.55	0.27
Tb	0.93	nd	nd		0.22	0.30
Ho	nd	0.058	0.72	0.54	nd	nd
Tm	nd	1.53	3.35		nd	nd
Yb	1.64	0.25	1.80	1.60	1.66	1.18
Lu	0.25	0.063	0.77		0.22	0.16

* Median rare earth element concentration in Oak Ridge Reservation (ORR) A horizon (Surface soil) and C horizon (Subsoil) from Watkins et al. 1993.

nd = not detected or determined; NIST = National Institute for Standards and Technology.

various radioisotopes via standard and project methods for method validation, detection, quantitation, and statistical comparison among different isotopes.

The standard LiBO_2 fusion-dissolution method was modified slightly for application to these soil samples. Samples of contaminated soil were crushed manually using a porcelain mortar and pestle in a laboratory hood; all fragments were crushed until all material passed a 60 mesh sieve. Plastic disposable sieves with stainless steel wire mesh were employed and discarded after use with contaminated soil. Uncontaminated soil samples were crushed in an agate ball mill with large fragments crushed in a steel hammer mill prior to ball milling; ball milling was continued until all material passed a 60 mesh sieve although typically a single 20-min treatment was sufficient to pulverize all solids to less than 60 mesh.

Although all samples had been previously oven-dried at 75°C , residual moisture was determined on sample aliquots by heating to 100°C ; the sample itself was not oven-dried as called for in the LiBO_2 fusion procedure. In addition, samples were not ashed at 550°C as called for in the procedure because of the very low organic matter content of all these soils. Corrections of sample weights for ambient moisture content as well as loss-on-ignition at 1000°C were made using drying and ignition data determined on subsamples. Typically, about 0.3 g of soil was fused for 20 min with 2 g of LiBO_2 at 1000°C with the resulting fused sample dissolved into a total of 250 mL of dilute nitric acid as prescribed in the procedure.

Aliquots of this dilute nitric acid, nominally 3% HNO_3 and 0.8% LiBO_2 , were submitted for elemental analyses via ICP/AES and for selected radiochemical analyses. All samples were assayed for ^{137}Cs and ^{90}Sr using a 20.0-mL aliquot placed in a 20-mL polypropylene scintillation vial. Standards of both ^{137}Cs (Dupont NEN standardized solutions) and ^{90}Sr (Environmental Monitoring Systems Laboratory standardized material) were prepared by spiking weighed amounts of standardized solutions in the same solution matrix using sample blanks, which had been run with each group of samples, once these blank solutions had been assayed to determine that they contained only detectable background activities.

Assay of ^{137}Cs was carried out using NaI gamma spectroscopy identical to that described in the project procedure for groundwater characterization (Appendix A); the roughly 1000-fold dilution of ^{137}Cs activity in the LiBO_2 solution versus the soil afforded assay conditions free from any photopeak distortion resulting from pulse pile up as was observed in some of the higher activity (detector deadtimes $>10\%$) soil samples. The assay of ^{90}Sr was carried out using Cerenkov radiation emission as described in the project procedure for groundwater assay; only a modest decrease in counting efficiency was observed in the nitric acid-lithium borate solution matrix compared to water. Use of the high-energy (5.0-40.0 keV) window for assay of the $^{90}\text{Sr}(^{90}\text{Y})$ Cerenkov radiation provided a typical counting efficiency of 39.3% while minimizing interference and necessary correction for ^{137}Cs with a typical 0.35% counting efficiency. Thus, low-interference detection of ^{90}Sr , even in the presence of more than 100 times more activity of ^{137}Cs , was routinely obtained.

Selected LiBO_2 dissolved samples were submitted to the ORNL radiochemical analyses group (building 2026) for determination of ^{137}Cs and other gamma-emitting isotopes (EPA method 901.1), total radioactive strontium, ^{90}Sr (EPA method 905.0), gross alpha and beta activities (EPA method 900.0), ^{238}Pu and ^{239}Pu (ASO Procedure No. AC-MM-2 31624, Rev. 2, 1993), and ^{234}U , ^{235}U , and ^{238}U (ASO Procedure No. AC-MM-2 31921, Rev. 2, 1993). These standard methods for radioisotopes were performed on these selected samples for comparison with both the direct soil gamma assays and with the above project procedures on the same LiBO_2 solutions. Results of these

selected samples are presented in Table 23. No other gamma-emitting radioisotopes were detected in these soil samples although detection limits were raised considerably by the high ^{137}Cs activity. Specifically, both ^{152}Eu and ^{154}Eu were below detection limits (<917 and <2920 Bq/g, respectively). These Eu isotopes had been identified in contaminated soil just to the northwest of pit 1 resulting from a leak in the waste transfer line from the decontamination facility, building 7819 (Williams et al. 1987); although this waste transfer line connected building 7819 to pit 1, Eu radioisotopes are not major contributors to the radioactivity in present pit 1 soil.

Several observations within this population of radionuclide analytical data are quite pertinent. First, the levels of activity of each radionuclide within pit 1 soils is compared to a median background activity described in a recent Oak Ridge Reservation survey of soils (Watkins et al. 1993). From this report, background activities of each radionuclide were selected from samples taken from the same geologic unit at remote, pristine sites. Although it is obvious that both ^{137}Cs and ^{90}Sr are present in all pit 1 soil samples at orders of magnitude greater than their background levels, the situation for Pu and U isotopes is not as dramatic. In 10 of the 13 soil samples, ^{239}Pu was detectable at least four order-of-magnitudes above its expected background activity in Noliucky soils; ^{238}Pu activities in pit 1 soils were also detected in 8 of 13 samples at several orders-of-magnitude above their expected background activities at considerably less than the activity of ^{239}Pu . This is not surprising because the typical activity ratio of $^{238}\text{Pu}/^{239}\text{Pu}$ would be expected to be about 0.04 and, thus, the activities of ^{238}Pu would be expected to be below the detection limit which was observed with these pit 1 soils (typically <0.5 Bq/g).

All U isotopes were detected about two orders-of-magnitude above their expected background activities. Disposal records indicated that about 200 kg of depleted U (^{238}U) was placed in pit 1; uniformly dispersing this amount of U into an estimated 1.5 Mg of pit 1 soil leads to an expected ^{238}U soil activity of 1.7 Bq/g. A similar soil activity of ^{234}U would also be expected as the natural activity ratio of $^{234}\text{U}/^{238}\text{U}$ is about 1.0. The observed activities of both ^{234}U and ^{238}U in pit 1 soil were consistent with those expected for dispersion of 200 kg of U in pit soil with some higher activities within maximally contaminated strata.

Second, the correlations among the various radionuclide analyses provide considerable information about pit 1 soils and the methods used for assay of their radioactivity (Table 24). The determination of ^{137}Cs in LiBO_2 solutions by either the standard method, used by the ORNL radiochemical group, or by the project method, used by the principal investigators, gave essentially the same results with the correlation coefficient, r , equal to 0.999. In addition, the nondestructive assay of ^{137}Cs directly on the soil samples was well correlated ($r=0.97$ and 0.96) with both assay methods on the lithium borate solutions; the slope of the regression was 0.94 ± 0.01 indicating that the ^{137}Cs had not volatilized during the LiBO_2 fusion procedure. Likewise, gross β activity was well correlated with all three ^{137}Cs assay methods; this would be expected because ^{137}Cs is a β -emitter, as well as a gamma emitter, and because ^{137}Cs accounted for more than 99% of the radioactivity in most of these soil samples.

It is also important to note that ^{137}Cs activity was not correlated with the activity of any α -emitter (U or Pu). However, the activity of ^{90}Sr did exhibit a strong correlation with activity of ^{137}Cs (Fig. 36). This good relationship between ^{137}Cs and ^{90}Sr is particularly useful in estimating the activity of ^{90}Sr in all the other soil samples for which the expensive and time-consuming standard destructive method for analysis of ^{90}Sr cannot be performed. The correlation provides a facile way to estimate the inventory of ^{90}Sr in pit 1 soil based on its "constant" ratio to the activity of ^{137}Cs which can be and was assayed nondestructively and, thus, inexpensively on every soil sample.

Table 23. Radionuclide activities (Bq/g) determined for selected soil samples from ORNL pit 1

Sample	¹³⁷ Cs Std	¹³⁷ Cs Dis	¹³⁷ Cs Dir	⁹⁰ Sr Std	⁹⁰ Sr Cer	Gross α
118-8-8	1290	1310	1060	6	19	33
118-8-11	13300	13400	8930	52	34	37
118-8-12	96400	94900	102000	177	52	64
118-8-16	5	56	1	nd	7	nd
119-8-3	336	362	274	80	83	nd
119-8-6	61900	62600	83200	182	114	214
119-8-7	135000	127000	220000	348	125	12
119-8-8	13600	12900	14200	42	32	9
120-8-3	96400	89300	96100	603	379	23
120-8-4	24700	24100	15600	216	208	93
120-8-6	10600	10700	10000	91	90	39
120-8-9	173	189	176	62	67	7
116-5-4	27	58	10	40	56	10
Median Bkg	0.019	0.019	0.019	0.025	0.025	

Sample	Gross β	²³⁸ Pu	²³⁹ Pu	²³⁴ U	²³⁵ U	²³⁸ U
118-8-8	988	1	10	4	nd	2
118-8-11	9120	1	58	nd	nd	6
118-8-12	88300	1	88	27	nd	28
118-8-16	20	nd	nd	nd	nd	nd
119-8-3	408	nd	nd	nd	nd	3
119-8-6	44400	2	18	1	nd	3
119-8-7	111000	nd	4	5	nd	5
119-8-8	9610	1	42	1	nd	1
120-8-3	79600	nd	4	5	nd	5
120-8-4	18500	3	35	nd	nd	2
120-8-6	8300	10	26	nd	nd	1
120-8-9	231	1	2	nd	nd	nd
116-5-4	117	nd	nd	6	1	2
Median Bkg		.0011	.0140	.047	.0026	.047

Std = Standard method using EPA Methods 901.1 for ¹³⁷Cs, EPA Method 905.0 for ⁹⁰Sr, and EPA method 900.0 for Gross α and β on LiBO₂ fusion dissolutions.

Dis = project method for ¹³⁷Cs using NaI gamma spectroscopy on LiBO₂ fusion dissolutions.

Dir = project method for direct assay of soil using NaI gamma spectroscopy.

Cer = project method for Cerenkov radiation detection using LiBO₂ fusion dissolutions.

nd = not detected.

Median Bkg = median expected background for Nolichucky formation C horizon soil (Watkins et al. 1993).

Table 24. Linear correlation coefficients among radionuclide activities in soils from ORNL pit 1

	¹³⁷ Cs Std	¹³⁷ Cs Dis	¹³⁷ Cs Dir	⁹⁰ Sr Std	⁹⁰ Sr Cer	Gross α	Gross β
¹³⁷ Cs(Std)	1						
¹³⁷ Cs(Dis)	0.999	1					
¹³⁷ Cs(Dir)	0.97	0.96	1				
⁹⁰ Sr(Std)	0.79	0.78	0.69	1			
⁹⁰ Sr(Cer)	NS	NS	NS	0.92	1		
Gross α		NS	NS	NS	NS	NS	1
Gross β		0.997	0.996	0.96	0.78	NS	NS
²³⁸ Pu	NS	NS	NS	NS	NS	NS	NS
²³⁹ Pu	NS	NS	NS	NS	NS	NS	NS
²³⁴ U	NS	NS	NS	NS	NS	NS	0.58
²³⁵ U	NS	NS	NS	NS	NS	NS	NS
²³⁸ U	NS	NS	NS	NS	NS	NS	0.59

	²³⁸ Pu	²³⁹ Pu	²³⁴ U	²³⁵ U	²³⁸ U
²³⁹ Pu	NS	1			
²³⁴ U	NS	0.60	1		
²³⁵ U	NS	NS	NS	1	
²³⁸ U	NS	0.75	0.95	NS	1

Std = Standard method using EPA Methods 901.1 for ¹³⁷Cs, EPA Method 905.0 for ⁹⁰Sr, and EPA method 900.0 for Gross α and β on LiBO₂ fusion dissolutions.

Dis = project method for ¹³⁷Cs using NaI gamma spectroscopy on LiBO₂ fusion dissolutions.

Dir = project method for direct assay of soil using NaI gamma spectroscopy.

Cer = project method for Cerenkov radiation detection using LiBO₂ fusion dissolutions.

NS = None significant correlation coefficient at the 5% level of confidence.

For computing the inventory of radionuclides in pit 1, an average ratio of each radionuclide activity to the activity of ¹³⁷Cs was computed. Only the three soil samples with the greatest ¹³⁷Cs activity from each of the three cores (118, 119, and 120) in Table 23 were used to perform this calculation. The resulting ratio for each soil sample, as well as each core's and the overall averages are presented in Table 25.

pt1rncor.tc

Fig. 36. Correlations and linear regressions of ^{137}Cs activity in samples of pit 1 soils with activities of ^{90}Sr , ^{239}Pu , and ^{238}U .

A significant savings in analytical costs was achieved by performing the assay of ^{90}Sr using Cerenkov radiation detection directly on the dilute nitric acid solutions from the lithium borate fusions. Although this technique is destructive in that it requires the dissolution of the soil, it does not require radiochemical fractionation and separation as does the standard method (EPA 905.0). Thus, there are considerable savings in time required for laboratory analyses. However, it was desirable to validate this project method with the standard method using a subset of samples as depicted in Fig. 37. The excellent correlation between the project method and the standard method allows confidence in the project method analyses for ^{90}Sr . This, in turn, allowed ^{90}Sr to be assayed economically on a much larger number of soil samples. The project method has the additional advantage in that it is the preferred method to dissolve soils for elemental analyses and, thus, requires no additional sample preparation or processing to complete the assays of both ^{137}Cs and ^{90}Sr activity in a soil or, ultimately, ISV product sample using the residual $\text{LiBO}_2\text{-HNO}_3$ solution.

Table 25. Activity ratios of ^{90}Sr , ^{238}U , and ^{239}Pu to ^{137}Cs determined in soil samples from maximally contaminated depths of ORNL pit 1

Sample	$^{90}\text{Sr}/^{137}\text{Cs}$	$^{238}\text{U}/^{137}\text{Cs}$	$^{239}\text{Pu}/^{137}\text{Cs}$
118-8-8	0.00464	0.00155	0.00774
118-8-11	0.00392	0.000453	0.00437
118-8-12	0.00184	0.000291	0.000913
Average-118	0.00347	0.000765	0.00434
119-8-6	0.00294	0.0000485	0.000291
119-8-7	0.00259	0.0000372	0.0000297
119-8-8	0.00308	0.0000734	0.00308
Average-119	0.00287	0.0000530	0.00113
120-8-3	0.00625	0.0000519	0.0000415
120-8-4	0.00875	0.0000811	0.00142
120-8-6	0.00862	0.0000947	0.00246
Average-120	0.00787	0.0000759	0.00131
Overall			
Average	0.00474	0.000298	0.00226
Std.Dev.	± 0.00273	± 0.000405	± 0.00180

pt1sr90c.tc

Fig. 37. Relationship between the determination of ^{90}Sr by Cerenkov radiation detection and by the standard method (EPA 905.0) in soil samples dissolved in nitric acid/lithium borate.

Of course, even more costs savings in the assay of ^{90}Sr could have resulted if a nondestructive method, like the excess bremsstrahlung detection were found to be accurate for these pit 1 soil samples. As discussed above, ^{90}Sr activity in soil was estimated from bremsstrahlung in excess of that caused by the measured activity of ^{137}Cs as an estimate of hard β -emitting isotopes like ^{90}Sr (^{90}Y). However, the estimate of ^{90}Sr in soil from bremsstrahlung in direct soil assays grossly overestimated the actual activity of ^{90}Sr in soil as determined by Cerenkov radiation detection on the $\text{LiBO}_2\text{-HNO}_3$ soil solutions; the regression between Cerenkov ^{90}Sr (Y) and bremsstrahlung ^{90}Sr (X) was $Y = 0.0039X + 2151$ ($r^2=0.37$, $n=45$ paired samples). Although there are potentially quite a few reasons for this disagreement, the obvious conclusion is that excess bremsstrahlung is not a good method to estimate ^{90}Sr in these samples.

As discussed above, the strong correlation between the assay of ^{137}Cs directly in soil with that in the LiBO_2 dissolution was excellent (Fig. 36). However, there is a potential for volatilization of ^{137}Cs from the soil sample as it fuses for the required 20 min with LiBO_2 at 1000°C . However, this potential effect was found to be small. First, a suite of 51 soil samples, from subsections of the maximally contaminated regions of the three soil cores collected within pit 1, were assayed for ^{137}Cs by both methods. The regression was excellent where the activity of ^{137}Cs via direct assay (X) was correlated with the activity of ^{137}Cs found in the LiBO_2 solution (Y): $Y = 0.94X$ ($r^2=0.991$, $n=51$). Although the slope of the regression was not unity, as would be expected for complete recovery of all ^{137}Cs in the solution, uncertainty in the direct assay, due to geometric, heterogenic, and/or counting efficiency variations among samples, could not be ruled out.

A more direct determination of correlation of the two methods was determined by performing the LiBO_2 dissolution on a soil of known ^{137}Cs activity; in this case, the soil sludge from ORNL pit 2, used in the 1991 ISV radioactive test (Spalding et al. 1992), was employed. Duplicate samples of this quite radioactive soil, which contained 20.7 and 5.12 $\mu\text{Ci/g}$ of ^{137}Cs and ^{90}Sr , respectively, were assayed for both radionuclides in the resulting LiBO_2 fusion solutions. Recoveries of ^{137}Cs and ^{90}Sr were $94.9 \pm 5.7\%$ and $103.3 \pm 4.0\%$, respectively. This indicates that the recovery of ^{137}Cs through the LiBO_2 dissolution process was quantitative within experimental error. Thus, there is little basis for further concern for volatile losses of ^{137}Cs using pit 1 soil and future ISV product during LiBO_2 fusion.

All of the soil core segments have been assayed for activity of ^{137}Cs and all results are depicted in graphs in Appendix B. In addition to the previously presented information on soil core 120 (Fig. 24), the vertical distribution of ^{137}Cs on the west side of pit 1 and from another location within the pit are depicted in Fig. 38 and Fig. 39, respectively. The three cores from within seepage pit 1, which had penetrated the maximally-contaminated region (i.e., points 118, 119, and 120, Fig. 6), indicated that the "peak" in ^{137}Cs was relatively sharp (Fig. 40). The "hot" tips of these three cores were cut into 2.5 cm segments and, when assayed separately, revealed that the majority of the ^{137}Cs was narrowly distributed over only a couple of segments within the whole core. These "peaks" also were correlated with a change in core color and bulk density; the ^{137}Cs was associated with soil material at a bulk density typical of the overlying soil fill (i.e., 1.5 g/cm^3). In contrast, the material underlying the maximally-contaminated soil appeared gray in color and exhibited bulk densities often above 2.0 g/cm^3 ; this probably represents the original contact of the pit 1 bottom with unrippable rock, originally presumed to be limestone. However, when elemental analyses of these dense materials were completed, they were identified as unweathered shale with little trace of the significant Ca and Mg contents typical of limestone.

Fig. 38. The vertical distribution of ^{137}Cs in soil core from sampling point 114 (Fig. 6) west of seepage pit 1.

Fig. 39. Vertical distribution of ^{137}Cs in soil core 119 (Fig. 6) from the center of seepage pit 1.

Distribution of Cs-137 and Sr-90 In Pit 1 Soil Cores

Fig. 40. Retention of ^{137}Cs in maximally contaminated soil core segments of the three sampling locations penetrating the bottom of pit 1.

In addition to ^{137}Cs , ^{90}Sr also exhibited significant activities in these core segment tips. However, several of the core segments contained too much ^{137}Cs activity to measure the ^{90}Sr activity validly via bremsstrahlung assay without significant interference due to low-energy pulse pile-up during signal processing with these high deadtime (i.e. activity) samples. Because of this uncertainty in the ^{90}Sr nondestructive assay method, reporting of ^{90}Sr activities in these cores was performed on dissolutions of these samples and unambiguous assay of ^{90}Sr via Cerenkov radiation from the dissolved materials was completed. Significant activities of ^{90}Sr appear to be present in the tip segments but were more diffusely distributed than the peaks in ^{137}Cs activity (Fig. 40).

2.9 GROUNDWATER SUSPENDED SOLIDS RADIOCHEMICAL COMPOSITION

As discussed previously, during the initial sampling of groundwater from the three Geoprobe driven well samplers positioned with their screens within the maximally-contaminated elevations within pit 1, comparatively large amounts of suspended solids were also obtained. These solids were collected during filtering of these water samples. Following assay of ^{137}Cs , samples were subjected to lithium borate fusion and dissolution of the fusate into nitric acid; assays of both ^{90}Sr and ^{137}Cs were then performed. Results are presented in Table 26. The activity of ^{137}Cs , measured in the lithium borate fused samples, was essentially equivalent to that measured in the starting material and also equivalent to that assayed following hydrofluoric acid digestion; this observation confirmed further that no ^{137}Cs was volatilized during lithium borate fusion at 1000°C and validates assay of ^{137}Cs after fusion. The activity of ^{137}Cs in these solids (about 4×10^6 dpm/g) was very similar to the activities observed in the hot tips of the three soil cores in Fig. 40; thus, it appears that these

Table 26. Radiochemical characteristics of maximally contaminated soil solids collected with water samples on February 14, 1994, from pit 1

	Well <u>105</u>	Well <u>106</u>	Well <u>107</u>
Percent recovery of ^{137}Cs after HF digestion	99	121	70
Percent recovery of ^{137}Cs after LiBO_2 fusion	99	125	nd*
Solids or "source" soil ^{137}Cs (dpm/g)	4,580,000	4,620,000	3,820,000
Solids or "source" soil ^{90}Sr (dpm/g)	40,000	59,500	12,200
Dissolved ^{137}Cs (dpm/mL)	78.5	141.6	79.6
Dissolved ^{90}Sr (dpm/mL)	141.6	53.2	359.3
Distribution Coefficient of ^{137}Cs , K_d (mL/g)	58,000	32,600	48,000
Distribution Coefficient of ^{90}Sr , K_d (mL/g)	282	1,120	340

*nd = not determined because sample was completely consumed for the HF digestion.

entrained solids were dominated by the "source" soil in the maximally-contaminated layer of pit 1. In addition, the equivalent activity of these suspended solids confirms that the screened intervals were indeed open within the maximally-contaminated layer of pit 1. However, the ^{90}Sr was present at much lower average activities, i.e., about 1.6% that of the ^{137}Cs . These three samples averaged about 4 times the ratio of $^{90}\text{Sr}/^{137}\text{Cs}$ than was observed in the maximally contaminated soil samples discussed previously.

Analyses of the ratio of adsorbed or particle-bound ^{137}Cs and ^{90}Sr to the dissolved concentrations demonstrates the particle reactivity of both these radionuclides. The distribution coefficient (K_d) for ^{137}Cs averaged 46,000 mL/g while that of ^{90}Sr average only 580 mL/g. The strong and specific adsorption of ^{137}Cs by soils like these, which contain illitic clay minerals, results in this characteristically high K_d . In contrast, ^{90}Sr would be present as an exchangeable cation on soil and, thus, have a two order of magnitude lower K_d . These ambient field distribution coefficients demonstrate the potential for ^{90}Sr , but not ^{137}Cs , to migrate from pit 1. Thus, it is ^{90}Sr , rather than ^{137}Cs , which determines the need for remediation of the seepage pits and trenches.

2.10 INVENTORY OF RADIONUCLIDES IN PIT 1

Cesium-137 was assayed on all segments of three continuous soil cores taken in three different positions within ORNL seepage pit 1. All showed maximal activity near the bottom of the core within the 26-ft depth interval. Assays for ^{137}Cs were performed per project methods using NaI gamma ray assay. Strontium-90 was assayed via Cerenkov emission from dissolved lithium borate fusions of groundwater suspended solids and soils sampled from the most radioactive sections of

in situ radioactive logs via driven wells. The total ^{137}Cs activity in each core was determined from the sum of activities throughout all segments of the core:

Core number	Activity (mCi)
118	0.0619
119	0.1094
120	0.0720
<i>Average</i>	0.0811

Each core has a diameter of 2.22 cm which calculates to a cross-sectional area of 3.871 cm². Thus, the average activity per unit area computes to 0.02095 mCi/cm² or, in other units, 19.47 mCi/ft². Based on rod probing data, ORNL pit 1 is estimated to be 70 ft long and 26 ft wide for a total area of 1,992 ft² (Fig. 25). This estimate was based on the software Autosketch® program's irregular polygon area which circumscribed all the "hot" assay pipes on a plan view including an approximate 5-ft buffer into non-"hot" areas. Thus, using the area estimate of 1,992 ft², a total pit 1 ^{137}Cs inventory of 38.8 Ci was calculated by multiplying the area by the average activity per unit area.

To estimate the inventory of ^{90}Sr , the data from three assays of hot solids or "source" soil, collected during water sampling from three wells in pit 1, was employed. The ^{90}Sr , expressed as a percent of the ^{137}Cs in these soils, was:

Hole number	^{90}Sr % of ^{137}Cs
118	0.347
119	0.287
120	0.787
<i>Average</i>	0.474

Using the highest number, the inventory of ^{90}Sr in pit 1 is estimated to be 0.305 Ci (i.e., 38.8 Ci of ^{137}Cs x 0.787%).

The radionuclide analyses for ^{90}Sr , uranium, and plutonium on the hottest core segments had not been completed at the time the project risk assessment was necessary. Thus, for these two alpha emitters, the more conservative (higher) disposal records inventory of 0.068 Ci of ^{238}U (depleted U) and 0.017 Ci of ^{239}Pu were used (page 4). For the estimate of ^{90}Sr inventory in the risk assessment, the highest ratio of $^{90}\text{Sr}/^{137}\text{Cs}$ in the groundwater suspended solids of 1.6% (Table 26) was used to compute a maximum inventory of 1.2 Ci of ^{90}Sr (i.e., 3.1% x 38.8 Ci of ^{137}Cs). The pit 1 inventory

assumed for risk analysis was only slightly different than the best estimate based on actual soil radionuclide analyses:

Isotope	Assumed Risk Assessment Inventory (Ci)	Actual Inventory
^{137}Cs	38.8	38.8
^{90}Sr	1.2	0.305
^{238}U	0.068	0.0116
^{239}Pu	0.017	0.0877

The agreement between disposal records and the calculated pit 1 inventory of ^{238}U and ^{239}Pu , based on measured soil radionuclides, is quite amazing. Such agreement lends much confidence in the pit 1 inventory as well as in the results of the risk assessment.

For a single ISV melt scenario as a maximum case, about 1/3 of the pit inventory might be processed if the melt goes to the extremity of the planned 50-ft long off-gas hood. Thus, for risk analysis, 33% of the pit 1 inventory was employed for a single melt setting. Thus, the probable accidental release scenario, through an off-gas hood to ground surface gap as described by Campbell and Ikenberry (1990) and summarized in the project health and safety plan (Spalding and Naney 1995), employed the following processing melt inventory:

Isotope	Single ISV Melt Inventory
^{137}Cs	12.9
^{90}Sr	0.4
^{238}U	0.023
^{239}Pu	0.006

Since 99% of this inventory is within the interval below 24 ft from the top of the soil column, the release scenario encompassed a worst-case release during the last 24 hours of the ISV melt during a hood and off-gas blower failure (total ISV run time would be about 160 hours but all but the last 24 hours will be in clean fill). For the release scenario, the same exponential time function as in previous risk analyses was used. The soil to off-gas release fractions measured during the 1987 Oak Ridge test (Spalding et al. 1989), which were 0.0012 and 0.000002 for Cs-137 and Sr-90, respectively, were used. These correspond to decontamination factors (DFs) of 833 and 500,000, respectively (where $\text{DF} = 1/\text{fraction released}$). For the soil to off-gas release fraction for U and Pu, the data for the La, Ce, and Nd tracers in the 1991 test (Spalding et al. 1992) where 0.00033, 0.00026, and 0.00014 of the totals were volatilized, were used. The highest volatilized fraction (La) was used as the most conservative estimate for U and all transuranics releases. Thus, the off-gas releases of each isotope in the worst-case risk assessment were:

$$\begin{aligned}
 ^{137}\text{Cs} & 12.9 \times 0.0012 = 0.015 \text{ Ci} \\
 ^{90}\text{Sr} & 0.4 \times 0.000002 = 8.0\text{E-}07 \text{ Ci} \\
 ^{238}\text{U} & 0.023 \times 0.00033 = 7.6\text{E-}06 \text{ Ci} \\
 ^{239}\text{Pu} & 0.006 \times 0.00033 = 2.0\text{E-}06 \text{ Ci}
 \end{aligned}$$

The actual release of ^{137}Cs would be expected to be much smaller because of the depth at which the contamination lies and because of the large size of the molten body when it finally encounters the ^{137}Cs contamination. However, there is no conservative assumption which would allow the use of a smaller release fraction in the risk/dose assessment. Although ^{137}Cs is the largest activity radionuclide released, the calculated dose was actually dominated by U and Pu.

2.11 MELT PROPERTIES OF PIT 1 SOIL AND VOLATILIZATION OF ^{137}Cs

During the 1991 pilot-scale ISV demonstration at ORNL, an unexpectedly high fraction, 2.4%, of the ^{137}Cs in the contaminated sludge included in the soil test configuration, volatilized from the melted zone and was trapped in the off-gas filtration system (Spalding et al. 1992). The previous 1987 pilot-scale ISV test at ORNL had found only 0.12% of the buried Cs inventory had volatilized during its vitrification (Spalding and Jacobs 1989). Subsequent research has identified that unusual sources and amounts of chlorine, such as the polyvinyl chloride (PVC) pipe used to enclose the radioactive sludge sample during the 1991 demonstration, as the probable cause of enhanced volatilization of ^{137}Cs (Spalding 1994); this later investigation identified several factors, in addition to chloride sources, such as limestone content, heating rate, processing temperature, and presence of other chemicals such as borate which can enhance or diminish the volatility of ^{137}Cs during vitrification of soil.

Prior to implementing ISV operations on pit 1, an investigation of ^{137}Cs volatilization during vitrification of pit 1 materials has been initiated in an effort to minimize the volatilization of ^{137}Cs during ISV or, alternately, to handle safely various potential degrees of ^{137}Cs volatilization which might be experienced during ISV. The inclusion of a ceramic fabric roughing filter at the exit point of off-gas from the new off-gas containment hood is an example of one technique to minimize the amount of contamination of off-gas handling equipment and to recycle ^{137}Cs contamination back into the pit 1 melt body. The in line HEPA prefilter is a secondary technique to prevent ^{137}Cs contamination from reaching the off-gas processing trailer; because this technique worked excellently during the 1991 demonstration, it has, therefore, been planned for use during the pit 1 melts. However, as highly effective as both these off-gas filtering techniques should prove during processing of pit 1 soil, it would be much more desirable to minimize volatilization of ^{137}Cs from the melt in the first place.

Given the amount of knowledge concerning the factors which affect the volatilization of ^{137}Cs from soil during heating and vitrification, a screening of pit 1 soil and groundwater for unusually high concentrations of chemicals such as chloride could eliminate a great deal of concern for potential volatilization of ^{137}Cs . The typical background concentrations of chloride found in all samples of pit 1 perched groundwater (Table 8) are not indicative of any potential for enhanced volatilization due to unusually high chloride concentrations which would be reflected in these soluble phases. A second approach, which is herein reported, is to melt samples of unamended pit 1 contaminated soil in crucibles in the laboratory and determine if unusual fractions of its ^{137}Cs contamination volatilize; this would be an empirical approach to determine if pit 1 soils behaved differently than previously studied ^{137}Cs -contaminated soil indicating the presence of unknown constituents which can contribute to ^{137}Cs volatilization.

Concomitantly, the effects of processing temperature and melting rate can also be determined in laboratory crucible melts so that these parameters might be adjusted in field operations if desirable reductions in volatility were obtainable in the laboratory. In particular, the effects of

Fig. 41. Retention of ^{137}Cs in soil samples from ORNL pit 1 following sequential thermal treatment to the indicated temperature.

limestone amendment to ISV melts on volatilization of ^{137}Cs needed to be examined for pit 1 soil and melt materials because of the potential for limestone for adjusting ISV processing temperature (Shade and Piepel 1990; Spalding 1994).

To determine if pit 1 soils exhibited unusually high volatilization of ^{137}Cs during melting, a group of forty-one 1-g samples of the maximally contaminated pit 1 soil from the three soil cores depicted in Fig. 40 were prepared in small alumina crucibles as described in Spalding (1994). These crucibles were assayed nondestructively via gamma spectroscopy for ^{137}Cs activity before and after sequential treatments of 2 hours at final temperatures of 100, 550, 800, 1000, 1200, 1300, 1400, 1500, 1600, and 1700°C in a box furnace with an average heating rate of 23°C/min. Crucible weights were also determined after each treatment to measure cumulative loss of volatiles from each treatment. All 41 samples appeared unmelted but strongly and cohesively sintered after treatment at 1200°C; many samples appeared melted and glazed the alumina crucibles after 1300°C while all samples appeared melted after treatment at 1400°C. Many samples were lost following treatment at 1500, 1600, and 1700°C due to crucible fracturing with only 10, 6, and 0 intact crucibles, respectively, remaining of the original 41; thus, no data was available for the highest temperature treatment in this series of samples.

Nonetheless, several pertinent observations are apparent in the results depicted in Fig. 41. As observed previously with other ^{137}Cs contaminated soils (Spalding 1994), no volatilization of ^{137}Cs was observed until treatment to temperatures above 1000°C where increasing temperature led to

increased volatilization of ^{137}Cs . Most importantly, the degree of ^{137}Cs volatilization observed in these pit 1 soil samples was not unusual compared with other soils investigated previously, such as the 1987 soils where only minimal volatilization was observed in the field.

The degree of ^{137}Cs volatilization in field applications is not directly measured using laboratory crucible tests which, probably due to higher melt surface area and lack of overlying molten material to contain off-gas, always result in much higher degrees of volatilization; it is, however, the relative degree of volatility in laboratory crucible tests at different temperatures, melt compositions, or heating regimes, which provides the evidence for expectations in field melts. Thus, pit 1 soil does not contain any substances which would be expected to result in unusual degrees of volatilization of ^{137}Cs during vitrification. However, the apparent increase in ^{137}Cs volatilization observed between 1400 and 1600°C in Fig. 41, merited additional investigation. With no limestone addition to pit 1 soil, an ISV processing temperature of well over 1700°C would be expected based on the previous research of Shade and Piepel (1990) and Spalding (1994); during the bench-scale melt of pit 1 soil at PNL in 1995, an unamended melt temperature of 1750°C was observed (unpublished data). However, previous ORNL ISV field tests have operated at about 1500°C because both of these tests included 20-30% limestone amendment; neglecting the aberrant 1991 Cs volatility results induced by chloride from PVC, only about 0.12% ^{137}Cs volatilization from pit 1 soil, if amended with 20% limestone, would be expected during field ISV. However, if pit 1 soil were processed unamended (i.e., at about 1750°C), then considerably more volatilization might be expected based on the decreasing retention of ^{137}Cs at higher temperature depicted in Fig. 41. One previous radioactive pilot-scale test without limestone amendment was performed in Richland, Washington, where 0.77% volatilization of ^{137}Cs was observed (Timmerman and Oma 1985); thus, significant volatilization of ^{137}Cs has been observed in the field when processing at higher temperature without limestone or other temperature-moderating additives.

Prior to discussing the current findings with laboratory crucible samples on the volatilization of ^{137}Cs from pit 1 soil with limestone additions, a brief summary of the effects of limestone addition on ISV operating parameters is pertinent. In general, ISV molten bodies are heated by the applied electrical power until the molten material reaches a viscosity where convective flow transfers heat to the unmelted soil boundary at the rate at which heat is added into the growing melt body; the elemental composition of the molten material determines the temperature at which this characteristic viscosity is attained and, hence, the operating temperature of the ISV melt.

Shade and Piepel (1990), in previous research funded by ORNL to support ISV technology development, found a highly precise relationship between the ISV operating temperature, the temperature of molten soil at which the viscosity is 100 poise (T100P), and percent inclusion of limestone and/or soda ash mixed with ORNL soil. The T100P of unamended ORNL soil of elemental composition virtually identical to that of pit 1, was determined to range between 1735 and 1750°C. A quadratic Scheffe mixture regression model, with limestone and soda ash addition variables, was found to simulate the empirical blend data extremely well ($r^2 = 0.983$); this model was used to calculate the T100P of pit 1 soil with limestone additions (Fig. 42). It can be determined from this relationship that addition of 20% limestone to a pit 1 soil melt would reduce its unamended ISV processing temperature from 1760 to 1450°C while a 10% addition would reduce the melt operating temperature from 1760 to 1580°C. The question, to be addressed in the present laboratory crucible soil melts, is whether such additions of limestone have any effect, beneficial or detrimental, on the volatilization of ^{137}Cs during melting.

Fig. 42. Limestone addition versus ISV operating temperature, i.e., temperature of 100 poise viscosity, calculated using quadratic Scheffe mixture model of Shade and Piepel (1990).

An initial experiment was carried out to determine the effect of limestone on volatilization of ^{137}Cs from pit 1 contaminated soil (a pulverized blend of the maximally-contaminated soil core from hole 118) mixed with pulverized limestone used in the 1987 ISV demonstration. Limestone additions of 0, 5, 10, 20, and 30% were prepared using 4 replicates in alumina crucibles and assay for ^{137}Cs was performed before and after thermal treatment as described above. Crucibles were treated to sequential temperatures of 1000, 1200, 1400, 1600, and 1700°C for intervals of 2 hr once final temperature had been attained after heating at 23°C/min. Unfortunately, neither the 20 or 30% limestone amended samples survived the 1600°C treatment due to the aggressive corrosion of the crucibles by these melts at such high temperature; it should be noted that 1600°C would be a considerably higher temperature than such melt compositions would attain during ISV processing because this temperature is well above the T100P. Also, the unamended soil samples did not survive the 1700°C treatment due to the fracturing of all crucibles; the rapid cooling of such melts and solidification at higher temperature probably led to excess stress applied to the crucible by the contracting soil glass. Only samples with limestone amendments of 10% or greater were melted after treatment at 1200°C but all samples appeared melted after 1400°C treatment.

Nonetheless, the available ^{137}Cs volatility results (Table 27) provide quite useful information on the behavior of ^{137}Cs during ISV processing with various limestone amendments. First, limestone amendment treatments of up to 20% did not induce any added volatilization of ^{137}Cs compared to unamended soil up to 1600°C. Increases in limestone amendment to 30% did induce significantly more volatilization of ^{137}Cs than in either unamended or less amended soil samples at all temperatures; this has been observed previously (Spalding 1994) where even higher amendments of limestone up to 50% produced even greater volatilization of ^{137}Cs . Thus, limestone amendments up to 20% of the pit 1 soil during ISV melts will clearly have two affects: 1) melt processing temperatures will be reduced and 2) volatilization of ^{137}Cs will be at least unaffected relative to processing unamended pit 1 soil.

Table 27. Retention of ^{137}Cs in ORNL pit 1 soil with limestone amendment after sequential heating to various temperatures

Limestone Added (%)	^{137}Cs Retained				
	1000°C	1200°C	1400°C (fraction)	1600°C	1700°C
0	1.006	1.005	0.997	0.962	nd
5	0.993	0.989	0.976	0.969	0.961
10	1.014	1.006	0.999	0.994	0.977
20	1.006	0.988	0.990	nd	nd
30	0.988	0.975	0.956	nd	nd

nd = not determined because all replicate alumina crucibles for this treatment were either corroded or fractured after treatment.

The key contrast to determine if limestone addition to the pit 1 ISV melts will decrease the volatilization of ^{137}Cs would be a comparison of unamended soil melt volatilization at its higher temperature (i.e., >1700°C) with a 10-20% limestone amended melt at its lower ISV operating temperature (i.e., 1500°C). To determine if such an effect could be observed using laboratory crucible melts, a second series of melts were prepared. In addition, pulverized limestone of actual stock-piled limestone gravel at the pit 1 site was used; this limestone became available when the pit 1 site was graded in preparation for receiving the large-scale ISV equipment and off-gas hood in April 1995. Use of this pulverized limestone in these laboratory crucible tests offered the important added opportunity to detect any chemical composition effect unique to this batch of limestone gravel which would be the actual material added to the pit 1 melt if this option were elected. Similar to the previous series, triplicate limestone amendment treatments of 0, 5, 10, 20, and 30% were prepared using 1 g of pulverized blended maximally-contaminated soil from sample hole 120 with assay of ^{137}Cs before and after thermal treatment. However, in this case a slower and more defined rate of heating of the samples was selected; samples were heated initially to 850°C from ambient at 10°C/min and held for 2 h (to effect decarbonation of the limestone) immediately prior to increasing temperature to either 1500 or 1700°C from 850°C at 1°C/min and holding for 2 h. This rate of heating was selected because previous work had indicated that slower heating can induce greater volatilization of ^{137}Cs (Spalding 1994) and, thus, the relative effect of limestone amendment on ^{137}Cs volatilization would be enhanced by the slower rate of heating. In addition, in an attempt to avoid the loss of crucibles either by melt corrosion or fracturing during cooling, a suite of samples was prepared for each final temperature rather than attempt repeated sequential heating to different temperatures on the same suite of samples.

The results for this suite of samples are presented in Table 28. All samples were melted after both final temperature treatments. The 1700°C treatment of both the 20 and 30% limestone amended samples, however, still resulted in corrosion of the alumina crucibles such that these samples were not available for radioactive assay; these missing samples, however, do not hamper the assessment because a 1700°C ISV operating temperature would not be experienced by such a melt composition because such a high temperature would be several hundred °C above its T100P.

Table 28. Retention of ^{137}Cs in pit 1 soil with limestone amendment after heating to 1500 and 1700°C

Limestone Added (%)	^{137}Cs Retained	
	1500°C	1700°C
	(fraction)	
0	0.953	0.924
5	0.949	0.948
10	0.952	0.932
20	0.944	nd
30	0.918	nd

nd = not determined because all replicate alumina crucibles for this treatment were either corroded or fractured after treatment.

As was concluded in the previous suite of sequentially heated soil samples, volatilization of ^{137}Cs from unamended soil was greater at its T100P (ca. 1700°C) than that from samples of 10-20% limestone amended soil at their T100P (1400-1500°C). However, it is not possible to extrapolate the exact magnitude of this effect (increased ^{137}Cs retention in the ISV melt) to the field scale. It should also be noted that overheating of 10-20% limestone amended melts to 1700°C did not lead to volatilization of ^{137}Cs greater than that experienced with unamended soil; this effect would also be expected at the field scale. Thus, it would appear that limestone addition up to 20% of the pit 1 soil will not result in any greater, and will likely result in significantly less, volatility of ^{137}Cs than processing unamended soil in field application.

There are other potential benefits to performing ISV in pit 1 with limestone amendment with the projected 200°C lower operating temperature. First, the lower processing temperature will likely result in slower oxidation of the graphite electrodes than would be experienced with unamended soil; oxidation rates of graphite has been found to exhibit a strong dependence on temperature. Second, the incorporation of alkaline earths into the soil makes a melt which is more corrosive to surrounding soil, much like the effect observed with 20-30% limestone treatments on the dissolution of alumina crucibles discussed above.

Even though a limestone amended ISV melt would operate 200-300°C lower than an unamended melt, its rate of melt growth may actually be greater than that of the higher temperature unamended melt; however, there is no experimental evidence from field or laboratory observations of melting rate as a function of corrosivity of molten materials to support this hypothesis. Conversely, it can be argued that unamended soil will process faster than limestone amended materials during ISV due solely to the elevated temperature of ISV processing which would place more heat into the soil. However, any possible effects of limestone amendment on electrode oxidation or melt dissolution kinetics should be a secondary consideration to any potential benefit in reducing volatilization of ^{137}Cs .

The decision whether or not to add limestone to at least the first pit 1 ISV melt is not unambiguously supported by the evidence from these and previous laboratory volatility tests. However, considering that all the laboratory data indicates that there is no possible detrimental effect

on ^{137}Cs volatilization, it is recommended that limestone addition be attempted at least on the first two field melts at pit 1. If there really is a significant field-scale benefit to limestone addition and such addition is not elected for the first melt, then contamination of off-gas handling equipment, particularly the hood panels and roughing filter, could be much greater than would have been experienced had limestone amendment been elected. Thus, subsequent melt operations will have to deal with such increased equipment contamination.

The final or third melt at pit 1 could be elected to proceed without limestone addition if the previous melts exhibited minimal ^{137}Cs emissions and, at that time, it is desired to determine what volatilization would occur without limestone amendment. Thus, there appears to be enough evidence for a potential decrease in ^{137}Cs volatilization from pit 1 soil to merit a decision to add limestone during the initial pit 1 ISV melts. The only risk associated with the implementation of limestone addition to pit 1 melts appears to be that the cost of the effort might prove, at worst, unnecessary; the cost of the limestone gravel itself is trivial, at a total of <\$1,000 for all three melts. The solid material addition system on the new off-gas hood would be used to add limestone during the initial phase of melting when uncontaminated soil was being processed.

A bench-scale ISV melt was completed using the bulk sample of soil fill from pit 1 described previously. In that test, approximately 150 lb of glass and sintered soil were produced with approximately 80 lb of glass alone. The average melt temperature was approximately 1700°C. This confirms that the pit 1 ISV operating temperature will be considerably hotter than the 1500°C ISV processing temperature in the 1991 and 1987 tests.

2.12 SOURCE SOIL LEACH PROPERTIES

The source contaminated soil from pit 1, collected by the methods described previously, was subjected to sequential leaching with dilute calcium chloride and dilute hydrochloric acid to simulate its weathering behavior (Spalding et al. 1992). As previously, it was also subjected to toxicity characteristic leach procedure (TCLP) and product consistency test (PCT) leaching procedures (Jantzen and Bibler 1989), so that its performance as a waste form can be compared with other materials and with the final ISV product made from it. A scaled-down version of ASTM Designation D 5233-92, Standard Test Method for Single Batch Extraction Method for Wastes, was also performed on contaminated source material from pit 1.

2.12.1 Leaching Summary

The source contaminated soils from ORNL pit 1 was subjected to sequential leaching with dilute calcium chloride (0.1N) and dilute hydrochloric acid (0.1N) to simulate a maximum possible weathering process. Samples were also subjected to toxicity characteristic leach procedure (TCLP) and product consistency test (PCT) leaching procedures so that its waste form performance can be evaluated. Results indicated that, in general, only a small fraction of ^{137}Cs (<0.5%) can be leached out from the soil or ISV product because Cs^+ is specifically adsorbed or fixed by the soil clay minerals, particularly the illitic minerals. On the other hand, ^{90}Sr can be easily exchanged by other cations (as much as 95%) from contaminated soils because ^{90}Sr is retained by soils primarily by the cation exchange.

Approximately 50% of ^{90}Sr may be present as $^{90}\text{SrCO}_3$ in soil Blends 118 and 119, so that they can only be extracted with dilute acid. However, when soils were solidified by the ISV technology,

only negligible amounts of ^{90}Sr or ^{137}Cs can be extracted by the above procedures. Within the detection limit, no detectable amounts of ^{90}Sr were observed in the TCLP, PCT, and 0.1N CaCl_2 leachates of the ISV product. The amount of ^{137}Cs extracted was only 0.075, 0.02, and 0.048%, respectively. Leaching with dilute acid (0.1N HCl) slightly increased the amounts of ^{137}Cs and ^{90}Sr in the leachate from the ISV product. These results demonstrate that ISV can significantly reduce the leachability of contaminants from soils and therefore retard the mobility of contaminants in the soil environment.

2.12.2 Materials and Methods

Soil and ISV Sample Preparation. Three maximally contaminated soil samples were collected from ORNL pit 1, WAG 7 following the method described by Spalding et al. (1992). The three samples were collected at a depth between 23 and 26 ft from the maximally contaminated sections (118-8, blend of sections 11&12; 119-8, blend of sects. 6, 7, and 8; and 120-8, blend of sections 3, 4, 5, and 6). The soil samples were air-dried, pulverized, and then sieved with a 100-mesh disposable sieve.

Due to a delay of the field ISV operation at pit 1, ISV product was synthesized (or simulated) in laboratory as follows. Soil 119-8-Blend (0.5 g) was first mixed with 24.5 g clean soil (without ^{90}Sr or ^{137}Cs) to give a 1:50 dilution. This dilution was necessitated because of high radioactivities of ^{137}Cs (4.2×10^6 dpm/g) and ^{90}Sr ($\sim 9.7 \times 10^3$ dpm/g) in the soil sludge. The mixed soil was transferred into a platinum crucible and placed in a furnace. The soil was then heated to 1000°C at which it was held for 1 h. The furnace temperature was then set at 1600°C for 2 h. After cooling, the melt (as ISV product) was broken into pieces by tapping the bottom and edges of the crucible. The broken pieces of ISV product was then ground with a pestle and mortar covered with a parafilm. The samples were sieved with a 100-mesh disposable sieve. The above procedures were repeated until enough ISV product was obtained for the leaching studies.

Leaching Procedures by dilute CaCl_2 and HCl . Soil and ISV samples were subjected to a sequential leaching with dilute CaCl_2 and HCl . This leaching experiment is to simulate a maximum possible weathering behavior, i.e., under the worst case scenario, how much ^{90}Sr and ^{137}Cs will be leached out from the soil and the ISV product. The leaching procedures were similar to that used by Spalding and Jacobs (1989). Briefly, one gram of pulverized soil or ISV product was placed in a 30 mL capacity polycarbonate centrifuge tube with 20 mL of 0.1N CaCl_2 . The tubes were shaken on a rotary shaker at 8 revolution per minute for 24 h at ambient room temperature. The soil suspensions were then centrifuged at 5000 rpm (or 3550 relative centrifugal force).

As a precaution, the supernatants were filtered through a $0.45\ \mu\text{m}$ nitrocellulose membrane in disposable filter holder units. The filtrate was saved in 20 mL polyethylene scintillation vials with polyethylene-lined caps for storage and radioactivity assays. An additional 20 mL of 0.1N CaCl_2 was added to the residual soil (or ISV product) pellet in the tube, and the suspension was shaken as above for 30 min. A second sequential extract was prepared from each sample as above. These sequential extractions were repeated three more times on each sample for a total of five 20 mL extracts from each of three duplicate samples.

Following the completion of the fifth extraction with CaCl_2 , 20 mL of 0.1N HCl was added and the suspension was shaken for 24 h. The initial acid extraction was followed by four additional extractions of 30 min each with additional 20 mL aliquots of 0.1N HCl . Blanks were prepared in a same manner as those samples except no soil or ISV product was added. All samples were assayed for ^{137}Cs via gamma-ray spectroscopy and for ^{90}Sr via Cerenkov radiation emission as described by Spalding et al. (1992).

Toxicity Characteristic Leaching Procedure (TCLP). TCLP (ASTM Designation D 5233-92) was performed to evaluate the effectiveness of ISV treatment on the leachability of ^{90}Sr and ^{137}Cs . A scale-down version of this standard test method was used because of the fact that the soils contain high activities of ^{137}Cs and ^{90}Sr and only a small amount of extract is needed to accurately determine ^{137}Cs and ^{90}Sr concentrations. It is pointed out, however, that such a scale-down did not change the solution to solid ratio (2000 mL/100 g as specified) so that the results should not be affected as a result of the scale-down of the testing method.

The TCLP extraction fluid was prepared by diluting 5.7 mL glacial acid and 64.3 mL 1 N NaOH to 1 L deionized water. The pH of this TCLP extraction fluid (acetate buffer) was 4.94 ± 0.02 . The extraction was performed by mixing 1 g soil (or ISV product) and 20 mL of the extraction fluid in 30-mL polycarbonate centrifuge tubes. The suspensions were then agitated at 8 rpm for 18 ± 2 h at ambient room temperature. Within 2 h after agitation, the soil (or ISV product) suspensions were filtered through a $0.45 \mu\text{m}$ nitrocellulose membrane in disposable filter holder units, and transferred to 20 mL scintillation vials. pH of the clear supernatant was recorded. Samples were then analyzed for ^{137}Cs and ^{90}Sr by the gamma-ray spectroscopy or Cerenkov radiation emission as described previously. The extracts were also analyzed for metal cations by inductively coupled plasma atomic emission spectroscopy (ICP-AES).

Product Consistency Test (PCT). Soil samples and the ISV product were also subjected to the Product Consistency Test (PCT) developed by Westinghouse Savannah River Company (Jantzen and Bibler 1989). The PCT was developed to evaluate the durability of nuclear, hazardous, and mixed-waste vitrified materials. The procedure is so called ASTM C26.13 (version 7.0), i.e. American standard test methods for determining chemical durability of nuclear waste glasses. Soil samples and the ISV product were crushed and sieved as described above. About 3 to 4 g of sample was used for each test in 100-mL Teflon bottles, to which 30-40 mL of deionized water (with the same solid/extractant ratio, 1:10) was added. The extractant (deionized water) is defined as water having a minimum electrical resistivity of $16.67 \text{ m}\Omega\cdot\text{cm}$ at 23°C . The soil and ISV samples were then kept in Teflon vessels at $90 \pm 2^\circ\text{C}$ for 7 days (± 3 h). After cooling to room temperature, approximately 2 mL of supernatant was used for pH measurement, and the remaining supernatant was filtered using a $0.45 \mu\text{m}$ filter as described previously. Triplicate tests were performed for each sample and for the blank containing no sample material.

2.12.3 Leaching Results

Sequential Leaching with Dilute CaCl_2 and HCl . Sequential leaching with 0.1N CaCl_2 and 0.1N HCl was performed to simulate the worst case scenario that radionuclides ^{137}Cs and ^{90}Sr may be leached out under natural environment. The cumulative fractional release of ^{137}Cs and ^{90}Sr from soil and the ISV product is shown in Figs. 1 and 2, respectively. Leaching with CaCl_2 is expected to exchange cations (e.g., Sr^{2+} and Cs^+) adsorbed on soil and the ISV surfaces. Results suggested that less than 0.5% of ^{137}Cs was exchanged by the Ca^{2+} after five consecutive washings (Fig. 43), whereas about 45-50% of ^{90}Sr was exchanged for soil blends 118 and 119, and about 90% for soil Blend 120 (Fig. 44). A low percentage of ^{137}Cs exchanged by Ca^{2+} (compared with that of ^{90}Sr) is not surprising because Cs^+ is known to form inner-sphere surface complexes and can be fixed tightly within the interlayers of clay minerals, particularly the illitic clay minerals.

Fig. 43. Sequential leaching of ^{137}Cs from ORNL pit 1 soils and pulverized laboratory vitrified product.

Fig. 44. Sequential leaching of ^{90}Sr from ORNL pit 1 soils and pulverized laboratory vitrified product.

The form of the specific adsorption or fixation of Cs^+ is neither as exchangeable cation nor a carbonate precipitate. Within the experimental error, the ISV product showed a negligible amount of ^{137}Cs in the leachate. On the other hand, a much higher percentage of ^{90}Sr was leached out at the end of CaCl_2 washings, because ^{90}Sr behaves chemically similar to Ca^{2+} so that a large percentage of ^{90}Sr can be exchanged. It is noted, however, that about 90% of ^{90}Sr was washed out from soil Blend 120 by 0.1N CaCl_2 , whereas only about 45-50% of ^{90}Sr was released by washing with 0.1N CaCl_2 for soil Blends 118 and 119. These results suggest that SrCO_3 may present in soils, particularly the soil Blends 118 and 119 because over 50% of ^{90}Sr in these two soils were later extracted with 0.1N HCl. However, after solidification of the soil (Blend 119) by the ISV technique, the leaching characteristics of ^{137}Cs and ^{90}Sr from the ISV product were greatly reduced (Figs. 43 and 44). Only negligible amounts of ^{137}Cs and ^{90}Sr were leached out with 0.1N CaCl_2 from the ISV product. These results support that ISV significantly reduces the leachability of contaminants once the contaminated soil is solidified. Similar results have been reported previously (Spalding et al., 1992). They have shown that ISV of soil reduced the contaminant leachability by several orders of magnitude.

When the extractant was switched to 0.1N HCl to initiate the dissolution, ISV product also showed a remarkably low leachability, compared with its corresponding soil samples. Less than 0.2 % of ^{137}Cs and <14% of ^{90}Sr were leached out after 5 consecutive leaching with 20 mL HCl (Figs. 43 and 44). It is pointed out that the cumulative ^{90}Sr released (~14%) from the ISV at the end of HCl leaching appears high compared with that (~3%) reported previously by Spalding et al. (1992). This may be partially due to the fact that a relatively large experimental error was involved in ^{90}Sr measurements because only few HCl leachate samples showed spikes [a relatively high ^{90}Sr activity (~20 dpm g^{-1})] compared to their duplicate samples (<0.2 dpm g^{-1}). The total ^{90}Sr activity in the ISV product was only 140.8 dpm g^{-1} after diluting the original soil (Blend 119) fifty times. Therefore, a measurement error could result due to such a low ^{90}Sr activity in the ISV sample. It is also pointed out that the actual ^{90}Sr release under field ISV conditions is expected to be much less because the ISV product for the present study was pulverized and sieved through 100 mesh. This process undoubtedly contributes to a higher release of ^{90}Sr from the ISV product than if the ISV product were unfragmented. It is estimated that the particle size of the pulverized ISV product is about 15 μm with a specific surface area of about 150 $\text{cm}^2 \text{g}^{-1}$ (Spalding et al. 1992). Therefore, the leachability of such an ISV waste form in the field, where the equivalent sphere would be much larger (~300 cm in diameter or ~0.028 $\text{cm}^2 \text{g}^{-1}$), would be expected to be lowered several orders of magnitude.

For those contaminated soils, however, leaching with 0.1N HCl showed almost quantitative recovery of ^{90}Sr (>95%) because HCl can dissolve SrCO_3 in soil. Soil Blends 118 and 119 appear to contain a higher percentage of SrCO_3 than soil Blend 120 because leaching with 0.1N HCl resulted in a release of >50% of ^{90}Sr from soil Blends 118 and 119. These results demonstrate that long-term soil weathering will result in the dissolution of the pit sludge containing $^{90}\text{SrCO}_3$, and thus release ^{90}Sr to the groundwater or the surrounding soil environment. The ISV will therefore dramatically slow down such a process.

Toxicity Characteristic Leaching Procedure (TCLP). The TCLP (ASTM Designation D 5233-92) was performed to evaluate the treatment effectiveness of ISV technique as the best demonstrated achievable technology (BDAT), or to determine whether a treated waste meets the BDAT criteria. The procedure is also to simulate some the most severe leaching conditions experienced in the land disposal of hazardous wastes, and therefore the results of these tests should simulate the worst case situations.

The TCLP results (Fig. 45) indicated that a relatively low amounts of ^{137}Cs was extracted from the contaminated soils and the ISV product (note that the Y-axis is on log-scale). Less than 0.5% of ^{137}Cs was extracted from the soil samples, and only 0.075% of ^{137}Cs extracted from the ISV product. As has been discussed previously, a low extractability of ^{137}Cs is partially due to its specific adsorption and fixation by the soil minerals. ISV resulted in an even lower leachability of ^{137}Cs , or about an order of magnitude lower compared with those soil samples.

However, TCLP resulted in a significant release of ^{90}Sr from the soil samples (Figs. 45 and 46). Approximately 47, 52, and 70% of ^{90}Sr was extracted from these soils by the TCLP procedure. Only ISV product showed an insignificant amount of ^{90}Sr in the leachate (-0.68% or below the detection limit), again indicating that ISV is a promising technique to retard contaminant leachability and therefore the mobility in the soil environment.

The elemental composition of the TCLP leachate was also analyzed by ICP-AES, and the results (Table 29) were compared with that of ^{137}Cs and ^{90}Sr . Among those metal cations analyzed, only Ca^{2+} behaved similarly to ^{90}Sr (Fig. 46 and Table 29). Larger than 50% of Ca^{2+} was extracted from the soils, and only 0.2% of Ca^{2+} extracted from the ISV product. These results are not surprising because both Ca^{2+} and Sr^{2+} are divalent cations and possess similar physical and chemical properties. The behavior of ^{137}Cs appears similar to those of structured metal ions (Al and Si) found in clay minerals. These cations can not be simply extracted unless surface dissolution occurs.

Product Consistency Testing. The soil samples and the ISV product were also subjected to the product consistency testing (PCT) developed by Westinghouse Savannah River Company (Jantzen and Bibler, 1989). The experimental procedures were modified slightly, that the crushed soil - ISV samples were not subjected to washing with water and ethanol. This was partly because the crushed soil and ISV samples (< 100 mesh) contained much of fine particles which would be washed off if the washing procedure was adopted. Therefore, the present PCT should represent the high-end leachability of the soil and ISV product because, by using larger-size particles (or lower specific surface areas per unit mass), lower amounts of contaminants would be leached out than by using fine particles with a higher specific surface area.

Results (Fig. 47) indicated that, within the experimental error, negligible amounts of ^{137}Cs and ^{90}Sr were leached out even by using the crushed fine ISV product. Less than 0.08% of ^{137}Cs was leached out from the contaminated soil samples. On the other hand, about 11, 14, and 30% of ^{90}Sr was extracted from the pit soils, but no ^{90}Sr (-0.25% or below detection limit) extracted from the ISV product by the PCT method. The amounts of ^{137}Cs and ^{90}Sr extracted also corresponded well with the total amounts of ^{137}Cs and ^{90}Sr in each soil sample (Fig. 47).

Similar to the TCLP experiment, the PCT leachate elemental composition was analyzed by ICP-AES. Because purified water was used as the extractant by PCT, lower amounts of ^{137}Cs and ^{90}Sr were extracted by PCT than by TCLP (using acetate buffer at pH ~4.9). However, the general conclusions are the same. Ca^{2+} behaved similarly to ^{90}Sr (Fig. 48 and Table 30). Approximately 10, 3.4, and 26% of Ca^{2+} was extracted from soil Blends 118, 119, and 120, and only 0.03% extracted from the ISV product.

Fig. 45. TCLP leaching of ^{137}Cs and ^{90}Sr from ORNL pit 1 soils and pulverized laboratory vitrified product.

Table 29. Normalized leachate elemental composition (mg/g) from TCLP test (numbers in parentheses are fractions of total element extracted)

Element	Sample Number			
	Blend 118	Blend 119	Blend 120	ISV
Ca	4.23 (0.851)	9.93 (0.507)	2.23 (0.907)	0.016 (0.002)
Mg	0.295 (0.032)	0.395 (0.033)	0.255 (0.025)	0.009 (0.0009)
Si	0.114 (0.0005)	0.110 (0.0005)	0.149 (0.0007)	0.028 (0.0001)
Al	0.026 (0.0003)	nd*	0.016 (0.0001)	0.890 (0.0094)
Fe	0.015 (0.0004)	nd	nd	0.015 (0.0004)
Mn	0.168 (0.353)	0.106 (0.210)	0.054 (0.184)	0.001 (0.001)

* nd = below detection limit.

Fig. 46. Fraction of ⁹⁰Sr and Ca²⁺ leached from ORNL pit 1 soils and pulverized laboratory vitrified product by TCLP test.

Fig. 47. Product consistency test (PCT) leaching of ^{137}Cs and ^{90}Sr from ORNL pit 1 soils and pulverized laboratory vitrified product.

Fig. 48. Fractions of ^{90}Sr and Ca^{2+} leached from ORNL pit 1 soils and pulverized laboratory vitrified product by the PCT procedure.

Table 30. Normalized leachate elemental composition (mg/g) from Product Consistency Tests (numbers in parentheses are fractions of total element extracted)

Element	Sample Number			
	Blend 118	Blend 119	Blend 120	ISV
Ca	0.51 (0.103)	0.66 (0.034)	0.63 (0.256)	0.003 (0.0003)
Mg	0.055 (0.006)	0.049 (0.004)	0.088 (0.008)	0.004 (0.0004)
Si	0.089 (0.0004)	0.015 (0.0001)	0.078 (0.0004)	0.195 (0.0008)
Al	nd*	nd	nd	nd
Fe	nd	nd	nd	nd
Na	0.045 (0.007)	0.053 (0.021)	0.118 (0.034)	0.023 (0.004)

* nd = below detection limit.

2.13 SITE PREPARATION FOR ISV

The spatial distribution of radioactivity will set limitations for the selection of many options for performing ISV operations and configuring melt geometries. In order to initiate ISV melts, the present asphalt cap on pit 1 will need to be removed; the nominal 2-in.-thick cap has been repeatedly surveyed during field sampling of the pit soil and has not been found to be radioactively contaminated. It will be removed by pushing down the slope to the west of pit 1. The comparatively level area surrounding the pit, which is presently covered by grass and maintained by mowing, will need to be covered with gravel to provide all-weather access for ISV equipment and vehicles. The results of the in situ activity radioactivity assays have determined that the depth of uncontaminated surface soil and, possibly, of fill materials that might be graded or moved to level any area needed for ISV operations.

Although the original assumption that the maximally contaminated depth of pit 1 was approximately 15 ft was incorrect, the maximally-contaminated depth of 26 ft, plus an additional 2 ft to ensure complete incorporation of source material into the ISV melt, can still be obtained within present ISV technology depth capability, i.e. 19 ft. The starting surface for the pit 1 ISV melt settings will be lowered by a combination of techniques. Firstly, the pit surface can be graded down to a lower flat surface. It would, obviously be desirable to grade down to a depth, i.e. 7-10 ft below present elevation, which would put the ISV depth target well within present proven ISV capabilities; however, the residual surface contamination on the original land surface to the west of pit 1 (see Fig. 38) limits grading to a maximum of 6 ft to avoid encountering this contamination.

However, this residual contamination resides on the original soil surface and, thus, the soil, imported to fill pit 1, has been found to be free of significant contamination to below 20 ft. Clean fill soil could be excavated considerably deeper than 6 ft as long as the western wall of the original pit were avoided. Thus, the concept of starting ISV in an excavated trench seems like the only feasible method for starting ISV at pit 1 and staying within proven depth capabilities. Current plans for ISV at pit 1 entail sculpting about 3 ft of soil, excluding the present asphalt cap, and using this as fill soil to extend the level area, probably by about 10 ft, to the west of pit 1. A trench would be excavated into the filled region of pit 1 to a maximum depth of 10 additional feet bringing the depth of the maximally-contaminated zone of pit 1 within 13 ft of the ISV starting surface.

However, starting ISV within a 10-ft-deep trench (13 ft below present grade, has raised several other issues related to both feasibility and safety of operations. First, the present perched water within pit 1 is presently located approximately 10 ft below the asphalt cap (Fig. 28). Thus, the present concept of a 13-ft reduction in ISV starting depth (3 ft of sculpting plus 10 ft of excavation) would encompass going 3 ft into the water table. Although pumping of pit 1 from the three present wells would entail collecting a large volume of highly contaminated water and its suspended solids, the possibility of pumping relatively uncontaminated water from shallower wells (e.g., 15 ft) will be investigated; there are presently no wells sampling pit 1 water at elevations more shallow than those described earlier. If uncontaminated perched water can be pumped from shallower elevation, then this approach will be used to allow excavation to the maximum desired depth. Otherwise, the startup ISV excavation will be limited to the depth of perched water.

Regardless of the approach, as soon as the grading of pit 1 is completed, as large a portion of the pit 1 area will be covered with an impermeable plastic sheet to minimize the recharge of water to the pit. The area will be uncovered immediately prior to excavating the startup trench which will be immediately covered by the off-gas hood; this will prevent filling of the startup excavation with water during whatever period is necessary before starting ISV.

Currently, it is estimated that approximately 36,000 gal of perched water reside in pit 1; this estimate includes only the free draining water, i.e., the water content between complete saturation (50%) and free drainage or field capacity (35%). The total volume of free-draining or standing water was estimated by multiplying the area of pit 1 (1,992 ft², **Fig. 25**) by the depth of water 16 ft (i.e., 26-10 ft) by the free draining water 15% (i.e. 50 - 35%). This estimate is important for planning ISV of pit 1 because all of the volume must either be boiled away by ISV or pumped prior to ISV during the initial melt to 28 ft below present grade. Field capacity water of the fill soil would be boiled away during ISV but only from the zone of vitrification and not from the entire pit.

A second and equally difficult problem posed by ISV startup in an excavation is the potential for subsidence "events" or cave-ins to occur as the original startup excavation is undercut by a widening and subsiding ISV melt surface. **Fig. 49** depicts the potential problem scenario at pit 1. The large-scale ISV equipment is used in this scenario with an 11-ft electrode spacing to produce a melt which will reach the target depth and encompass the entire width of pit from the east to west sides. In **Fig. 49**, a 21-ft wide trench is excavated for the startup of ISV at a depth of 10 ft 9 in.; however, as ISV proceeds, the melt will widen to approximately 27 ft leaving the darkened area at risk for potential cave-in.

The risk of cave-in centers on either damage to the electrodes or a transient pressurization of the off-gas hood when cool, moist soil falls on molten glass. The potential for off-gas hood differential settlement is quite minimal because the hood, as presently planned, will have a 50-ft span which greatly exceeds the potential cave-in area radius. This is more clearly seen in plan view of the excavation (**Fig. 50**). Several variations of the ISV startup trench can be conceived which minimize the perimeter areas at risk for cave-in (**Fig. 51** and **Fig. 52**). However, at this point in time, the exact dimensions of a startup trench with minimal risk of cave-in cannot be assessed.

Although the scenario with the largest trench (**Fig. 52**) appears to minimize risk of cave-in, the necessity of a wide and tapered excavation could not be determined without collecting soil strength information about the pit 1 fill material and the host soil formation. Penetrometer tests were performed using a hand-operated pocket soil penetrometer (Brainard-Kilman S-170 Pocket Penetrometer which reads 0 to 5 tons/ft²). Vane shear strength tests were obtained using a Torvane 51600200 tester (Sinco Slope Indicator Co.) which reads 0 up to 2.5 kg/cm² (0 to 2.44 tons/ft²). In situ tests were performed at 15 locations around and under the asphalt cap on pit 1 in October 1994.

Several 1.5-in diameter cores of about 12 in. lengths were retrieved (starting at 8-12 in. below the asphalt grade) at four locations within pit 1. These were segmented in the laboratory into 1 in. thick sections. One batch of 8 samples was used for tests at ambient moisture content (i.e., 30-35% as determined on other segments). Another batch of 8 segments was oven dried at 100°C and an additional suite was oven baked at 600°C prior to testing. For vane shear tests, impressions of the vanes were made into specimens prior to oven-drying or baking which allowed for subsequent vane insertion which otherwise would have been impossible after drying.

The results of these soil strength tests are summarized as follows:

- In situ penetrometer tests: average = 1.96 (range 1.0 to 3.4) tons/ft²,
- In situ vane shear tests: average = 0.90 (range 0.63 to 1.49) tons/ft²,
- Laboratory penetrometer tests at ambient moisture: range 0.7 to 3.1 tons/ft²,

Fig. 49. Cross-section of possible ISV melt at seepage pit 1 with startup in a straight-walled, 10-ft deep excavation.

Fig. 50. Plan view of pit 1 ISV melt setting using a 50-ft square hood and a 32-ft wide startup trench.

Fig. 51. Potential ISV scenario at seepage pit 1 using 32-ft wide straight walled startup trench.

Fig. 52. Potential ISV scenario at seepage pit 1 using a startup trench with walls tapered from 40 to 32 ft.

- Laboratory vane shear tests at ambient moisture: range 0.64 to 1.35 tons/ft²,
- Laboratory penetrometer tests on oven-dried soil: all >5.0 tons/ft² (instrument maximum),
- Laboratory vane shear tests on oven-dried soil: one sample at 1.25 tons/ft², all others >2.25 tons/ft²,
- Laboratory penetrometer tests on oven-baked soil: all >5.0 tons/ft²,
- Laboratory vane shear tests on oven-baked: all >2.25 tons/ft²

All oven-dried specimens appeared hard and cohesive like adobe brick while all oven-baked specimens appeared like typical fired bricks. It would appear that the proposed slopes for startup trench excavation are of sufficient strength to be stable. When the asphalt cap was removal and site sculpting were completed in June 1994, as general soil slope between 40 and 60° above horizontal was established on the east side of the pit area; the total height differential of these slopes approached a maximum of 5 ft. These slopes have remained stable, other than frost heaving of surface soil aggregates, up to the present (February 1996). Such a test excavation lends excellent empirical support to the slope stability analysis for the proposed startup trench excavation to a probable depth of 7 ft below the present reduced surface elevation over the pit.

3. REFERENCES

- Amoozegar, A. and A. W. Warrick. 1986. *Hydraulic Conductivity of Saturated Soils: Field Methods*. pp. 735-770. In, *Methods of Soil Analysis*. A. Klute (ed.). Soil Science Society of America, Madison, Wisconsin.
- Battelle Pacific Northwest Laboratory. 1995. *In Situ Vitrification Large-Scale System Safe Operating Procedure*. Procedure 58, Revision 9. Battelle Pacific Northwest Laboratory, Richland, Washington, 69pp.
- Buel, J. L., C. L. Timmerman, K. H. Oma, V. F. Fitzpatrick, and J. G. Carter. 1987. *In situ vitrification of transuranic waste: Systems evaluation and applications assessment*. PNL-4800, Supplement 1. Battelle Pacific Northwest Laboratory, Richland, Washington.
- Callow, R. A., L. E. Thompson, J. R. Weidner, C. A. Loehr, B. P. McGrail, and S. O. Bates. 1991. *In situ vitrification application to buried waste: Final report of intermediate field tests at Idaho National Engineering Laboratory*. EGG-WTD-9807. Idaho National Engineering Laboratory, Idaho Falls, Idaho.
- Campbell, B. E. and T. A. Ikenberry. 1990. *Safety Evaluation Document for the 116-B-6A Crib ISV Demonstration Project*. Battelle Pacific Northwest laboratory, Richland, Washington.
- Carrier, R. F., J. K. Williams, and J. A. Roberts. 1989. *Surface radiological investigations at pit 1 environs*. ORNL/RAP/LTR-88/55. Oak Ridge National Laboratory, Oak Ridge, Tennessee.
- Energy Systems Environmental Restoration Program. 1996. *Technical Evaluation Summary of the In Situ Vitrification Melt Expulsion at the Oak Ridge National Laboratory on April 21, 1996, Oak Ridge, Tennessee*. ORNL/ER-374/R1.
- Farnsworth, R. K., K. H. Oma, and C. E. Bigelow. 1990. *Initial tests on in situ vitrification using electrode feeding techniques*. PNL-7355. Battelle Pacific Northwest Laboratory, Richland, Washington.
- Ghiorso, M. S. 1987. "Modeling magmatic systems: Thermodynamic relations." In *Thermodynamic modeling of geologic materials: Minerals, fluids, and melts*. I. S. E. Carmichael and H. P. Eugster (eds.), Reviews in Mineralogy 17:443-465. Mineralogical Society of America, Washington, D.C.
- Govindaraju, K. 1989. *1989 Compilation of Working Values and Sample Description for 272 Geostandards*. Geostandards Newsletter 13: 1-113.
- Janzten, C. M. and N. E. Bibler. 1989. *Nuclear waste glass product consistency test (PCT) method*. Version 3.0. Westinghouse Savannah River Company, Aiken, South Carolina.
- Lamar, D. A. and T. J. McLaughlin. 1987. *Safety Analysis Documentation Large-Scale Radioactive Testing of the In Situ Vitrification Process at the 216-Z-12 Crib*. Battelle Pacific Northwest Laboratory, Richland, Washington.

Lomenick, T. F., D. G. Jacobs, and E. G. Struxness. 1967. "The behavior of strontium-90 and cesium-137 in seepage pits at ORNL." *Health Physics*. 13:897-905.

Luthin, J.H. and D. Kirkham. 1949. *A Piezometer Method for Measuring Permeability of Soil In Situ Below a Water Table*. *Soil Science*. 68:349-358.

Moore, G. K. and L. E. Toran. 1992. *Supplement to a Hydrologic Framework for the Oak Ridge Reservation, Oak Ridge, Tennessee*. ORNL/TM-12191.

Mortimore, J.A. 1987. *Piezometer Installation in WAG 7: LLW Pits & Trenches Area and the Decontamination Facility*. ORNL/RAP/LTR-87/59, Sept. 2, 1987.

Shade, J. W. and G. F. Piepel. 1990. *Viscosity, electrical conductivity, and cesium volatility of ORNL vitrified soils with limestone and sodium additives*. PNL-7331. Pacific Northwest Laboratory, Richland, Washington.

Solomon, D. K., G. K. Moore, L. E. Toran, R. B. Dreier, and W. M. McMaster. 1992. *Status Report, A Hydrologic Framework for the Oak Ridge Reservation*. ORNL/TM-12026.

Spalding, B. P. and G. K. Jacobs. 1989. *Evaluation of an in situ vitrification field demonstration of a simulated radioactive liquid waste disposal trench*. ORNL/TM-10992. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Spalding, B. P., G. K. Jacobs, N. W. Dunbar, M. T. Naney, J. S. Tixier, and T. D. Powell. 1992. *Tracer-level radioactive pilot-scale test of in situ vitrification for the stabilization of contaminated soil sites at ORNL*. ORNL/TM-12201. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Spalding, B. P., G. K. Jacobs, and E. C. Davis. 1989. *Demonstrations of technology for remediation and closure of Oak Ridge National Laboratory waste disposal sites*. ORNL/TM-11286. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Spalding, B. P. 1994. *Volatilization of cesium-137 from soil with chloride amendments during heating and vitrification*. *Environ. Sci. Tech.* 26: 1116-1123.

Spalding, B. P. and M. T. Naney. 1995. *Site Safety and Health Plan (Phase III) for the Treatability Study for In Situ Vitrification at Seepage Pit 1 in Waste Area Grouping 7 Oak Ridge National Laboratory, Oak Ridge, Tennessee*. ORNL/ER-314. Lockheed Martin Energy Systems, Inc., Oak Ridge, Tennessee.

Shade, J. W. and G. F. Piepel. 1990. *Viscosity, Electrical Conductivity, and Cesium Volatility of ORNL Vitrified Soils with Limestone and Sodium Additives*. PNL-7331. Battelle Pacific Northwest Laboratory, Richland, Washington.

Timmerman, C. L. and K. H. Oma. 1985. *A Pilot-Scale Radioactive Test Using In Situ Vitrification*. *Nuclear Technol.* 71: 471-481.

United States Environmental Protection Agency (U.S. EPA). 1989. *Guide for conducting treatability studies under CERCLA Interim Final*. EPA/540/2-89/058. Office of Research and Development, Cincinnati, Ohio.

United States Environmental Protection Agency (U.S. EPA). 1992. *Handbook vitrification technologies for treatment of hazardous and radioactive waste*. EPA/625/R-92/002 EPA, Office of Research and Development, Washington, D.C.

Watkins, D. R. et al. 1993. *Final report on the background soil characterization project at the Oak Ridge Reservations, Oak Ridge,, Tennessee*. Volume 1. DOE/OR/01-1175/V1. Lockheed Marietta Energy Systems. Oak Ridge, Tennessee.

Williams, J. K., C. Clark, Jr., and J. W. Crutcher. 1987. *Radiological and RCRA Hazardous Waste Scoping Survey of the Decontamination Facility (Building 7819) Transfer Line Leak Site*. ORNL/RAP-22. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

APPENDIX A

Project Procedures

**SUBJECT: DRIVING RODS AND PIPES FOR DETERMINATION OF PIT/TRENCH BOUNDARIES
AND IN SITU LOGGING OF RADIOACTIVITY**

I. Scope and Application

This procedure describes the use of a hand-operated vibratory hammer (jack hammer) to drive either 0.5-inch diameter threaded rod or AQ-size (1.75-inch diameter) drill rod into potentially contaminated soil or other unconsolidated geologic materials. The threaded rod is used to determine depth to "rock" as evidenced by refusal for further penetration; penetration rate data is collected during driving as an index of density or consolidation of materials. The AQ drill rod is used to position an access pipe for in situ logging of radioactivity with depth within the surrounding soil or pit material; penetration rate data is also collected to infer consolidation or density properties of the geologic material being penetrated. These access pipes are then logged with depth for radioactivity using both a Geiger-Muller (G-M) detector and a NaI(Tl-activated) gamma scintillation detector; the detectors are coupled to either a scaler/ratemeter or multichannel analyzer for data collection. Well screen can also be driven by the jack hammer to "construct" groundwater or perched water monitoring wells within the contaminated pit/soil formation. The procedure is applicable to many unconsolidated materials, such as soils, sediments, and sludges, contained in these old seepage pits.

II. References

- A. Instruction Manual Model 1000 Scaler. 1975. Ludlum Measurements, Inc. Sweetwater, Texas 79556. 915-235-5494.
- B. ORNL Health Physics Manual. 1990. ORNL/M-804. Martin Marietta Energy Systems, Inc., Oak Ridge, Tennessee.
- C. Environmental Surveillance Procedures Quality Control Program. 1988. Martin Marietta Energy Systems, Inc, Oak Ridge, Tennessee.
- D. Instruction Manual Pavement Breaker 5027. 1989. Black & Decker, Inc., Hunt Valley, Maryland 21030-0798.
- E. Geoprobe 1991 Catalog. 1992. Geoprobe Systems. Salina, Kansas 67401.
- F. Standard Method for Penetration Test and Split-Barrel Sampling of Soil. 1984. D1586-84. American Society for Testing and Materials. Philadelphia, Pennsylvania 19103.
- G. Instruction Manual for TN-1705 and TN-1706 Pulse Height Analyzers. 1979. Tracor Northern, Middleton, Wisconsin 53563. 608-831-6511.

III. Summary of Method

This procedure describes the driving of various tools into the depths of seepage pits and trenches and surrounding soil using a electrically-powered vibratory hammer (jack hammer). Tools which can be driven include 0.5-inch diameter threaded rod (to probe for consolidated material or hard rock depth), 1.68-inch outside diameter/1.25-inch inside diameter galvanized or stainless-steel pipe (to provide

access holes up to 25 ft deep for in situ logging of radioactivity), 1.75-inch outside diameter/1.375-inch inside diameter AQ drill rod with flush-joint threaded solid drive points (to provide hydrologically sealed access holes for in situ logging of radioactivity with depth), or 1-inch outside diameter/0.5-inch inside diameter rod (for placement of ground or perched water sampling screens. All tools can be placed to desired or attainable depth without returning any contaminated materials (soil, sludge, or groundwater) to the surface which obviates the potential for exposure of personnel to probable but poorly-defined contamination. Rates of penetration are measured during tool driving and are used to infer degree of consolidation or density of geologic materials similar to the standard penetration test (Reference F). Driven pipe is then logged with depth for beta/gamma activity using small diameter Geiger-Muller (G-M) tubes connected to a scaler; detector performance is established prior to logging each pipe by recording background counting rates and rates in response to a standard source of ^{137}Cs . Driven pipe can also be logged using a small diameter NaI(Tl-activated) detector connected either to a multichannel analyzer or a scaler. The distribution of radioactivity with depth can be graphically represented in a three-dimensional map of a seepage pit/trench and its environment. Penetration rate data and depth of refusal data are used to infer pit/trench dimensions and bedrock locations. Driven well screen is used to determine piezometric head, to measure hydraulic conductivity in their proximate environment, and to provide access for sampling any perched water within the pit/trench.

IV. Comments

A. This tool driving procedure is similar to that used in procedure ESP-303-4, "Penetration Test and Split-Barrel Sampling," in Reference C and to the method used in ASTM D-1586-84 (Reference F). However, significant modifications in tools, materials, and methods have been established to control contamination and personnel exposure during sampling of known radioactively-contaminated materials in the ORNL seepage pits and trenches. Drill rod, driven to refusal using this method's electrically-operated jack hammer, could not be driven further using the standard 140-pound cathead-operated safety hammer as specified in the standard methods (References C and F). Thus, the jack hammer technique drives tools to depths and refusal equivalent to those attainable with the standard methods.

B. The driving of 1.68-inch diameter galvanized or stainless-steel pipe, using external pipe couplings, should not be prolonged more than 1 minute after first apparent refusal. Collapse of pipe train sections appears to occur at pipe coupling.

V. Required Equipment and Apparatus

A. Fixed-Mount Work Platform - 33-inch height with three steps and handrails, 500-pound capacity (McMaster-Carr Supply Co, P.O. Box 740100, Atlanta, GA, Part No. 8031T42).

B. Fixed-Mount Work Platform - 45-inch height with four steps and handrails, 500-pound capacity, (McMaster-Carr Supply Co, P.O. Box 740100, Atlanta, GA, Part No. 8031T43).

C. Polyethylene tubing, 4-inch wide by 1500-ft roll, 4-Mil thickness (McMaster-Carr Supply Co., P.O. Box 740100, Atlanta, GA, Part No. 2062T27).

D. Polyethylene tubing, 2-5/8-inch wide by 1500-ft roll, 4-Mil thickness (McMaster-Carr Supply Co., P.O. Box 740100, Atlanta, GA, Part No. 2062T16).

E. Electric Pavement-Breaker Hammer, 120 volts AC, 60 Hz, 12.2 amps, 850 blows/min, 70.5 pound

Procedure Number: ISV-TS-P01

Revision Number: Draft

Date: January 20, 1994

Page: 3 of 17

weight, using 1-1/8-inch hex tools (chisels), Black and Decker Model 5027 (McMaster-Carr Supply Co., P.O. Box 740100, Atlanta, GA, Part No. 59045A11).

F. Standard galvanized welded steel pipe, schedule 40, both end threaded, 1-1/4-inch IPS, 60-inch lengths (McMaster-Carr Supply Co., P.O. Box 740100, Atlanta, GA, Part No. 4499K64), and standard galvanized couplings (Part No. 4638K167).

G. 304 stainless steel welded steel pipe, schedule 40, both end threaded, 1-1/4-inch IPS, 60-inch lengths (McMaster-Carr Supply Co., P.O. Box 740100, Atlanta, GA, Part No. 4813K74), and couplings (Part No. 4464K66).

H. Plain steel threaded rod, 1/2-inch diameter, coarse thread (13), three-ft lengths (McMaster-Carr Supply Co., P.O. Box 740100, Atlanta, GA, Part No. 98837A033) and grade 2 zinc-plated steel coupling nut for 1/2-inch diameter and 13 thread screw (Part No. 90264A220).

I. Standard AQ drill rod, 1.75-inch outside diameter, 1.375-inch inside diameter, with flush-joint threads for coupling rods, one end box and other end pin, 5-ft lengths (Driller's Service, Inc., Hickory, North Carolina 28603-1407, 804-973-6207) and some lengths of 1- and 2-ft for finishing top of drill rod strings.

J. Custom threaded drive point for AQ drill rod per Fig. 1 with AQ rod box and solid steel 30-degree cone point (Driller's Services, Inc., Hickory, North Carolina 28603-1407).

K. Custom drive head for AQ rod per Fig. 2 with AQ-threaded pin on 2-5/8-inch diameter by 7-inch long round blank with 1-5/16-inch diameter by 3-inch deep box (Driller's Services, Inc., Hickory, North Carolina 28603-1407).

L. Assembled screen point ground water sampler, 1-inch outside diameter/0.5-inch inside diameter (Geoprobe Systems, Inc. Salina, Kansas 67401, Part No. GW-440R) and required parts: 36-inch long probe rod (AT-10B), 24-inch long probe rod (AT-105B), 12-inch long probe rod (AT-106B), cleaning brush kit (AT-100K), sampling tubing (3/8-inch outside diameter/0.25-inch inside diameter polyethylene in roll of 500 ft, TB-25L), bottom check valve (GW-42), stainless steel extension rod (AT-67), extension rod couplings (AT-68), drive cap for rod (AT-11B), expendable drive point holder for rod (AT-13B), expendable drive point (AT-14), O-rings for expendable drive points (AT-14R), gas sampling cap for rod (AT-15B), and extracting jack for 1-inch geoprobe rod (AT-99).

M. Penetrometer point, steel, 2-inch diameter, slip-fit pin (Acker Drill Company, Scranton, Pennsylvania, 717-586-2061, Part No. 110870) and drill head assembly for 2-inch diameter penetrometer point to AW drill rod (Part No. 21078-12).

N. Survey meter - ORNL-calibrated beta/gamma exposure meter for range 0.25 to 25 mR/hr.

O. Water level meter - nominal 0.59-inch diameter nickel-plated brass probe with plastic tape, 200-ft long, scribed in 0.02 ft intervals, with audible alarm at water contact (Solinst, Inc., Model 101, Environmental Instruments Co., Concord, California 94520. 415-686-4474).

P. Geiger-Muller (G-M) probes - 4-inch long x 0.875-inch outside diameter probes, with anodized finish and C-type connector, operating at 550 volts, with linear ranges of 0-200mR/hr, 0-2R/hr, and 0-20R/hr with nominal responses of 1000, 150, and 20 counts per minute/mR/hr for ¹³⁷Cs gamma,

respectively (Models 133-2, 133-4, 133-6, respectively, Ludlum Measurements, Inc., Sweetwater, Texas 79556. 915-235-5494).

Q. Scaler - line-powered (115 V, 60 Hz) gross count scaler, regulated high voltage power supply to 2500 volts, 6 decade scaler, clock capacity to 99 minutes, suitable for G-M or scintillation counting (Model 1000, Ludlum Measurements, Inc., Sweetwater, Texas 79556. 915-235-5494).

R. Scintillation probe - Sodium iodide (Thallium-activated) 0.5-inch diameter crystal, with 0.75-inch outside diameter dimension (Model .5ML5/75L, Bicron, Solon, Ohio 44139. 216-248-7400).

S. Multichannel pulse height analyzer - portable, 2048 channels, 115-volt, 60 Hz powered, with cathode ray tube display and region-of-interest integrator (Model TN-1705, Tracor Northern, Inc., Middleton, Wisconsin 53562. 608-831-6511).

T. Pipe monitor - gamma scintillation probe, sodium iodide (Thallium-activated) 0.5-inch diameter x 3-inch long crystal, with 0.75-inch outside diameter housing dimension (Model .5MT3/5L-SS-X, Pipe Monitor, Bicron, Solon, Ohio 44139. 216-248-7400).

VI. Safety

It is the policy of Martin Marietta Energy Systems to maintain an effective program for control of employee exposure to chemical, radiological, and physical stress which is consistent with the requirements of Martin Marietta Corporation, DOE, and OSHA established standards and requirements. All field personnel will be provided with appropriate protective clothing and safety equipment.

Personal protective equipment, required while performing this procedure, will be specified on the approved Radiation Work permit. As a minimum, field personnel are required to wear safety shoes, company-issued clothing, and safety glasses while performing any part of this procedure. Refer to the site safety and health plan for detailed health and safety procedures. The site safety and health plan should be reviewed prior to beginning work employing this procedure. A Radiation Work Permit is required for use of this procedure in the seepage pits and trenches waste area grouping.

VII. Procedures

A. Driving 0.5-inch diameter threaded rod

1. Survey the desired penetration point surface with the G-M survey meter to verify the starting background counting rate. If the desired penetration point is overlain by asphalt, use a moil-point tool in the jack hammer to break an approximately 3-inch diameter hole in the asphalt surface. Survey the opened hole with the G-M survey meter to verify the continuing background counting rate.

2. Place a polyethylene sheet (approximately 3-ft square) over the penetration point with a small hole (approximately 2-inch diameter) cut in its center. Cut a 3-4 ft length of narrow (2-5/8-inch wide) polyethylene bagging with a scissors and produce two flaps at one end of the bagging to attach to the plastic ground-covering sheet with 2-inch-wide vinyl tape. Tape all contacts of the bagging sleeve to the ground sheet so that there are no openings. Position pieces of cinder block, or other convenient weights, on the corners of the ground sheet to hold in place; two feet of the 33-inch-high work platform can be used to hold two corners of the plastic down when it is positioned over the work area.

3. Place a 3-ft section of 0.5-inch threaded rod, coupled with a nut to a 6-8 inch long extension section, which is used for contact with the electric jack hammer, which otherwise would foul the rod threads, inside the plastic sleeve. The first rod section can be manually pushed into the ground so that it will stand erect. Secure the top of the plastic sleeve to the extension rod using a reusable plastic clamp. The 3-ft rod sections should be marked at 1-ft intervals using bright yellow spray paint; such marking will allow timing of penetration to be determined.

4. Position the electric jack hammer and driving tool over the threaded rod train using a blank hex shank tool with a 1/2-inch by 3-inch deep hole in the middle. With this overlap, there is virtually no danger of the tool slipping off the threaded rod during driving.

5. A second person, the data recorder, should prepare the field log book for recording the penetration rate information. Every foot of penetration should be timed with a stop watch and recorded. Because it is not desirable to stop the jack hammer after every foot of penetration, the data recorder should record cumulative time at which each of the three markings on a rod section penetrate the ground level.

6. After completing the driving of the initial 3-ft section of threaded rod, remove the jack hammer from the extension piece and secure safely on the ground or work platform. Survey the plastic and ground surface for any increase over the starting background counting rate; it is extremely unlikely that any increase will occur as no soil, cuttings, or tools are withdrawn from the penetration hole.

7. Push down the plastic sleeve so that the extension can be unscrewed from the coupling nut. Place another 3-ft section of threaded rod on the previous 3-ft section with a new coupling nut and attach the short extension piece for driving. Extend the plastic sleeve back to the top coupling nut and secure with reusable clamp.

8. Position jack hammer and driving tool over rod extension and continue driving and recording penetration times as above.

9. Repeat the process of attaching 3-ft sections of threaded rod and driving until the desired depth is attained or refusal is encountered. Refusal is defined as no observable penetration progress in 5 minutes of jack hammer operation on the rod. The data recorder should record the fractional progress of the penetration, in inches, from the last foot driven into the ground.

10. After terminating driving at a particular penetration point, survey plastic and ground surface and the threaded rod extension for contamination. If uncontaminated, discard plastic sheeting and sleeve as ordinary solid waste. In the unlikely event that either the tool or plastic exhibits contamination, discard as radioactive solid waste.

11. Label the ground surface with the penetration hole number, as logged in the field notebook, using spray paint. Unscrew any rod section protruding above ground which might pose a safety hazard to anyone walking in the area. Alternately, if the rod section cannot be removed, add another section to it and flag with brightly colored tape or plastic.

12. Data should be transferred to a spreadsheet database file (e.g., lotus or excel) where plots of cumulative penetration, in feet, versus penetration rate, in feet/sec, can be plotted for graphical interpretation of penetration data.

B. Driving 1.75-inch diameter AQ rod

1. The penetration point should be prepared following the steps described in sections VII.A.1 and 2 except that 4-inch wide plastic bagging/sleeve should be used to accommodate the wider AQ rod. The 45-inch high work platform should be used instead of the lower 33-inch platform.
2. Place a 5-ft section of 1.75-inch AQ drill rod (fitted with a custom flush-joint threaded drive point (Fig. 1) and coupled on top with a custom AQ rod drill head (Fig. 2), which is used for contact with the electric jack hammer through a blank hex shank tool) inside the plastic sleeve. Tighten the drive point and rod together using pipe wrenches or the special AQ-rod clamp wrenches provided by the AQ-rod manufacturer. The first rod section can be manually pushed into the ground so that it will stand erect. Secure the top of the plastic sleeve to the top of the AQ rod using a reusable plastic clamp. The 5-ft rod section should be marked at 1-ft intervals using bright yellow spray paint; such marking will allow timing of penetration to be determined.
3. Position the electric jack hammer with attached hex blank tool into the AQ rod drive head (Fig. 2) onto the AQ rod train. With the 3-inch insertion depth in the drive head, there is virtually no danger of the jack hammer falling off the rod train during driving.
4. A second person, the data recorder, should prepare the field log book for recording the penetration rate information. Every foot of penetration should be timed with a stop watch and recorded. Because it is not desirable to stop the jack hammer after every foot of penetration, the data recorder should note cumulative times at which each of the first four markings on a rod section penetrate the ground level. Driving of the 5-ft AQ rod should be stopped when approximately 6 inches (0.5 ft) is still protruding above the ground surface; leaving the short, above-ground extension facilitates connecting and wrench-tightening the next AQ rod section without removing the plastic containment sleeve. Push down the plastic sleeve so that the drive head sub can be unscrewed from the AQ rod. The time between the penetration of the 4-ft mark and the 4-1/2-ft penetration should also be recorded.
5. After completing the driving of 4-1/2-ft of the initial 5-ft section of AQ rod, remove the jack hammer from the drive head sub and secure safely on the ground or work platform. Survey the plastic and ground surface for any increase over the starting background counting rate; it is extremely unlikely that any increase will occur as no soil, cuttings, or tools are withdrawn from the penetration hole.
6. Measure the depth of rod from the bottom of the hole to the top of rod using the nickel-plated brass probe electric water level indicator; the measuring point of the water level meter is actually in the middle of the depth probe and the constant difference (0.25 ft) must be added to the apparent depth as measured with the tape to the top of rod. This depth or length of rod should be approximately 5 feet unless the rod has collapsed or the drive point failed. Record the exact measured depth and note the sound of water level probe as it contacts the bottom of the rod train; a hard metal-to-metal sound is indicative of an undisturbed rod and drive point. As the water level probe is removed from the rod, survey with the G-M meter to determine if any contamination has been encountered.
7. Add and tighten another 5-ft section of AQ rod on the previous 5-ft section and attach the drive head sub for additional driving. Extend the plastic sleeve back to the top of the AQ rod and secure with reusable clamp.
8. Position jack hammer onto the drive head and continue driving and recording penetration times

as above.

9. Repeat the process of attaching 5-ft sections of AQ rod and driving until the desired depth is attained or refusal is encountered. Refusal is defined as no observable penetration progress in 5 minutes of jack hammer operation on the AQ rod. The data recorder should measure and record the fractional progress of the penetration, in inches, from the last foot driven into the ground. Also record the height of rod extending above the ground surface and the depth of rod from the bottom of the hole to the top of rod as for previous sections of rod.

10. After terminating driving at a particular penetration point, survey plastic and ground surface and the drive head sub for contamination. If uncontaminated, discard plastic sheeting and sleeve as ordinary solid waste. In the unlikely event that either the tool or plastic exhibits contamination, discard as radioactive solid waste.

11. Label the ground surface with the penetration hole number, as logged in the field notebook, using spray paint. Unscrew any rod section protruding above ground which might pose a safety hazard to anyone walking in the area. Alternately, if the rod section cannot be removed, add another section to it and flag with brightly colored tape or plastic. Tape over opening of the AQ rod with vinyl tape to prevent entry of precipitation into the pipe.

12. Data should be transferred to a spreadsheet database file (e.g., lotus or excel) where plots of cumulative penetration, in feet, versus penetration rate, in feet/sec, can be plotted for graphical interpretation of penetration data.

C. Driving 1.68-inch diameter galvanized or stainless-steel pipe

1. The penetration point should be prepared following the steps described in sections VIIA.1 and 2 except that 4-inch wide plastic bagging/sleeve should be used to accommodate the wider 1.68-inch outside diameter pipe and couplings. The 45-inch high work platform should be used instead of the lower 33-inch platform to accommodate driving the longer 5-ft pipe sections.

2. Place inside the plastic sleeve a 5-ft section of 1.68-inch pipe, fitted on the bottom with a penetrometer point and holding assembly and coupled on top with a 6-inch long pipe nipple with an additional pipe coupling on top, which is used for contact with the electric jack hammer using a pipe-driving tool. The drive point assembly, which is machined as an AW-drill rod pin sub, can be slipped into the 1.25-inch inside diameter pipe, with a few windings of 2-inch-wide vinyl tape, to provide a snug friction fit so that the penetrometer point does not fall out of the assembly when the pipe is held with the point downward; alternately, a penetrometer point with machined AW drill rod threaded pin, can be friction-fit into the driving end of the pipe. The first pipe section can be manually pushed into the ground so that it will stand erect. Secure the top of the plastic sleeve to the top of the pipe using a reusable plastic clamp. The 5-ft pipe section should be marked at 1-ft intervals using bright yellow spray paint; such marking will allow timing of penetration to be determined.

3. Position the electric jack hammer, with pipe driving tool, into the top pipe coupling of the pipe train. With the 1-inch insertion depth in the pipe driving tool, there is always the possibility that the jack hammer pipe driving tool will fail during driving; several instances of such tool failure have been experienced usually resulting from the tool shearing at the hex shank to metal cylinder contact, or at the point of tool insertion, or within the extension nipple-coupling. The data recorder should stand clear of the work platform during driving so that a falling jack hammer would not be within reach.

The jack hammer operator should maintain one hand under the jack hammer handle so that, if tool breakage occurs, the jack hammer can be lifted onto the work platform or lowered onto the ground surface. At no point should the jack hammer operator put his/her weight on the jack hammer or balance his/her position on the jack hammer. The work platform railing should be positioned between the operator and the jack hammer to function as a safety restraint for the operator should the jack hammer tool fail. If the operator cannot lift the jack hammer onto the work platform after a tool failure, the jack hammer should be released to prevent injury to the operator.

4. A second person, the data recorder, should prepare the field log book for recording the penetration rate information. Every foot of penetration should be timed with a stop watch and recorded. Because it is not desirable to stop the jack hammer after every foot of penetration, the data recorder should note cumulative times at which each of the first four markings on a pipe section penetrate the ground level. Driving of the 5-ft pipe should be stopped when approximately 6 inches (0.5 ft) of the 5-ft section is still protruding above the ground surface; leaving this short above ground extension facilitates coupling and wrench-tightening the next pipe section without removing the plastic containment sleeve.

5. After completing the driving of the initial 5-ft section of pipe, remove the jack hammer from the extension nipple and secure safely on the ground or work platform. Survey the plastic and ground surface for any increase over the starting background counting rate; it is extremely unlikely that any increase will occur as no soil, cuttings, or tools are withdrawn from the penetration hole.

6. Push down the plastic sleeve so that the extension nipple and coupling can be unscrewed from the pipe with two pipe wrenches. Measure the depth of pipe from the bottom of the hole to the top of rod using the nickel-plated brass probe electric water level indicator; the measuring point of the water level meter is actually in the middle of the depth probe and the constant difference (0.25 ft) must be added to the apparent depth as measured with the tape to the top of pipe. This depth or length of open pipe should be approximately 5 feet unless the pipe has collapsed or the drive point failed. Record the exact measured depth and note the sound of water level probe as it contacts the bottom of the pipe; a hard metal-to-metal sound is indicative of an undisturbed pipe and drive point. As the water level probe is removed from the pipe, survey with the G-M meter to determine if any contamination has been encountered.

7. Place another 5-ft section of pipe on the previous 5-ft section and attach the extension nipple and coupling for additional driving. The coupling of extension nipple to new pipe section is most easily performed on the ground surface where two pipe wrenches can be manipulated to tighten couplings. Extend the plastic sleeve back to the top of the pipe and secure with reusable clamp.

8. Position jack hammer and driving tool on the extension nipple and coupling and continue driving and recording penetration times as above.

9. Repeat the process of attaching 5-ft sections of pipe and driving until the desired depth is attained, refusal is encountered, or pipe/coupling collapse is observed. Refusal is defined as no observable penetration progress in 5 minutes of jack hammer operation on the pipe. Pipe/coupling collapse is indicated when the measured depth of pipe in the ground is more than one foot less than the cumulative length of pipe driven into the ground. The data recorder should measure and record the fractional progress of the penetration, in inches, from the last foot driven into the ground. Also record the height of pipe extending above the ground surface and the depth of pipe from the bottom of the hole to the top of pipe.

10. After terminating driving at a particular penetration point, survey plastic, the ground surface, the extension nipple, and the coupling for contamination. If uncontaminated, discard plastic sheeting and sleeve as ordinary solid waste. In the unlikely event that either the driving tool or plastic exhibit contamination, discard as radioactive solid waste.

11. Label the ground surface with the penetration hole number, as logged in the field notebook, using spray paint. Unscrew any pipe section protruding above ground which might pose a safety hazard to anyone walking in the area. Alternately, if the pipe section cannot be removed, add another 2-ft section to it and flag with brightly colored tape or plastic. Tape end of pipe or cap to prevent entry of precipitation.

12. Data should be transferred to a spreadsheet database file (e.g., lotus or excel) where plots of cumulative penetration, in feet, versus penetration rate, in feet/sec, can be plotted for graphical interpretation of penetration data.

D. Driving 1-inch diameter Geoprobe rod or ground water sampler

1. The penetration point should be prepared following the steps described in sections VII.A.1 and 2. The 33-inch high work platform should also be used to accommodate driving the shorter 3-ft long rod sections.

2. Place inside the plastic sleeve a 3-ft section of 1-inch Geoprobe rod, fitted on the bottom with a threaded penetrometer point or ground water sampler and coupled on top with a 1-ft long Geoprobe rod with a drive cap on top, which is used for direct insertion into the electric jack hammer. The first rod section can be pushed into the ground surface so that it will stand erect. Secure the top of the plastic sleeve to the top of the rod using a reusable plastic clamp. The 3-ft rod section should be marked at 1-ft intervals using bright yellow spray paint; such marking will allow timing of penetration to be determined.

3. Position the electric jack hammer over the top of the rod train. With the 6-inch insertion depth into the jack hammer head, there is virtually no possibility of the jack hammer falling off the rod during driving.

4. A second person, the data recorder, should prepare the field log book for recording the penetration rate information. Every foot of penetration should be timed with a stop watch and recorded. Because it is not desirable to stop the jack hammer after every foot of penetration, the data recorder should note cumulative times at which each of the first two markings on a rod section penetrate the ground level. Driving of the 3-ft rod should be stopped when approximately 3 inches (0.25 ft) of the rod is still protruding above the ground surface; leaving this short extension above ground facilitates coupling and wrench-tightening the next rod section without removing the plastic containment sleeve.

5. After completing the driving of the initial 3-ft section of rod or the ground water sampler, remove the jack hammer from the 1-ft rod extension and secure safely on the ground or work platform. Survey the plastic and ground surface for any increase over the starting background counting rate; it is extremely unlikely that any increase will occur as no soil, cuttings, or tools are withdrawn from the penetration hole.

6. Push down the plastic sleeve so that the 1-ft rod extension can be unscrewed from the rod train with two pipe wrenches if necessary. Measure the depth of rod from the bottom to the top of rod

using the small-diameter (3/8-inch) nickel-plated brass probe electric water level indicator; the measuring point of this small-diameter water level meter is actually at the end of the probe and, thus, correction for the difference between measuring point and the end of probe is not necessary as in the case of the 1/2-inch water level used for larger diameter pipe. This depth or length of open rod should be approximately 3 feet unless the rod has collapsed; for the ground water sampler assembly, the open interval should be 1 ft. Record the exact measured depth and note the sound of water level probe as it contacts the bottom of the rod train; a hard metal-to-metal sound is indicative of an undisturbed rod and drive point. As the water level probe is removed from the rod, survey with the G-M meter to determine if any contamination has been acquired.

7. Place another 3-ft section of rod on the previous 3-ft section and attach the 1-ft rod extension for additional driving. Extend the plastic sleeve back to the top of the rod and secure with reusable clamp.

8. Position jack hammer over the rod extension and continue driving and recording penetration times as above.

9. Repeat the process of attaching 3-ft sections of rod and driving until the desired depth is attained, refusal is encountered, or pipe/coupling collapse is observed. Refusal is defined as no observable rod penetration progress in 5 minutes of jack hammer operation on the rod train. Rod or ground water sampler collapse is indicated when the measured depth of open rod in the ground is more than one foot less than the cumulative length of rod driven. The data recorder should measure and record the fractional progress of the penetration, in inches, from the last foot marker driven into the ground. Also record the height of rod extending above the ground surface and the depth of rod from the bottom of the train to the top of rod.

10. Using the water level meter with the 0.375-inch diameter probe, record any depth to water present in the rod train or ground water sampler assembly. The small diameter probe is necessary to fit into the nominal 0.5-inch inside diameter of Geoprobe rod. Record also the date and time of this initial observation of water level elevation in the ground water sampler; this water level measurement procedure is similar to Method ESP-302-1 in Reference C which is herein incorporated by reference. When removing a ground water elevation probe from any pipe, rod, or well, the rubber-glove-wearing operator should draw the probe into a water-adsorbing material such as a paper or cotton towel. Survey the probe and sections of any submerged measurement tape with the G-M survey meter to verify the presence of any contamination. If contaminated, attempt to decontaminate the probe by wiping with dampened paper towels. Discard decontamination materials as radioactive solid waste. If probe remains contaminated, use another probe/meter for next water level measurement; bag and tag contaminated portion of water level probe and/or measuring tape. Record contamination information, including the survey meter readings, in the field log book.

11. After terminating driving at a particular penetration point, survey plastic and ground surface and the rod extension for contamination. If uncontaminated, discard plastic sheeting and sleeve as ordinary solid waste. In the unlikely event that either the rod extension or plastic exhibits contamination, discard as radioactive solid waste.

12. Label the ground surface with the penetration hole number, as logged in the field notebook, using spray paint. Unscrew any rod section protruding above ground which might pose a safety hazard to anyone walking in the area. Alternately, if the rod section cannot be removed, add another section to the train and flag with brightly colored tape or plastic.

13. Data should be transferred to a spreadsheet database file (e.g., lotus or excel) where plots of cumulative penetration, in feet, versus penetration rate, in feet/sec, can be plotted for graphical interpretation of penetration data.

E. Logging beta/gamma activities in pipes and/or drill rods

1. Connect power to the scaler and determine if LED-display of cumulative counts is working. Connect a G-M probe to the scaler using a length of high-voltage coaxial cable of sufficient length (i.e., 35 ft) to reach the bottom of the desired pipe or rod. To facilitate logging, the coaxial cable should be labelled with colored tape at 1-ft intervals starting at the end of the G-M probe.

2. Set high voltage to the probe at 550 or 600 volts using the screwdriver-operated potentiopot on the scaler. Set the timer thumb wheel to 1 minute counting time and select the timer operation mode. Record instrument configuration, including high voltage setting, G-M probe model and serial number, and scaler model and serial number.

3. Perform a 1-minute background counting check for the assembled scaler-G-M probe while it is positioned in a 1-ft section of pipe or rod; previously, the ground surface activity can be checked with the much more sensitive ORNL G-M survey meter. If the background counting rate is >30 counts/min (cpm), check for contamination in vicinity of the probe and test security of cable connections. If no cpm are detected during the background check, the instrument is malfunctioning. Proceed with diagnosis of the problem using the scaler operations manual.

4. Perform a 1-minute counting check using the designated sealed 1 microcurie standard of ^{137}Cs contained in an unbreakable 20-mL plastic scintillation vial. The end of the G-M probe must contact the bottom of the standard vial completely to maintain the standard source check geometry. The counting rate with the 0-200mR/hr range (Model 133-2) G-M probe should be at least 5 times the observed background counting rate. If the observed standard counting rate is lower, check for appropriate source-probe contact or instrument malfunction. If the standard source check is not within this specification, replace G-M probe and/or scaler until performance is verified.

5. Measure the depth of pipe or rod to be logged, from the top of casing to the bottom of the hole, using the water level meter. Measure also the depth to water in the hole. Do not attempt to measure in situ counting rates below the observed water level because the connections on the high-voltage coaxial cable are not water-tight and the scaler will go into continuous discharge.

6. Lower G-M probe to either the observed water level in the hole or the bottom of the hole, if dry. Mark the hoisting/high-voltage cable with a small piece of yellow tape. Press the count initiation button and record the counts in the 1-minute counting interval. Intervals of greater than 1 minute can be selected and must be noted clearly in the field log book. If any uncertainty in the performance of the instrument during any count is suspected or rapid counting rates may have resulted in cumulative counts greater than the scaler capacity of 999,999, then repeat the 1 minute count and record the duplicate observation.

7. Raise the probe a predetermined height, usually 1 foot, up from the initial probe depth using the 1-ft interval markings on the coaxial cable. If the initial probe depth is not an exact multiple of 1-ft, raise the probe to the nearest 1-ft interval for the next logging position in the hole. Should the cable slip into the hole during counting, the proper elevation can be repeated by pulling the cable back to the labelled tape mark. Count the probe's activity for another 1-minute counting interval by pressing

the reset button on the scaler.

8. Continue raising the probe at 1-ft intervals and recounting activities while recording the depths and counts in the field log book until the entire hole is completed. If additional depth resolution is desired within a section of pipe, logging intervals shorter than 1-ft can be employed.

9. Perform background and standard source check counts immediately after removing the probe from the hole. Record these in the field log book. Also record the length of pipe projecting above the ground surface which is needed to calculate the actual depth of logging beneath the ground surface. If either of these counting rates are more than 20% different than their counting rates before insertion into the hole, detector performance may have changed during logging. Check for contamination on the probe using the G-M survey meter and decontaminate if necessary. Hole logging will need to be repeated with another probe and/or scaler if post-hole performance logging checks fall outside the 20% tolerance range.

10. If total counts at any depth interval are greater than 200,000 using the most sensitive G-M probe (Model 133-2, 0-200mR/hr linear range), then repeat logging of the hole using the next most sensitive probe (Model 133-4, 0-2R/hr linear range) to keep the range of activity determinations within the linear range of the G-M detector.

11. Transfer all logging information into a spreadsheet data file (e.g., lotus or excel) and record when, by whom, and where (filename and location) the data were entered.

F. Logging activity of ^{137}Cs in pipes and/or drill rods

1. Connect power to the multichannel analyzer (TN-1705) and determine if CRT display is working. Connect the NaI scintillation detector signal output to the multichannel analyzer using a length of high-voltage coaxial cable of sufficient length (i.e., 35 ft) to reach the bottom of the desired pipe or rod. Also connect a source of variable high voltage (e.g., the Ludlum Model 1000 scaler) to the detector high voltage input using a coaxial cable of length equal to the signal cable.

2. Set high voltage to the probe at approximately 900 volts using the screwdriver-operated potentiopot on the scaler. Set the timer to 10 minute counting time and select the timer operation mode on the multichannel analyzer.

3. Perform a 10-minute performance counting check for the assembled scintillation detector while it is lying on uncontaminated ground surface with the standard ^{137}Cs source disc centered on the end of the probe; previously, the ground surface activity can be checked with the much more sensitive ORNL G-M survey meter. Identify the photopeak belonging to the 0.66MeV gamma ray of ^{137}Cs and set a window or region-of-interest spanning the photopeak in the gamma ray spectrum. Record the integral number of counts in the 10 minute interval accumulated in this region-of-interest. If no photopeak is detected during the performance check, the instrument is malfunctioning. Proceed with diagnosis of the problem using the multichannel analyzer operations manual (Reference G).

4. Perform a 10-minute background counting check with the detector positioned in a noncontaminated area on the ground surface. If any apparent photopeak in the ^{137}Cs region is observed, search for nearby sources of activity or remove detector to another noncontaminated region and repeat background counting check.

5. Measure the depth of pipe or rod to be logged using the water level meter. Measure also the depth to water in the hole. Do not attempt to measure in situ counting rates below the observed water level because the connections on the high-voltage coaxial cable are not water-tight and the scaler will go into continuous discharge.

6. Lower scintillation probe to either the observed water level in the hole or the bottom of the hole, if dry. Mark the hoisting/high-voltage cable at 1-ft intervals with a small pieces of yellow tape starting from the bottom of the detector. Press the count clear-data button and, then, the acquire button to initiate counting and record the integral counts in the 10-minute counting interval. Note and record dead time indicator reading. If dead time is greater than 50% the pulse height analyzer will yield an erroneous gamma ray spectrum and ^{137}Cs photopeak due to pulse pile up phenomenon; do not use any counting information for dead times greater than 50%. Counting intervals of greater than 10 minutes can be selected and must be noted clearly in the field log book. If any uncertainty in the performance of the instrument during any count is suspected or rapid counting rates may have resulted in cumulative integral counts greater than the capacity of 999,999, then repeat the 10 minute count and record the duplicate observation.

7. Raise the probe to the next 1-ft interval up from the initial probe elevation; if the initial probe elevation is not at a multiple of 1-ft, then raise cable to the next marked 1-ft interval. Should the cable slip into the hole during counting, the proper elevation can be repeated by pulling the cable back to the marked interval. Count the probe's activity for another 10-minute counting interval by pressing the clear data and acquire buttons on the multichannel analyzer.

8. Continue raising the probe at 1-ft intervals and recounting activities while recording the depths and counts in the field log book until the entire hole is completed.

9. Perform background and standard source check counts immediately after removing the probe from the hole. Record these in the field log book. If either of these counting rates are more than 20% different than their counting rates before insertion into the hole, detector performance may have changed during logging. Check for contamination on the probe using the G-M survey meter and decontaminate if necessary. Hole logging will need to be repeated with another probe if post-hole performance logging checks fall outside the 20% tolerance range.

10. Transfer all logging information into a spreadsheet data file (e.g., lotus or excel) and record when, by whom, and where (filename and location) the data was entered.

G. Sampling groundwater from Geoprobe ground water sampler or pipes

1. Prior to sampling groundwater in any well, Geoprobe rod, or driven pipe, measure water level using an electric water level meter following method ESP-302-1 in Reference C.

2. Prepare a length of Geoprobe 3/8-inch O.D. polyethylene tubing sufficient to reach the bottom of the selected sampling point plus approximately 6 ft extra to allow sufficient tubing to reach a sampling container. Thread approximately 1-inch of tubing through a two-hole rubber stopper of a size adequate to seat the opening of selected sampling container. Use a precleaned glass sampling container up to 1-gallon in size depending on the volume of sample needed for analyses (See project procedure ISV-TS-P03). Prepare another 5-ft length of tubing and thread a 1-inch length into the other hole of the two-hole stopper and position the stopper in the sample bottle.

Procedure Number: ISV-TS-P01

Revision Number: Draft

Date: January 20, 1994

Page: 15 of 17

IX. Quality Assurance/Quality Control (QA/QC)

In addition to adhering to the specific requirements of this sampling protocol and any supplementary site specific health and safety measures, the minimum QA/QC requirements for this sampling activity are the following.

A. Control of deviations

When feasible, any departure from specified requirements will be justified and authorized prior to deviation from the requirements and sufficiently documented to allow repetition of the activity as actually performed.

B. QC Samples

The governing treatability study work plan (DOE/OR/01-1158&D2) requires no specific QC samples for any of the perched groundwater samples from pit 1 (section 4.1.5); a copy of the work plan, which has been formally approved by both U.S.EPA, Region IV, and State of Tennessee, Department of Environment and Conservation, is attached. QC samples for the in situ radiation logging data are performed as specified for background and standards in the procedures of sections E and F of ISV-TS-P01. The water analyses are to be performed by the ORNL Analytical Chemistry Division who have responsibility for the QC and QA of the analyses.

C. Verification

Verification activities are required for the above practices including surveillance and periodic record audits. These activities will be documented and become part of the complete project records.

Drawing # 1
Custom AQ Rod Drive Point
Cross Section

Fig. 1. Sketch of custom flush-joint threaded AQ drill rod drive point.

Drawing # 2
AQ Rod Drive Head
Cross Section

Fig. 2. Sketch of custom AQ drill rod drive head.

Procedure Number: ISV-TS-P03

Revision No.: Draft

Date: January 7, 1994

Page : 1 of 8

SUBJECT: LABORATORY CHARACTERIZATION OF TRENCH LEACHATE AND GROUNDWATER SAMPLES

Scope and Application

These procedures provide reference for modified specific methods for laboratory analyses of water for selected chemical and radioisotopic characteristics. The gross chemical characteristics (suspended solids, dissolved solids, electrical conductivity, pH, hardness, and alkalinity) provide an excellent summary of the degree of interaction of the water with soil, rock, or waste as all these characteristics increase as infiltrating precipitation percolates through ground materials. In addition, the dissolved activities of gamma emitters, ^{137}Cs and ^{60}Co , hard-beta emitters, ^{90}Sr (in equilibrium with its progeny, ^{90}Y), and soft-beta emitters, like ^3H , provide characteristics indicative of the degree of interaction with contaminated materials. These radionuclides include all the dominant activities routinely observed in contaminated groundwater samples and waste leachates at ORNL. Unusual characteristics, observed by these procedures, can indicate the need for detailed analyses of metals, anions, or additional specific radionuclides.

Equipment

1. Canberra Series 35 Multichannel Analyzer. Canberra Industries, Inc. Meridan, Connecticut 06450.
2. Packard Model 5320 Auto-Gamma Spectrometer System. Packard Instrument Co., Downers Grove, Illinois 60515.
3. Packard 2000CA TRI-CARB Liquid Scintillation Analyzer. Packard Instrument Co., Downers Grove, Illinois 60515.
4. Hach Digital Titrator. Hach Company, Loveland, Colorado 80537.
5. Corning Model 610A Portable pH Meter. Corning Glass Works, Medfield, MA 02052.
6. YSI Model 35 Conductance Meter, Yellow Springs Instrument Co., Yellow Springs, Ohio 45387.
7. Mettler PK300 Electronic Balance. Mettler Instrument Corp., Highstown, NJ 08520.
8. Scientech Electronic Balance, Scientech Inc., Boulder, Colorado 80303.

Summary of Method

Water samples from field wells are filtered in the laboratory. Filters are weighed to determine the suspended solids in the sample; the filtered solids are assayed via gamma spectroscopy to determine their activity of ^{137}Cs and ^{60}Co . A subsample of the filtered water is dried to determine dissolved solids. Filtered water is also analyzed for pH, electrical conductivity, alkalinity, hardness, and activities of ^{137}Cs , ^{60}Co , ^{90}Sr , and ^3H .

Comments

1. All pipette tips, filter unit housings, filters, sample containers, and scintillation vials must be disposed as solid low-level radioactive waste. These solid wastes must be disposed in the doubly bag-lined compactible-waste 30-gal can in room 295, building 1505. All liquids, including residual samples, diluted samples for procedures, must be disposed as radioactive liquid waste in the large, secondarily-contained polypropylene

carboys in room 295, building 1505. All operators of these procedures must be trained as low-level radioactive waste generators.

2. Transfer of samples from the field (i.e., ORNL seepage pit 1) to room 295, building 1505, must be accompanied by a radiation survey tag (i.e., yellow tag) prepared by the designated area radiation protection officer.

Procedures

A. Sample Filtration (Total suspended solids per modified Method 2540D, Reference 9)

1. Label and record a tare weight of a 115-mL disposable filtering unit (Nalgene Cat No. 130-4045 containing a 0.45 micron filter) for each sample using the Mettler PK300 balance and weighing to the nearest 0.001g. Note calibration sticker expiration date on the balance; if calibration has expired, do not use balance for weighing until calibration has been performed by I&C personnel.
2. Shake up and resuspend the settled solids in the field collection plastic bottle of each sample.
3. Pour enough sample to fill the reservoir of the disposable filtering unit and turn on the vacuum. The sample being filtered will represent the amount of suspended solids in the sample; thus, the filtering unit reservoir (approximately 115 mL) must be filled immediately after shaking up the sample in the larger field container.
4. After all liquid has been transferred through the filter, record the gross weight of the filter unit with its liquid sample.
5. Calculate the weight of sample filtered as the difference between the gross weight and the tare weight.
6. Transfer the filtered liquid to a 4-oz. precleaned plastic bottle with screw top. Label with trench or well number, date taken, and date of filtration.
7. Break off filter unit reservoir (per manufacturer's instructions) and remove filter pad with tweezers and place on a stainless steel tray. Make a map of filter pad locations on the tray (up to 12 per tray) and dry in a still-air oven at 110°C for at least four hours (overnight would be acceptable also).
8. Record weight of dried filter pad and place into a scintillation vial labeled with well/trench number and sample date. Record weight of three unused filter pads, previously dried at 110°C, whose average will be used as a tare weight for subtraction from the dried sample filter weights.
9. Store the filtered solutions in refrigerator (<5°C but >0°C) until further analyses.

B. Planchet Preparation (total dissolved solids via modified method 2540C, reference 9)

1. Label the back of a ringed stainless steel planchet (Model 129-019 Atomic Products Corp., Shirley, New York) with well/trench number and sampling date for each sample. Record the tare weight of each planchet using the Scientech balance to the nearest 0.0001g.
2. Using a 5-mL disposable tip pipette (Pipetman Model P-5000D, Rainin Instrument Company, Brighton, MA 02135), place a 5-mL aliquot of the filtered sample on the first planchet. Distribute the sample by wetting

Procedure Number: ISV-TS-P03

Revision No.: Draft

Date: January 7, 1994

Page : 3 of 8

it with a few drops of ethanol. Dry down the sample under the heat lamps, cool, and record gross weight. Calculate the difference between gross and tare weights.

3. After aging each sample for two weeks, these planchets can be counted for gross alpha and beta activities. However, such determinations are not within the present definitions of this procedure.

C. Electrical Conductivity (conductivity via modified method 2510, reference 9)

1. Prepare a fresh distilled water rinse solution for the electrical conductivity probe. Dunk the electrode several times in the rinse before making a sample measurement. This assures the previous samples do not affect the measured conductivity and also prevents any cross-contamination between samples. Also use a squeeze bottle of distilled water to spray off the electrode after pulling from the rinse water.

2. Measure the electrical conductivity of each filtered solution and record the reading and the range setting.

3. Perform meter performance check via manufacturer's operation manual.

D. pH (starting acidity via modified method 2310B, reference 9)

1. Calibrate the pH meter per the manufacturer's instructions for the meter (see reference 5 for complete procedures). Use reference buffer solutions of pH 4.0 and 7.0. If sample pH is above 7.0, use buffer solutions of 7.0 and 10.0 per manufacturer's operating procedure.

2. Profusely rinse the electrode with a squeeze bottle of distilled water between sample or buffer solution insertions.

3. After placing electrode into filtered sample in its plastic bottle, allow about 30 seconds for the reading to stabilize and record pH to the nearest 0.1 units.

E. Hardness (hardness via modified method 2340, reference 9)

1. Place approximately 90 mL of distilled water into an 125-mL Erlenmeyer flask.

2. Add 5.00 mL of sample using a disposable tip pipette.

3. Add 2 mL of hardness titration buffer with an automatic burette dispenser.

4. Add 10 drops of Eriochrome Black indicator solution.

5. Reset digital titrator to zero and insert a 0.0800M EDTA cartridge. Force enough solution through the right-angle delivery tube to clear any entrapped air. Check for zero reset on the titrator.

6. Initiate the magnetic stirrer and titrate slowly until the color transition from red to blue (no purple). Record number of digits required.

7. Record number of digits for a blank (using 5 mL of distilled water instead of 5 mL of sample).

8. Rinse flask and its magnetic stirrer with distilled water and repeat for next sample.

Procedure Number: ISV-TS-P03

Revision No.: Draft

Date: January 7, 1994

Page : 4 of 8

9. Compute hardness (mg CaCO_3/L) by multiplying net digits (sample-blank) by 2.

F. Alkalinity-Color Indicator Method (alkalinity via modified method 2320, reference 9)

1. Add 10 mL of sample to approximately 90 mL of distilled water in an Erlenmeyer flask containing a magnetic stirrer.
2. Add 10 drops of bromcresol green/methyl red indicator solution.
3. Place a 0.16M sulfuric acid cartridge in the digital titrator, attach the right-angle delivery arm, and clear any entrapped air. Reset the titrator to zero.
4. Titrate until the blue to pinkish gray endpoint and record the number of digits on the titrator. Run blanks (100 mL of distilled water) beforehand to provide a color reference for the endpoint. Compare the samples to the blank(s). Record digits for the blank(s).
5. Rinse flask and magnetic stirrer with distilled water and repeat titration for next sample.
6. Compute alkalinity (mg CaCO_3/L) from the difference between sample and average blank digits.

G. Alkalinity-pH Meter method (alkalinity via modified method 2320, reference 9)

1. Add 10mL of sample to approximately 90 mL of distilled water in an Erlenmeyer flask containing a magnetic stirrer.
2. Place the pH electrode into the flask and initiate stirring making sure that the magnetic stirrer does not contact the electrode. [Previously, calibrate the pHmeter with pH buffers of 4.0 and 7.0 and periodically recheck meter calibration with the pH 7.0 buffer.]
3. Record the initial pH.
4. Insert the right-angle delivery arm of the digital titrator containing a 0.16M sulfuric acid cartridge. Previously, clear the arm and cartridge of any entrapped air or wash water.
5. Reset the titrator to zero digits and continue to add sulfuric acid until the pH equals 4.5.
6. Record digits of the sample.
7. Run at least 2 blanks (100 mL of distilled water) and record number of digits to get to pH 4.5.
8. Rinse flask and magnetic stirrer with distilled water and repeat titration of next sample.
9. Compute alkalinity (mg CaCO_3/L) from the difference between sample and average blank digits.

H. Preparation of Sample for Tritium Counting

1. Label a 20-mL plastic scintillation vial with the sample location (well or trench number), sampling date, and the tritium symbol (^3H). Place this label in the top centimeter of the vial so that the color shielding, provided by the black ink label, does not interfere with the detection of light emitted from vial by the liquid

Procedure Number: ISV-TS-P03

Revision No.: Draft

Date: January 7, 1994

Page : 5 of 8

scintillation spectrometer.

2. Using a disposable-tip pipette (Pipetman Model P-5000D, Rainin Instrument Company, Brighton, MA 02135), add 2.00 mL of filtered water sample to the vial.
3. Using an automatic pipette bottle dispenser, add 18 mL of Ecolume (ICN Radiochemicals) scintillation cocktail to the sample. Cap the vial and shake several times to mix contents.
4. Store vials in rack until counting is completed.

I. Preparation of Sample for Gamma Scanning

1. Label a 20-mL plastic scintillation vial with the sample location (well or trench number), sampling date, and the word, "gamma". Place this label in the top centimeter of the vial so that the color shielding, provided by the black ink label, does not interfere with the detection of light emitted from vial by the liquid scintillation spectrometer when assayed for Cerenkov radiation in section J.
2. Using a disposable-tip pipette, add four 5.00-mL volumes of filtered water sample to the vial (for a total of 20 mL per vial).
3. Cap the vial and store at least two weeks before performing a gamma scan count or Cerenkov radiation analysis.

J. Gamma Spectroscopy for Determination of ^{137}Cs and ^{60}Co Activities and for Estimation of ^{90}Sr Activity

1. Using a Packard Auto-Gamma sample changer controlled by a Canberra Multichannel Analyzer, set up three regions-of-interest per manufacturer's directions. Two regions-of-interest should span the photopeaks for ^{137}Cs and ^{60}Co gamma rays at 0.67 MeV and 1.17/1.33 MeV. Set up a third region-of-interest below the lower limit of ^{137}Cs photopeak down to the lower limit of the gamma/x-ray spectrum. Use radioisotopic standards prepared in 20 mL of water from certified solutions as documented in data set c:\123\radstan.wk1 or D:\excel\radstan.xls. Copies of the certificates of analyses of these standards are kept in reference files in room 292, Building 1505, Oak Ridge National Laboratory. Records of dilutions and handling of these certified standards are kept in the project notebooks of B. P. Spalding. Additional standards of ^{90}Sr in water should also be measured along with background samples of uncontaminated water.
2. Test the functioning of the sample changer and brief region-of-interest output to the serial printer. A brief region-of-interest prints out the sample number, date, time, counting interval (clock and live time), the upper and lower channel numbers of each region-of-interest, the integral and area counts in each region-of-interest. Select 30 second counting intervals for a programmed number of samples (cycles) to include at least one standard of each isotope and one blank. Observe the accumulation of counts in each region-of-interest for each radioisotopic standard to ascertain that the regions-of-interest have been set up correctly to bracket each photopeak. Check the printout of each standard or blank to establish the correct printout format and printer functions.
3. Select the counting interval for each sample in the group of samples and standards to be assayed; usually 30 minute counting intervals yield detection limits well below maximum permissible concentrations (activities) for drinking water and, thus, are adequate for routine measurements. Select the number of samples (cycles) to be counted and activate the sample changer and multichannel analyzer controller per manufacturer's operation manuals. Position blanks and standards at regular intervals (e.g., every fifth position in the sample

changer belt) so that the sequence of sample printouts can be checked against the order of samples; occasionally, the sampler changer can skip samples or fail to drop a sample into the counting well during unattended operations. With blanks and/or standards at regular intervals, only a small subset of samples, rather than an entire suite of up to 300 samples, may require recounting to determine which one in a group of five had been skipped. Setting the number of cycles for two or three times the number of samples should give multiple counts per sample by repeating counting operations on the sequence of vials two or three times, respectively.

4. Before unloading samples from the sample changer, manually record on the printout the sample identity corresponding to each sample. Sample identity information includes whatever is written on the scintillation vial. After it has been verified that a printout has been obtained for each sample/standard/blank, samples can be removed from the changer. If printouts for some samples are missing, repeat the counting operations for those subsets which cannot be identified.

5. Record each sample's integral and area counts for each of the three regions-of-interest from the printout to a spreadsheet data set file (either Excel or Lotus 1-2-3) along with the printout data for each standard and blank. Using the area counts in the ^{137}Cs and ^{60}Co photopeak regions-of-interest for standards of these two isotopes and the computed activities of these standards, calculate the counting efficiency for each radioisotope; typical counting efficiencies should range between 8 and 14% [i.e., (counts per minute x 100)/disintegrations per minute]. Also compute "crosstalk" factors for both the ^{137}Cs and ^{60}Co standards to the lowest region-of-interest integral; these factors are the ratio of counts per minute in the integral to the disintegrations per minute in the standard. Compute the counting efficiency of ^{90}Sr in the lowest region-of-interest from the net integral counting rate divided by the activity in the standard; net integral counting rate is the counts per minute in the ^{90}Sr region-of-interest minus the counting rate in this region-of-interest for a water blank. The counts from ^{90}Sr (with the ^{90}Y daughter in equilibrium) in this low energy region-of-interest are due to bremsstrahlung and not specific x- or gamma-ray emissions; there is no photopeak for ^{90}Sr bremsstrahlung but only an exponentially decreasing spectrum of x-rays with increasing energy or channel number.

6. Compute the activities of both ^{137}Cs and ^{60}Co in the samples from the samples area counting rate (area count divided by the counting interval) divided by the counting efficiency of the standards. The activity concentration of each isotope can then be computed by dividing the total activity by the volume (i.e., 20 mL) of sample in the scintillation vial. Area counts are computed automatically by the multichannel analyzer by computing an average baseline counts per channel, for four channels on both sides of the photopeak region-of-interest, multiplied by the number of channels in the region-of-interest and subtracting this product from the integral counts. Thus, the area counts are background corrected. Thus, in theory, a sample with no ^{137}Cs or ^{60}Co , would exhibit an area count number of zero although the integral count could be substantially above the blank counts due to other radioactivities in the sample.

7. Computing or estimating the activity of ^{90}Sr in a sample involves calculating the amount of bremsstrahlung in the sample which cannot be ascribed to other beta emissions, like those of both ^{137}Cs and ^{60}Co which emit beta particles in addition to gamma-rays, or x-rays due to Compton or photoelectric effects, or ambient x-ray backgrounds. This estimation of ^{90}Sr is performed by subtracting these other sources of x-rays in the ^{90}Sr bremsstrahlung region-of-interest. The contributions of both ^{137}Cs and ^{60}Co are computed from a sample's measured activities of these radioisotopes (see previous step) multiplied by the "crosstalk" factors computed using the radioisotopic standards; the sum of these two computations yield the integral counts in the ^{90}Sr region-of-interest due to these isotopes and are subtracted from a sample's integral for this region-of-interest. In addition, background integral counts are subtracted using the integral counts for water blanks. The net integral counting rate for a sample is computed and, thus, the activity of ^{90}Sr by dividing it by the counting efficiency for the ^{90}Sr standard. Due to the inherently low counting efficiency for ^{90}Sr for bremsstrahlung from

water and the correction for other x-ray sources often resulting in a small difference between large numbers, calculated activities can often be negative and this technique can, thus, only be used for estimation. In addition, any other hard beta-emitter in the sample, other than ^{137}Cs or ^{60}Co , may be included in ^{90}Sr by this bremsstrahlung method.

K. Activity of ^{90}Sr via Measurement of Cerenkov Radiation

The activity of ^{90}Sr is accurately determined from the emission of Cerenkov radiation from these same samples. Cerenkov radiation is measured using a liquid scintillation counter (e.g., Packard Model 2000CA TRI-CARB) from the same unamended water samples used for measuring gamma activities above. A window of interest is set up on the liquid scintillation spectrometer between 2.5 and 40.0 keV. Counting efficiencies for ^{90}Sr typically range about 50% while efficiencies for both ^{137}Cs and ^{60}Co are typically less than 1%. Standards for each radioisotope are counted via these techniques to compute these counting efficiencies for each suite of samples and water blanks are run concurrently to determine background counting rates. From the measured activities of ^{137}Cs and ^{60}Co in each sample, determined by gamma-ray spectroscopy, and the Cerenkov counting efficiencies in the window of interest, corrections for contributions to the Cerenkov counts by these isotopes can be made; in most cases, such corrections prove very marginal. It is imperative to allow at least two weeks (full 14 days) to elapse between placing sample water in the vial and counting for Cerenkov emissions; most of the Cerenkov radiation is produced by the ^{90}Y daughter of ^{90}Sr and this time is needed to allow sequential equilibrium of the daughter to be established. If iron floc and its associated discoloration form in a sample, these can be eliminated by additions of 10 drops of 85% phosphoric acid to a sample vial; suspended solids and/or coloration will otherwise result in self-absorption of Cerenkov emissions and erroneously low sample activities.

L. Estimation of Tritium via Direct Liquid Scintillation Counting

The activity of tritium in a sample can be estimated from the counting rate of the samples prepared in Ecolume liquid scintillation. However, contributions to the measured liquid scintillation counts from beta emissions due to ^{90}Sr , ^{137}Cs , and ^{60}Co must be made. Counting efficiencies for each of these isotopes and for tritium are determined for Ecolume liquid scintillation cocktail formulated standards (i.e., 2 mL of standard solution or dilution plus 18 mL of Ecolume cocktail). From the measured activities of ^{90}Sr , ^{137}Cs , and ^{60}Co in the water samples and the liquid scintillation counting efficiencies of the standards, counts in the low-energy window, where tritium counts would also appear, can be calculated and subtracted from the gross counts of the sample. After additionally subtracting background or blank counting rates in the window, the net "tritium" counting rates are calculated and, when divided by the tritium counting efficiency, yield apparent tritium activity in the sample. This technique must be regraded as an estimation method because beta-emitters other than ^{90}Sr , ^{137}Cs , and ^{60}Co may contribute to the net counting rate and be included in the apparent tritium activity. In addition, alpha-emitters, if present, would also contribute to the apparent tritium activity. However, the value of the method lies in its lack of false negatives, i.e., if tritium is present in the sample, it will be detected.

M. Gamma Activity in Suspended Solids

Assay the dried filters in plastic scintillation vials for gamma activities of ^{137}Cs and ^{60}Co and estimation of ^{90}Sr via bremsstrahlung as in section J. Express activities on a per unit weight (g) of dried solids

References

1. Canberra Series 35 Multichannel Analyzer Operator's Manual. 1978. Canberra Industries, Inc. Meridan,

Procedure Number: ISV-TS-P03

Revision No.: Draft

Date: January 7, 1994

Page : 8 of 8

Connecticut 06450.

2. Packard Model 5320 Auto-Gamma Spectrometer System Operation Manual. 1975. Packard Instrument Co., Downers Grove, Illinois 60515.

3. Packard 2000CA TRI-CARB Liquid Scintillation Analyzer Operations Manual. 1985. Packard Instrument Co., Downers Grove, Illinois 60515.

4. Hach Digital Titrator Methods Manual. 1981. Hach Company, Loveland, Colorado 80537.

5. Corning Model 610A Portable pH Meter Instruction Manual. 1979. Corning Glass Works, Medfield, MA 02052.

6. YSI Model 35 Conductance Meter Instruction Manual. 1987. Yellow Springs Instrument Co., Yellow Springs, Ohio 45387.

7. Mettler PK300 Electronic Balance Operating Instructions. 1983. Mettler Instrument Corp., Highstown, NJ 08520.

8. Scientech Electronic Balance Setup and Operating Instructions. 1990. Scientech Inc., Boulder, Colorado 80303.

9. Standard Methods for the Examination of Water and Wastewater. 1992. 18th Edition, American Public Health Association, Washington, DC 20005.

Procedure Number: ISV-TS-P04

Revision No.: Draft

Date: January 10, 1994

Page : 1 of 6

SUBJECT: LABORATORY PROCESSING AND CHARACTERIZATION OF RADIOACTIVELY CONTAMINATED SOIL AND SEEPAGE PIT/TRENCH SLUDGE

Scope and Application

These procedures provide reference for modified specific methods for laboratory analyses of soil or other noncohesive solids for selected physical, chemical, and radioisotopic characteristics. The gross physical characteristics (color, structure, bulk density, moisture) provide an excellent summary of the physical characteristics which will affect in situ vitrification (ISV) processing. Chemical composition information provides additional characteristics which will affect the ISV operating temperatures, cooling and crystallization of ISV product, and volatility of elements and radioisotopes during ISV. In addition, assay of gamma emitters, ^{137}Cs and ^{60}Co , and hard-beta emitters, ^{90}Sr (in equilibrium with its progeny, ^{90}Y), provide information on the quantities of radionuclides to be processed by ISV as well as information on their three-dimensional distribution in and around pit 1.

Equipment

1. Canberra Series 35 Multichannel Analyzer. Canberra Industries, Inc. Meridan, Connecticut 06450.
2. Packard Model 5320 Auto-Gamma Spectrometer System. Packard Instrument Co., Downers Grove, Illinois 60515.
3. Packard 2000CA TRI-CARB Liquid Scintillation Analyzer. Packard Instrument Co., Downers Grove, Illinois 60515.
4. Mettler PK300 Electronic Balance. Mettler Instrument Corp., Highstown, NJ 08520.
5. Scientech Electronic Balance, Scientech Inc., Boulder, Colorado 80303.

Summary of Method

Soil samples from field sampling points are subdivided, dimensionally measured, weighed, dried, and weighed again in the laboratory. The dried weight, bulk density, and moisture content of each segment is determined. Color and structure information is also recorded for stratigraphic correlations among the sample locations. All undisturbed segments of soil core, after drying but before additional processing, are assayed via gamma spectroscopy to determine their activity of ^{137}Cs and ^{60}Co . The activity of ^{90}Sr is also estimated from the bremsstrahlung region of the gamma-ray spectrum. Following these radioactivity assays, selected representative samples are crushed, homogenized, and sieved to <2 mm to provide material for further chemical and radiochemical analyses. Selected samples are subjected to lithium borate fusion and dissolution in acid for elemental analyses via inductively-coupled plasma emission spectroscopy. The dissolved samples are also analyzed for gamma activities, ^{90}Sr via Cerenkov radiation emission, and for specific U and transuranium isotopes via alpha spectroscopy. The dissolved samples are also analyzed for inorganic anions which may affect volatility of radioisotopes during ISV processing. Such samples are also analyzed for organic matter content via thermal oxidative weight loss.

Comments

1. All sample containers and excess or residual samples must be disposed as solid low-level radioactive waste. These solid wastes must be disposed in the doubly bag-lined compactible-waste 30-gal can in room 295,

building 1505. All liquids, including residual sample digests, diluted samples for procedures, must be disposed as radioactive liquid waste in the large, secondarily-contained polypropylene carboys in room 295, building 1505. All operators of these procedures must be trained as low-level radioactive waste generators.

2. Transfer of samples from the field (i.e., ORNL seepage pit 1) to room 295, building 1505, must be accompanied by a radiation survey tag (i.e., yellow tag) prepared by the designated area radiation protection officer.

Procedures

A. Core Sample Segmentation and Processing for Weight, Bulk Density, and Moisture Measurement

1. Line the hood table top with at least two layers of absorbent paper and lay the 36-inch-long x 1-inch-diameter soil core liner on it. Inspect soil core material in its transparent polyester plastic liner in the laboratory hood in room 295, building 1505. Describe the soil structure and color of the materials (USDA 1962) as they appear in the liner.
2. Mark the core liner at the intended points of segmentation and label each liner segment with the sample point information and sample interval using the depth range from the top of the whole core sample. Use a wooden yard/meter stick with a minimum scale of 1/8-inch. Mark each segment with core number, depth interval, date, and segment number.
3. Cut the core and liner with a sharp knife at the marked segmentation points. Maximum segment length is 3 inches. Position the cut segments in order on the absorbent paper liner. Place a vinyl cap on the bottom of each segment.
4. Within ten minutes of completing the cutting of all core segments of each liner sample, record the fresh weight of the bottom-capped core-liner segment. Measure the length of each liner segment. If segments cannot be weighed within this 10 min interval, cap the top of the segments to prevent loss of moisture. Then, remove caps prior to weighing at a later time.
5. Place suite of segments in forced-air oven between 70 and 80°C for at least 16 hr (overnight) or until constant weight is attained. The oven must not exceed 80°C which is the maximum use temperature for liner plastic!
6. Remove segments from oven, allow to cool to room temperature in a desiccator, and record weight using the Mettler balance as previously. Repeat drying, cooling, and weighing of segments until a constant weight ($\pm 1\%$) is attained.
7. Place three measured 3-inch lengths of unused sample tubing in the oven after recording their ambient weights. Likewise place at least three of the vinyl caps in the oven to determine their weight retention on thermal treatment.
8. Compute the average weight per unit length of the empty oven-dried sampling tubing and the average oven-dried weight of the vinyl caps. Compute the liner plus cap tare weight for each soil segment by multiplying its length by the average weight per unit length.
9. Cover each liner segment with a snap-on vinyl cap to prevent reabsorption of moisture or loss of contents during further storage and processing.

Procedure Number: ISV-TS-P04

Revision No.: Draft

Date: January 10, 1994

Page : 3 of 6

10. Compute the volume of each segment from its measured length and inside diameter of the core liner (0.90 in.) and express in cm^3 . Compute the oven-dried weight of material, in grams, in each segment. Then, compute the bulk density of each segment by dividing the over-dried weight by the sample volume and express in g/cm^3 (reference 5). Compute the moisture content of each segment by the loss of weight after oven-drying divided by the oven-dry weight; express as a percent of oven-dried weight (reference 5). Records should be recorded in a registered project notebook and transcribed to a personal computer file using either Lotus-123 or Excel software.

B. Homogenization and Sieving of Soil Samples

1. The dried contents of each liner segment are homogenized by forcing through a 4-inch diameter sieve with 2-mm openings (Tyler designation 10) in stainless steel wire cloth. Use an agate pestle to facilitate maximum passage of soil sample through the sieve. Sieving must be performed in the laboratory hood using absorbent paper to line the hood floor. Hardened dried soil can be separated from the plastic sample liner by rolling between gloved fingers until all soil aggregates are released from the plastic liner.
2. Place the <2-mm material into a prelabeled and preweighed vial, record weight, and reseal with original cap. Use a clean sheet of waxed paper to police solids from sieve bottom pan into the vial.
3. Any >2-mm material should be weighed, using the Mettler balance, using zero-tared weighing paper. Place residual into a seal-lock plastic bag for storage. Record weight in project notebook.
4. Survey the sieve with a calibrated G-M meter and, if less than 0.5 mR/hr, reuse for the next sample sieving operation. If >0.5 mR/hr, attempt to decontaminate by wiping with a dampened paper towel. If the sieve cannot be decontaminated to <0.5 mR/hr, then employ a new sieve for next sample.

C. Preparation of Homogenized Soil Samples for Gamma Scanning

1. Label a 20-mL plastic scintillation vial with the sample identification (sampling point, depth interval, segment number), sampling date, and the word, "gamma".
2. Weigh out 10.00 g, recording to the nearest 0.001 g, of <2-mm material on weighing paper and quantitatively transfer to the prelabeled scintillation vial.
3. Cap the vial and store.

D. Gamma Spectroscopy for Determination of ^{137}Cs and ^{60}Co Activities and for Estimation of ^{90}Sr Activity

1. Using a Packard Auto-Gamma sample changer controlled by a Canberra Multichannel Analyzer, set up three regions-of-interest per manufacturer's directions. Two regions-of-interest should span the photopeaks for ^{137}Cs and ^{60}Co gamma rays at 0.66 MeV and 1.17/1.33 MeV. Set up a third region-of-interest below the lower limit of ^{137}Cs photopeak down to the lower limit of the gamma/x-ray spectrum. Use radioisotopic standards prepared in 10 g of soil from certified solutions as documented in data set c:\123\radstan.wk1 or D:\excel\radstan.xls. Copies of the certificates of analyses of these standards are kept in reference file "Radioactive Standards" in room 292, Building 1505, Oak Ridge National Laboratory. Records of dilutions and handling of these certified standards are kept in the project notebooks of B. P. Spalding. Additional standards of ^{90}Sr in soil should also be measured along with background samples of uncontaminated soil.
2. Test the functioning of the sample changer and brief region-of-interest output to the serial printer. A brief

region-of-interest prints out the sample number, date, time, counting interval (clock and live time), the upper and lower channel numbers of each region-of-interest, and the integral and area counts in each region-of-interest. Select 30 second counting intervals for a programmed number of samples (cycles) to include at least one standard of each isotope and one blank. Observe the accumulation of counts in each region-of-interest for each radioisotopic standard to ascertain that the limits of the regions-of-interest have been set up correctly to bracket each photopeak. Check the printout of each standard or blank to establish the correct printout format and printer functions.

3. Select the counting interval for each sample in the group of samples and standards to be assayed; usually 30 minute counting intervals yield adequate detection limits and, thus, are adequate for routine measurements. Select the number of samples (cycles) to be counted and activate the sample changer and multichannel analyzer controller per manufacturer's operation manuals. Position blanks and standards at regular intervals (e.g., every fifth position in the sample changer belt) so that the sequence of sample printouts can be checked against the order of samples; occasionally, the sampler changer can skip samples or fail to drop a sample into the counting well during unattended operations. With blanks and/or standards at regular intervals, only a small subset of samples, rather than an entire suite of up to 300 samples, may require recounting to determine which one in a group of five had been skipped. Setting the number of cycles for two or three times the number of samples should give multiple counts per sample by repeating counting operations on the sequence of vials two or three times, respectively.

4. Before unloading samples from the sample changer, manually record on the instrument printout the identity of each sample corresponding to each printout. Sample identity information includes whatever is written on the scintillation vial. After it has been verified that a printout has been obtained for each sample/standard/blank, samples can be removed from the changer. If printouts for some samples are missing, repeat the counting operations for those subsets which cannot be identified.

5. Record each sample's integral and area counts for each of the three regions-of-interest from the printout to a spreadsheet data set file (either Excel or Lotus 1-2-3) along with the printout data for each standard and blank. Using the area counts in the ^{137}Cs and ^{60}Co photopeak regions-of-interest for standards of these two isotopes and the computed activities of these standards, calculate the counting efficiency for each radioisotope; typical counting efficiencies should range between 8 and 14% [i.e., (counts per minute x 100)/disintegrations per minute]. Also compute "crosstalk" factors for both the ^{137}Cs and ^{60}Co standards to the lowest-energy region-of-interest integral; these factors are the ratio of counts per minute in the integral to the disintegrations per minute in the standard. Compute the counting efficiency of ^{90}Sr in the lowest region-of-interest from the net integral counting rate divided by the activity in the standard; net integral counting rate is the counts per minute in the ^{90}Sr region-of-interest minus the counting rate in this region-of-interest for a soil blank. The counts from ^{90}Sr (with the ^{90}Y daughter in equilibrium) standard in this lowest-energy region-of-interest are due to bremsstrahlung and non-specific x- or gamma-ray emissions; there is no photopeak for ^{90}Sr bremsstrahlung but rather an exponentially decreasing spectrum of x-rays with increasing energy or channel number.

6. Compute the activities of both ^{137}Cs and ^{60}Co in the samples from the samples area counting rate (area count divided by the counting interval) divided by the counting efficiency of the standards. The activity concentration of each isotope can then be computed by dividing the total activity by the weight (i.e., 10 g) of sample in the scintillation vial. Area counts are computed automatically by the multichannel analyzer by computing an average baseline counts per channel, for the four channels on both sides of the photopeak region-of-interest, multiplied by the number of channels in the region-of-interest and subtracting this product from the integral counts. Thus, the area counts are background corrected. Therefore, in theory, a sample with no ^{137}Cs or ^{60}Co , would exhibit an area count of zero although the integral count could be substantially above

a blank count due to other radioactivities in the sample.

7. Computing or estimating the activity of ^{90}Sr in a sample involves calculating the amount of bremsstrahlung in the sample which cannot be ascribed to other beta emissions, like those of both ^{137}Cs and ^{60}Co which emit beta particles in addition to gamma-rays, or x-rays due to Compton or photoelectric effects, or ambient x-ray backgrounds. This estimation of ^{90}Sr is performed by subtracting these other sources of x-rays in the ^{90}Sr bremsstrahlung region-of-interest. The contributions of both ^{137}Cs and ^{60}Co are computed from a sample's measured activities of these radioisotopes (see previous step) multiplied by the "crosstalk" factors computed using the radioisotopic standards; the sum of these two computations yield the integral counts in the ^{90}Sr region-of-interest due to these isotopes and are subtracted from a sample's integral for this region-of-interest. In addition, background integral counts are subtracted using the integral counts for uncontaminated soil (blanks). The net integral counting rate for a sample is computed and, thus, the activity of ^{90}Sr by dividing it by the counting efficiency for the ^{90}Sr standard. Due to the inherently low counting efficiency for ^{90}Sr for bremsstrahlung from soil (e.g. 4%) and the correction for other x-ray sources often resulting in calculating a small difference between large numbers, calculated activities can often be negative and this technique can, thus, only be used for estimation. In addition, any other hard beta-emitters in the sample, other than ^{137}Cs or ^{60}Co , may be included in ^{90}Sr by this bremsstrahlung method.

E. Determination of Organic Matter in Soil Samples

1. Label 20-mL glass scintillation vial with the sample's identification information as written on the homogenized and sieved soil material container.
2. After zeroing the Scientech balance, record the empty weight of each vial to the nearest 0.0001 g. Prepare two extra vials (labeling as Blank 1 and Blank 2) which will be carried through the drying and ashing procedures but will not contain any soil.
3. Add enough of the sieved soil to each vial to fill it approximately half full.
4. After checking that the balance is still zeroed, record the weights of each vial containing soil and the two blanks.
5. Place all vials in still-air oven in our laboratory (set to 105°C) and leave overnight. Cool vials the next morning and reweigh all.
6. Place vials in muffle furnace(s) set to 550°C for overnight ashing. Because the vial labels will burn off during ashing, prepare a furnace layout diagram of the sample vials so that, after the vials are removed from the furnace, they can be relabeled correctly. The vials may need to be divided into batches to be placed into different furnaces in order to complete the whole lot of vials. Record all dates and times of placement and removal from ovens and furnaces.
7. After vials have cooled to room temperature and have been relabeled, reweigh all samples.
8. Record all four weights (vial tare, ambient, oven-dried, and ashed) for each sample and blank in the project notebook.
9. Compute the percent loss in weight of each sample between 105°C and 550°C and report as loss-on-ignition implying combustion of organic matter.

Procedure Number: ISV-TS-P04

Revision No.: Draft

Date: January 10, 1994

Page : 6 of 6

10. To determine if any radioactivity volatilizes during this ashing or organic matter determination, samples can be assayed for ^{137}Cs , ^{60}Co , and ^{90}Sr before and after thermal treatment using the methods in section D (above).

References

1. Canberra Series 35 Multichannel Analyzer Operator's Manual. 1978. Canberra Industries, Inc. Meridan, Connecticut 06450.
2. Packard Model 5320 Auto-Gamma Spectrometer System Operation Manual. 1975. Packard Instrument Co., Downers Grove, Illinois 60515.
3. Packard 2000CA TRI-CARB Liquid Scintillation Analyzer Operations Manual. 1985. Packard Instrument Co., Downers Grove, Illinois 60515.
4. Soil Survey Manual. 1962. USDA (United States Department of Agriculture), Washington. D.C. 20402.
5. Methods of Soil Analysis. 1986. Part 1 Physical and Mineralogical Methods, Second Edition, American Society of Agronomy, Madison, Wisconsin.
6. Standard Practice for Dissolution of Solid Waste by Lithium Metaborate Fusion (D4503-86). 1986. ASTM (American Society for Testing Materials), Philadelphia, Pennsylvania.
7. Mettler PK300 Electronic Balance Operating Instructions. 1983. Mettler Instrument Corp., Highstown, NJ 08520.
8. Scientech Electronic Balance Setup and Operating Instructions. 1990. Scientech Inc., Boulder, Colorado 80303.
9. Standard Methods for the Examination of Water and Wastewater. 1989. American Public Health Association, Washington, DC 20005.

APPENDIX B

Bulk Densities and ^{137}Cs Activities in Pit 1 Soil Cores

PIT 1 by Type

○AQ	(34)
◇Core	(9)
◆Core/AQ	(6)
↑Corner	(4)
*Geoprobe	(3)
▽Pipe	(11)
▲stake	(7)
+Threaded Rod	(53)

PT1XYZBT

Type	Label	X10 East (ft)	X10 North (ft)	Ground Elev. (ft)	DriveDept (ft)	Protrusion (ft)	Insd.Dept (ft)
AQ Rod	24	26864.34	18811.05	826.04	24.5	1.5	25.29
AQ Rod	66	26849.93	18857.14	826.20	25.25	1.854167	27.21
AQ Rod	67	26859.21	18824.60	825.96	26.83	3.125	30.21
AQ Rod	68	26863.86	18804.32	825.95	24.17	1.875	26.21
AQ Rod	69	26840.25	18823.86	825.43	12	2.67	15.21
AQ Rod	70	26846.56	18869.85	826.29	24.58333	2.333333	27.21
AQ Rod	71	26869.70	18859.81	826.48	10.67	4.375	15.19
AQ Rod	72	26863.14	18858.79	826.50	11	0	11.29
AQ Rod	73	26856.95	18856.80	826.40	23.5	1.5	25.21
AQ Rod	74	26839.32	18851.16	825.88	23.8	1.2	25.21
AQ Rod	75	26833.34	18849.78	825.55	13.5	1.4	15.19
AQ Rod	77	26845.72	18853.59	826.09	25.75	0.2	26.21
AQ Rod	78	26841.33	18884.49	826.11	11.4	3.62	15.19
AQ Rod	79	26843.54	18878.97	826.23	16.8	3.33	20.19
AQ Rod	80	26854.65	18841.31	826.12	27.32	2.54	30.19
AQ Rod	81	26877.64	18831.71	826.40	9.916667	0.1	10.19
AQ Rod	82	26871.91	18830.56	826.42	7.083333	2.96	10.19
AQ Rod	83	26846.66	18825.48	825.69	25.65	4.67	30.22
AQ Rod	84	26852.78	18826.72	825.91	26	3.95	30.21
AQ Rod	85	26864.37	18830.43	826.24	22.8	2.3	25.2
AQ Rod	86	26868.56	18789.37	826.00	14.45833	0.541667	15.19
AQ Rod	87	26872.51	18774.57	825.87	9.67	0.3	10.19
AQ Rod	88	26874.75	18769.19	825.66	10.125	-0.125	10.21
AQ Rod	89	26860.11	18771.02	825.43	8.916667	1.041667	10.19
AQ Rod	93	26858.42	18802.69	825.78	23.29167	1.708333	25.19
AQ Rod	94	26870.33	18805.54	826.22	9.5	0.5	10.19
AQ Rod	95	26877.73	18807.21	826.36	10	0	10.19
AQ Rod	96	26852.45	18801.31	825.63	22	2.916667	25.19
AQ Rod	97	26846.54	18798.64	825.43	11	0	11.19
AQ Rod	98	26883.41	18808.92	826.35	7.25	2.541667	10.19
AQ Rod	99	26858.72	18882.71	826.51	11	0	11.19
AQ Rod	100	26833.59	18877.14	825.90	11.83333	3.083333	15.19
AQ Rod	101	26884.09	18777.36	826.13	9.166667	0.833333	10.19
AQ Rod	102	26869.83	18781.68	825.96	8.5	1.541667	10.19
G.Pipe1.25	5	26853.17	18846.26	826.14	26.08333	0.395833	22.29
G.Pipe1.25	7	26857.71	18829.06	825.88	15.25	0.458333	15.97
G.Pipe1.25	15	26865.99	18795.92	825.98	19.25	0.958333	20.04
G.Pipe1.25	21	26852.29	18860.45	826.31	24.5	0.791667	25.12333
G.Pipe1.25	22	26868.21	18794.47	826.02	18.08333	1.854167	19.69
G.Pipe1.25	23	26863.33	18807.86	825.97	24.5	0.458333	18.29
S.S.Pipe1.25	33	26850.80	18853.63	826.16	25.25	0.4375	26.04
S.S.Pipe1.25	35	26844.63	18806.95	825.47	11	4.083333	14.99
S.S.Pipe1.25	36	26839.49	18825.49	825.39	14	1	15.02
S.S.Screen	20	26847.01	18859.13	826.17	10.2	0.5	9.96
S.S.Screen	34	26854.90	18839.78	826.09	6.5	0.6875	5.16
Threaded Rod	1	26878.61	18852.84	826.54	15	0	
Threaded Rod	2	26861.26	18847.69	826.40	30	0	
Threaded Rod	3	26868.78	18850.06	826.41	39	0	
Threaded Rod	4	26845.64	18844.48	826.00	27	0	

PT1XYZBT

Type	Label	Notes	X10 East	X10 North	Bot.Elv.
		N.B. Insid.Depth adds 0.29 ft to measured!	(ft)	(ft)	(ft)
AQ Rod	24	AQslip point on sub with Farrow's rod	26864.34	18811.05	801.54
AQ Rod	66	air-hammer test no progress	26849.93	18857.14	800.95
AQ Rod	67	air-hammer test no progress	26859.21	18824.60	799.13
AQ Rod	68	air-hammer test no progress	26863.86	18804.32	801.78
AQ Rod	69	air-hammer test added 2.5 ft	26840.25	18823.86	813.43
AQ Rod	70	refusal	26846.56	18869.85	801.71
AQ Rod	71		26869.70	18859.81	815.81
AQ Rod	72		26863.14	18858.79	815.50
AQ Rod	73		26856.95	18856.80	802.90
AQ Rod	74		26839.32	18851.16	802.08
AQ Rod	75		26833.34	18849.78	812.05
AQ Rod	77		26845.72	18853.59	800.34
AQ Rod	78		26841.33	18884.49	814.71
AQ Rod	79		26843.54	18878.97	809.43
AQ Rod	80		26854.65	18841.31	798.80
AQ Rod	81		26877.64	18831.71	816.48
AQ Rod	82		26871.91	18830.56	819.34
AQ Rod	83		26846.66	18825.48	800.04
AQ Rod	84		26852.78	18826.72	799.91
AQ Rod	85		26864.37	18830.43	803.44
AQ Rod	86		26868.56	18789.37	811.54
AQ Rod	87		26872.51	18774.57	816.20
AQ Rod	88		26874.75	18769.19	815.54
AQ Rod	89		26860.11	18771.02	816.51
AQ Rod	93		26858.42	18802.69	802.49
AQ Rod	94		26870.33	18805.54	816.72
AQ Rod	95		26877.73	18807.21	816.36
AQ Rod	96		26852.45	18801.31	803.63
AQ Rod	97		26846.54	18798.64	814.43
AQ Rod	98		26883.41	18808.92	819.10
AQ Rod	99		26858.72	18882.71	815.51
AQ Rod	100		26833.59	18877.14	814.07
AQ Rod	101		26884.09	18777.36	816.96
AQ Rod	102		26869.83	18781.68	817.46
G.Pipe1.25	5	60deg cone point, refusal, partial collapse	26853.17	18846.26	800.06
G.Pipe1.25	7	green point, refusal, partial collapse	26857.71	18829.06	810.63
G.Pipe1.25	15	AW slip point, soft bottom, refusal	26865.99	18795.92	806.73
G.Pipe1.25	21	acom nut point, refusal	26852.29	18860.45	801.81
G.Pipe1.25	22	acom nut point, refusal, partial collapse	26868.21	18794.47	807.94
G.Pipe1.25	23	AW drive point, refusal	26863.33	18807.86	801.47
S.S.Pipe1.25	33	pipe cut off	26850.80	18853.63	800.91
S.S.Pipe1.25	35	refusal	26844.63	18806.95	814.47
S.S.Pipe1.25	36	refusal	26839.49	18825.49	811.39
S.S.Screen	20	refusal, collapse near bottom	26847.01	18859.13	815.97
S.S.Screen	34	collapsed at screen-pipe joint	26854.90	18839.78	819.59
Threaded Rod	1	slow	26878.61	18852.84	811.54
Threaded Rod	2	fast	26861.26	18847.69	796.40
Threaded Rod	3	well	26868.78	18850.06	787.41
Threaded Rod	4	well	26845.64	18844.48	799.00

PT1XYZBT

Type	Label	MaxGMR (cpm)	Depth of Max (ft)	Elevation of Max (ft)				
AQ Rod	24	494380	23.07	802.97	26864.34	18811.05	494380	
AQ Rod	66	666027	24.15	802.05	26849.93	18857.14	666027	
AQ Rod	67	914805	25.4	800.56	26859.21	18824.60	914805	
AQ Rod	68	1207161	23.15	802.80	26863.86	18804.32	1207161	
AQ Rod	69	40801	7.25	818.18	26840.25	18823.86	40801	
AQ Rod	70	1392684	22.67	803.62	26846.56	18869.85	1392684	
AQ Rod	71	29	8.62	817.86	26869.70	18859.81	29	
AQ Rod	72	32	7	819.50	26863.14	18858.79	32	
AQ Rod	73	1275794	22.5	803.90	26856.95	18856.80	1275794	
AQ Rod	74	1240269	22.83	803.05	26839.32	18851.16	1240269	
AQ Rod	75	22483	13.33	812.22	26833.34	18849.78	22483	
AQ Rod	77	153437	24.75	801.34	26845.72	18853.59	153437	
AQ Rod	78	76964	10.38	815.73	26841.33	18884.49	76964	
AQ Rod	79	1764	13.7	812.53	26843.54	18878.97	1764	
AQ Rod	80	703209	25.46	800.66	26854.65	18841.31	703209	
AQ Rod	81	31	7.9	818.50	26877.64	18831.71	31	
AQ Rod	82	32	7.04	819.38	26871.91	18830.56	32	
AQ Rod	83	288096	24.33	801.36	26846.66	18825.48	288096	
AQ Rod	84	208244	25.05	800.86	26852.78	18826.72	208244	
AQ Rod	85	50464	16.7	809.54	26864.37	18830.43	50464	
AQ Rod	86	83765	12.46	813.54	26868.56	18789.37	83765	
AQ Rod	87	26	8.7	817.17	26872.51	18774.57	26	
AQ Rod	88	97	7.12	818.54	26874.75	18769.19	97	
AQ Rod	89	28	8.96	816.47	26860.11	18771.02	28	
AQ Rod	93	213829	22.33	803.45	26858.42	18802.69	213829	
AQ Rod	94	30	7.5	818.72	26870.33	18805.54	30	
AQ Rod	95	30	8	818.36	26877.73	18807.21	30	
AQ Rod	96	594923	21.85	803.78	26852.45	18801.31	594923	
AQ Rod	97	9777	8	817.43	26846.54	18798.64	9777	
AQ Rod	98	33	7.46	818.89	26883.41	18808.92	33	
AQ Rod	99	33	11	815.51	26858.72	18882.71	33	
AQ Rod	100	9766	8.92	816.98	26833.59	18877.14	9766	
AQ Rod	101	30	5.17	820.96	26884.09	18777.36	30	
AQ Rod	102	48	6.46	819.50	26869.83	18781.68	48	
G.Pipe1.25	5	76	21.6	804.54	26853.17	18846.26	76	
G.Pipe1.25	7	101	15.22	810.66	26857.71	18829.06	101	
G.Pipe1.25	15	770669	19.23	806.75	26865.99	18795.92	770669	
G.Pipe1.25	21	1344463	24.03	802.28	26852.29	18860.45	1344463	
G.Pipe1.25	22	51342	13.4	812.62	26868.21	18794.47	51342	
G.Pipe1.25	23	37	17.64	808.33	26863.33	18807.86	37	
S.S.Pipe1.25	33	1137272	25.31	800.85	26850.80	18853.63	1137272	
S.S.Pipe1.25	35	1817	6.6	818.87	26844.63	18806.95	1817	
S.S.Pipe1.25	36	70206	13.73	811.66	26839.49	18825.49	70206	
S.S.Screen	20							
S.S.Screen	34							
Threaded Rod	1							
Threaded Rod	2							
Threaded Rod	3							
Threaded Rod	4							

PT1XYZBT

Type	Label	X10 East (ft)	X10 North (ft)	Ground Elev. (ft)	DriveDept (ft)	Protrusion (ft)	Insd.Dept (ft)
Threaded Rod	6	26834.47	18841.81	825.45	30	0	
Threaded Rod	8	26856.41	18828.65	825.94	30	0	
Threaded Rod	9	26861.94	18813.55	825.94	18	0	
Threaded Rod	10	26866.73	18796.09	825.98	18	0	
Threaded Rod	11	26870.56	18781.73	825.96	12	0	
Threaded Rod	12	26873.32	18771.24	825.73	15	0	
Threaded Rod	13	26868.62	18788.36	825.99	16.75	2.25	
Threaded Rod	14	26867.92	18792.20	825.99	39	0	
Threaded Rod	16	26849.53	18859.96	826.19	18	0	
Threaded Rod	17	26846.21	18870.83	826.29	39	0	
Threaded Rod	18	26842.34	18884.61	826.13	21	0	
Threaded Rod	19	26844.34	18878.58	826.26	18.75	2.25	
Threaded Rod	25	26855.89	18763.55	824.86	25	2	
Threaded Rod	26	26850.10	18784.76	825.36	18	0	
Threaded Rod	27	26844.35	18808.02	825.47	15	0	
Threaded Rod	28	26839.84	18824.77	825.40	15	0	
Threaded Rod	29	26830.07	18859.07	825.44	24	0	
Threaded Rod	30	26825.10	18880.17	825.27	18	0	
Threaded Rod	31	26862.27	18889.61	826.49	19	2	
Threaded Rod	32	26867.89	18868.99	826.54	21	0	
Threaded Rod	37	26872.51	18850.85	826.44	17	1	
Threaded Rod	38	26877.37	18833.04	826.40	13.5	1.5	
Threaded Rod	39	26881.15	18816.71	826.34	11.5	0.5	
Threaded Rod	40	26887.55	18793.92	826.35	12	0	
Threaded Rod	41	26892.48	18774.29	826.19	12	0	
Threaded Rod	42	26874.02	18768.80	825.61	27	0	
Threaded Rod	43	26879.52	18770.39	825.81	12	0	
Threaded Rod	44	26885.47	18772.08	826.02	12	0	
Threaded Rod	45	26880.44	18791.86	826.37	14.3	0.7	
Threaded Rod	46	26874.16	18790.08	826.21	12	0	
Threaded Rod	47	26874.31	18816.15	826.36	18	0	
Threaded Rod	48	26868.31	18814.99	826.21	30	0	
Threaded Rod	49	26856.58	18811.81	825.82	30	0	
Threaded Rod	50	26851.19	18810.17	825.67	30	0	
Threaded Rod	51	26862.55	18786.45	825.79	18	0	
Threaded Rod	52	26857.49	18785.01	825.60	18	0	
Threaded Rod	53	26867.77	18766.79	825.32	15	0	
Threaded Rod	54	26862.02	18765.17	825.17	13.7	1.3	
Threaded Rod	55	26836.89	18835.11	825.45	18	0	
Threaded Rod	56	26844.19	18836.98	825.81	30	0	
Threaded Rod	57	26850.08	18838.41	825.99	30	0	
Threaded Rod	58	26855.62	18839.63	826.11	30	0	
Threaded Rod	59	26861.87	18841.36	826.33	30	0	
Threaded Rod	60	26867.26	18843.04	826.45	14.5	0.5	
Threaded Rod	61	26860.75	18867.16	826.49	15	0	
Threaded Rod	62	26854.00	18865.71	826.37	21	0	
Threaded Rod	63	26848.00	18864.01	826.24	27	0	
Threaded Rod	64	26842.47	18862.61	826.12	30	0	
Threaded Rod	65	26836.41	18861.41	825.91	30	0	

PT1XYZBT

Type	Label	Notes	X10 East	X10 North	Bo. Elev.
		N.B. Insid.Depth adds 0.29 ft to measured!	(ft)	(ft)	(ft)
Threaded Rod	6	well	26834.47	18841.81	795.45
Threaded Rod	8	well	26856.41	18828.65	795.94
Threaded Rod	9	fast	26861.94	18813.55	807.94
Threaded Rod	10	fast	26866.73	18796.09	807.98
Threaded Rod	11	refusal	26870.56	18781.73	813.96
Threaded Rod	12	slow	26873.32	18771.24	810.73
Threaded Rod	13	refusal	26868.62	18788.36	809.24
Threaded Rod	14	well	26867.92	18792.20	786.99
Threaded Rod	16	fast	26849.53	18859.96	808.19
Threaded Rod	17	fast	26846.21	18870.83	787.29
Threaded Rod	18	slow	26842.34	18884.61	805.13
Threaded Rod	19	refusal	26844.34	18878.58	807.51
Threaded Rod	25	refusal	26855.89	18763.55	799.86
Threaded Rod	26	slow	26850.10	18784.76	807.36
Threaded Rod	27	slow	26844.35	18808.02	810.47
Threaded Rod	28	well	26839.84	18824.77	810.40
Threaded Rod	29	slow	26830.07	18859.07	801.44
Threaded Rod	30	refusal	26825.10	18880.17	807.27
Threaded Rod	31	refusal	26862.27	18889.61	807.49
Threaded Rod	32	well	26867.89	18868.99	805.54
Threaded Rod	37	refusal	26872.51	18850.85	809.44
Threaded Rod	38	refusal	26877.37	18833.04	812.90
Threaded Rod	39	refusal	26881.15	18816.71	814.84
Threaded Rod	40	well	26887.55	18793.92	814.35
Threaded Rod	41	slow	26892.48	18774.29	814.19
Threaded Rod	42	slow	26874.02	18768.80	798.61
Threaded Rod	43	well	26879.52	18770.39	813.81
Threaded Rod	44	well	26885.47	18772.08	814.02
Threaded Rod	45	refusal	26880.44	18791.86	812.07
Threaded Rod	46	well	26874.16	18790.08	814.21
Threaded Rod	47	fast	26874.31	18816.15	808.36
Threaded Rod	48	fast	26868.31	18814.99	796.21
Threaded Rod	49	fast	26856.58	18811.81	795.82
Threaded Rod	50	fast	26851.19	18810.17	795.67
Threaded Rod	51	refusal	26862.55	18786.45	807.79
Threaded Rod	52	slow	26857.49	18785.01	807.60
Threaded Rod	53	well	26867.77	18766.79	810.32
Threaded Rod	54	refusal	26862.02	18765.17	811.47
Threaded Rod	55	slow	26836.89	18835.11	807.45
Threaded Rod	56	fast	26844.19	18836.98	795.81
Threaded Rod	57	fast	26850.08	18838.41	795.99
Threaded Rod	58	fast	26855.62	18839.63	796.11
Threaded Rod	59	fast	26861.87	18841.36	796.33
Threaded Rod	60	refusal	26867.26	18843.04	811.95
Threaded Rod	61	well	26860.75	18867.16	811.49
Threaded Rod	62	slow	26854.00	18865.71	805.37
Threaded Rod	63	well	26848.00	18864.01	799.24
Threaded Rod	64	well	26842.47	18862.61	796.12
Threaded Rod	65	well	26836.41	18861.41	795.91

PT1XYZBT

Type	Label	MaxGMR (cpm)	Depth of Max (ft)	Elevation of Max (ft)				
Threaded Rod	6							
Threaded Rod	8							
Threaded Rod	9							
Threaded Rod	10							
Threaded Rod	11							
Threaded Rod	12							
Threaded Rod	13							
Threaded Rod	14							
Threaded Rod	16							
Threaded Rod	17							
Threaded Rod	18							
Threaded Rod	19							
Threaded Rod	25							
Threaded Rod	26							
Threaded Rod	27							
Threaded Rod	28							
Threaded Rod	29							
Threaded Rod	30							
Threaded Rod	31							
Threaded Rod	32							
Threaded Rod	37							
Threaded Rod	38							
Threaded Rod	39							
Threaded Rod	40							
Threaded Rod	41							
Threaded Rod	42							
Threaded Rod	43							
Threaded Rod	44							
Threaded Rod	45							
Threaded Rod	46							
Threaded Rod	47							
Threaded Rod	48							
Threaded Rod	49							
Threaded Rod	50							
Threaded Rod	51							
Threaded Rod	52							
Threaded Rod	53							
Threaded Rod	54							
Threaded Rod	55							
Threaded Rod	56							
Threaded Rod	57							
Threaded Rod	58							
Threaded Rod	59							
Threaded Rod	60							
Threaded Rod	61							
Threaded Rod	62							
Threaded Rod	63							
Threaded Rod	64							
Threaded Rod	65							

PT1XYZBT

Type	Label	X10 East (ft)	X10 North (ft)	Ground Elev. (ft)	DriveDept (ft)	Protrusion (ft)	Insd.Dept (ft)
Geoprobe	105	26847.72	18867.16	826.19			
Geoprobe	106	26865.51	18800.36	825.96			
Geoprobe	107	26855.89	18836.51	826.07			
Sample	111	26870.12	18856.78	826.47			
Sample	112	26877.32	18831.08	826.40			
Sample	113	26881.65	18803.72	826.34			
Sample/AQ R	114	26847.13	18798.02	825.42			
Sample/AQ R	115	26840.56	18822.64	825.38			
Sample/AQ R	116	26833.92	18848.21	825.56			
Sample	117	26858.52	18827.42	825.97			
Sample/AQ R	118	26862.12	18804.76	825.88			
Sample/AQ R	119	26850.88	18851.59	826.14			
Sample/AQ R	120	26857.80	18832.80	826.05			
Sample	121	26863.39	18891.66	826.28			
Sample	122	26823.67	18881.18	824.78			
Sample	123	26854.93	18761.62	823.75			
Sample	124	26894.50	18773.20	826.11			
Well	well 179	26991.85	18834.25	843.88			
Well	well 676	26804.95	18796.86	817.86			
Well	well 676	26805.00	18796.84	817.83			
Well	well 718	26784.00	18863.66	816.98			
Well	well 719	26915.45	18848.69	827.27			
Zero	stake	26867.45	18883.56	826.46			
Zero	stake	26867.45	18883.56	826.47			
Zero	stake	26867.46	18883.56	826.47			
Zero	stake	26867.45	18883.56	826.46			
Zero	stake	26867.46	18883.56	826.46			
Zero	stake	26867.46	18883.56	826.45			
Zero	stake	26867.46	18883.56	826.45			
Zero	stake	26867.46	18883.56	826.45			
Corner	NE Corner	26863.13	18891.01	826.29			
Corner	NW Corner	26824.25	18881.32	825.05			
Corner	SE Corner	26893.72	18773.49	826.12			
Corner	SW Corner	26855.35	18762.34	824.32			
stake	eslope1	26904.64	18767.77	824.90			
stake	eslope2	26930.42	18837.79	827.00			
stake	eslope3	26963.60	18939.16	830.36			
stake	wslope1	26828.39	18830.70	823.18			
stake	wslope2	26822.82	18829.13	821.29			
stake	wslope3	26813.63	18827.57	818.61			
stake	wslope4	26793.29	18823.44	816.73			

PT1XYZBT

Type	Label	Notes	X10 East	X10 North	Bot.Elv.
		N.B. Insid.Depth adds 0.29 ft to measured!	(ft)	(ft)	(ft)
Geoprobe	105				
Geoprobe	106				
Geoprobe	107				
Sample	111		26870.12	18856.78	
Sample	112		26877.32	18831.08	
Sample	113		26881.65	18803.72	
Sample/AQ R	114		26847.13	18798.02	
Sample/AQ R	115		26840.56	18822.64	
Sample/AQ R	116		26833.92	18848.21	
Sample	117		26858.52	18827.42	
Sample/AQ R	118		26862.12	18804.76	
Sample/AQ R	119		26850.88	18851.59	
Sample/AQ R	120		26857.80	18832.80	
Sample	121		26863.39	18891.66	
Sample	122		26823.67	18881.18	
Sample	123		26854.93	18761.62	
Sample	124		26894.50	18773.20	
Well	well 179				
Well	well 676				
Well	well 676				
Well	well 718				
Well	well 719				
Zero	stake				
Zero	stake				
Zero	stake				
Zero	stake				
Zero	stake				
Zero	stake				
Zero	stake				
Zero	stake				
Zero	stake				
Comer	NE Comer				
Comer	NW Comer				
Comer	SE Comer				
Comer	SW Comer				
stake	eslope1				
stake	eslope2				
stake	eslope3				
stake	wslope1				
stake	wslope2				
stake	wslope3				
stake	wslope4				

PT1XYZBT

Type	Label	MaxGMR	Depth of	Elevation				
		(cpm)	Max (ft)	of Max (ft)				
Geoprobe	105							
Geoprobe	106							
Geoprobe	107							
Sample	111							
Sample	112							
Sample	113							
Sample/AQ R	114							
Sample/AQ R	115							
Sample/AQ R	116							
Sample	117							
Sample/AQ R	118							
Sample/AQ R	119							
Sample/AQ R	120							
Sample	121							
Sample	122							
Sample	123							
Sample	124							
Well	well 179							
Well	well 676							
Well	well 676							
Well	well 718							
Well	well 719							
Zero	stake							
Zero	stake							
Zero	stake							
Zero	stake							
Zero	stake							
Zero	stake							
Zero	stake							
Zero	stake							
Comer	NE Comer							
Comer	NW Comer							
Comer	SE Comer							
Comer	SW Comer							
stake	eslope1							
stake	eslope2							
stake	eslope3							
stake	wslope1							
stake	wslope2							
stake	wslope3							
stake	wslope4							

Pit 1 - Hole 111
 ^{137}Cs Activity vs Depth

Pit 1 - Hole 111
Bulk Density vs Depth

Pit 1 - Core 112
 ^{137}Cs Activity vs Depth

Pit 1 - Core 112
Bulk Density vs Depth

Pit 1 - Core 113
 ^{137}Cs Activity vs Depth

Pit 1 - Core 113
Bulk Density vs Depth

Pit 1 - Core 114
 ^{137}Cs Activity vs Depth

Zero activity values replaced with one-half the detection limit value.

Pit 1 - Core 114

Zero activity values replaced with one-half the detection limit value.

Pit 1- Core 114
Bulk Density vs Depth

Pit 1 - Core 115
 ^{137}Cs Activity vs Depth

Pit 1 - Core 115

Zero activity values replaced with one-half the detection limit value.

Pit 1- Core 115
Bulk Density vs Depth

Pit 1 - Core 115B
¹³⁷Cs Activity vs Depth

Zero activity values replaced with one-half the detection limit value.

Pit 1- Core 115B
Bulk Density vs Depth

Pit 1 - Core 116
¹³⁷Cs Activity vs Depth

Pit 1 - Core 116

—○— Cs-137 Activity (dpm/g) -●- Logging Data (cpm)

Pit 1- Core 116
Bulk Density vs Depth

Pit 1 - Core 117
 ^{137}Cs Activity vs Depth

Zero activity values replaced with one-half the detection limit value.

Pit 1- Core 117
Bulk Density vs Depth

Pit 1 - Core 118

Pit 1 - Core 118

Zero activity values replaced with one-half the detection limit value.

Pit 1 - Core 118
Bulk Density vs Depth

Pit 1 - Core 119
 ^{137}Cs Activity vs Depth

Zero activity values replaced with one-half the detection limit value.

Pit 1 - Core 119

Pit 1- Core 119
Bulk Density vs Depth

Pit 1 - Core 120

Zero activity values replaced with one-half the detection limit value.

Pit 1 - Core 120

Zero activity values replaced with one-half the detection limit value.

Pit 1- Core 120
Bulk Density vs Depth

Pit 1 - Core 121
 ^{137}Cs Activity vs Depth

Zero activity values replaced with one-half the detection limit value.

Pit 1- Core 121
Bulk Density vs Depth

Pit 1 - Core 122
 ^{137}Cs Activity vs Depth

Zero activity values replaced with one-half the detection limit.

Pit 1- Core 122
Bulk Density vs Depth

Pit 1 - Core 123
 ^{137}Cs Activity vs Depth

Zero activity values replaced with one-half the detection limit value.

Pit 1- Core 123
Bulk Density vs Depth

Pit 1 - Core 124
 ^{137}Cs Activity vs Depth

Zero activity values replaced with one-half the detection limit value.

Pit 1- Core 124
Bulk Density vs Depth

DISTRIBUTION

1. W. D. Brickeen
2. A. J. Kuhaida, Jr.
3. P. T. Owen
4. L. B. Raulston
5. Central Research Library
6. File—EMEF DMC—RC
7. J. S. Tixier, Battelle Pacific Northwest National Laboratory, Battelle Boulevard, Richland, WA 99352
8. J. L. McElroy, Geosafe Corporation, 2950 George Washington Way, Richland, WA 99352
9. J. R. Kubarewicz, Jacobs Engineering, 125 Broadway Avenue, Oak Ridge, TN 37830
10. B. P. Spalding, Oak Ridge National Laboratory, 2597 B 3/4 Road, Grand Junction, CO 81503