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Data Package for the Low-Level Waste Disposal Development and Demonstration Program Environmental Impact Statement

Volume 1 of 2

Sections 1-7 and Appendices A-D

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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ENERGY DIVISION

DATA PACKAGE FOR THE LOW-LEVEL WASTE DISPOSAL DEVELOPMENT AND DEMONSTRATION PROGRAM ENVIRONMENTAL IMPACT STATEMENT

Volume 1 of 2
Sections 1-7 and Appendices A-D

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OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
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DATA PACKAGE FOR THE LOW-LEVEL WASTE DISPOSAL DEVELOPMENT AND DEMONSTRATION PROGRAM ENVIRONMENTAL IMPACT STATEMENT

EDITORS: B. A. Walker[1], R. E. Saylor[1]

TECHNICAL STAFF

PRINCIPAL AUTHOR: R. H. Ketelle[1]

G. F. Cada[2]
R. B. Clapp[2]
J. L. Collins[3]
K. L. Daniels[4]
W. H. Griest[5]
A. D. Kelmers[3]
R. L. Kroodsma[2]
S. Y. Lee[2]
R. R. Lee[1]
J. M. McMahon[5]
P. D. Parr[2]
W. L. Pattison[3]
B. A. Tomkins[5]

CONTRIBUTORS

J. T. Ammons[6]
M. Cunningham[6]
N. D. Farrow[2]
B. J. Frederick[6]
M. J. Gentry[2]
K. Greenberg[6]
R. E. Lambert[6]
D. A. Lietzke[10]
L. A. Melroy[7]
L. Pounds[5]
K. T. Stocking[8]
M. E. Timpson[6]
R. S. Weaver[9]

---

[1] Energy Division

[2] Environmental Sciences Division

[3] Chemical Technology Division

[4] Environmental Compliance and Health Protection Division

[5] Analytical Chemistry Division

[6] The University of Tennessee, Knoxville

[7] First Environmental, Inc., 314 West Broadway, Lenoir City, Tennessee

[8] Department of Hydrology and Water Resources, University of Arizona, Tucson

[9] Health and Safety Research Division

[10] Ph.D Soil Science

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ABSTRACT

This data package is required to support an Environmental Impact Statement (EIS) to be written to evaluate the effects of future disposal of low-level waste at four sites on the Oak Ridge Reservation. Current waste disposal facilities are exceeding their capacities and increasingly stringent disposal requirements dictate the need for sites and new waste disposal technologies. The Low-Level Waste Disposal Development and Demonstration Program has developed a strategy for low-level waste disposal built around a dose based approach. This approach emphasizes contamination pathways, including surface and groundwater and ALARA conditions for workers. This strategy dictates the types of data needed for this data package.

The data package provides information on geology, soils, groundwater, surface water and ecological characterization of the Oak Ridge Reservation in order to evaluate alternative technologies and alternative sites. The results of the investigations and data collections indicate that different technologies will probably have to be used at different sites. This conclusion, however, depends on the findings of the Environmental Impact Statement.

1. INTRODUCTION

The U.S. Department of Energy's (DOE) Low-Level Waste Disposal Development and Demonstration (LLWDDD) Program encompasses a variety of technical research and technology development activities focused on developing environmentally acceptable low-level waste disposal facilities at Oak Ridge, Tennessee. As part of the LLWDDD Program, three candidate sites have been studied intensively to obtain baseline environmental data. These sites include the Bear Creek Valley site, the West Chestnut Ridge site and the Solid Waste Storage Area (SWSA) 7 site. A fourth site, East Chestnut Ridge, is in the initial stages of characterization. However, ecological studies (vegetation, terrestrial fauna, and aquatic biota) have been conducted and site characterization is included in Sect. 5 of this report. Locations of the four sites within the Oak Ridge Reservation (ORR) and, with respect to one another and the ORNL and Y-12 facilities, are shown in Fig. 1.1.

This report is divided into three parts and serves as a guide to basic data sources and various environmental characterization studies performed at three sites on the ORR. Part I consists of seven sections. Sections 2-5 include studies ranging from inventories of biota and descriptions of terrestrial fauna and vegetation through basic geologic studies and detailed groundwater pathways investigations. Section 6 discusses laboratory characterization and leaching of five different waste forms involving depleted uranium that result from production operations at the Oak Ridge Y-12 Plant. Sections 7 presents results of leaching studies of uranium-bearing waste solids from manufacturing operations. Part II of this report presents fourteen appendices that contain data from the most recent characterization studies performed. These studies address soil properties, well construction, hydrographs, water quality and discharge characteristics, and small mammal surveys. Part III is an annotated bibliography of 42 LLWDDD characterization studies, referenced by author and by LLWDDD publication number and covers a wide range of previous studies done on the ORR and the candidate sites as well as support documents for some studies presented in Part I. These documents are also available as components of Part III, but under separate cover.

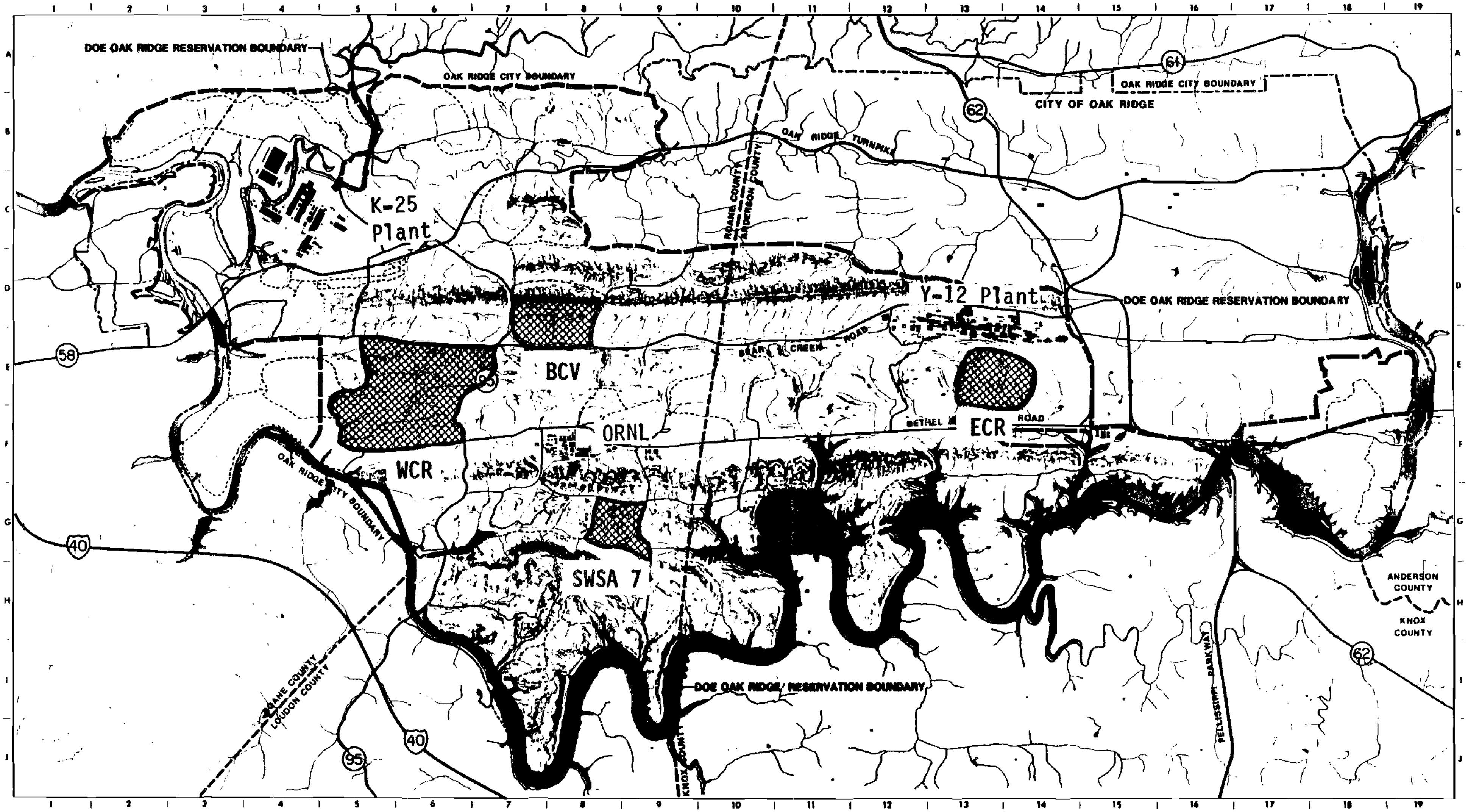

Fig. 1.1 Four areas on the ORR proposed for Low-Level Waste disposal. 1. West Chestnut Ridge (WCR), 2. Bear Creek Valley (BCV), 3. East Chestnut Ridge (ECR), and 4. Proposed Solid Waste Storage Area 7 (SWSA 7).

2. SWSA 7

The LLWDDD SWSA 7 site area, located south of the ORNL Main Plant facilities in Melton Valley (Fig 1.1), comprises about 200 acres of gently sloping to steep land. Soils are generally thin and overlie saprolite formed by weathering of bedrock. The site is underlain by bedrock formations of the Cambrian age Conasauga Group and includes portions of the Nolichucky Shale, the Maryville Limestone, the Rogersville Shale, and the Rutledge Limestone.

In the following sections, sources of published data and information and previously unpublished data are presented. Data sources and new data are organized by disciplinary field (e.g., geology, soils, groundwater).

A site topographic map included with this report (Plate 1) shows detailed site topography, locations of groundwater piezometers, and surface water discharge measurement station locations.

2.1 GEOLOGY

Geology of SWSA 7 is reported in Rothschild et al. (1984a). Investigations reported therein include results of rock core drilling and geophysical investigations performed on the site. An areal geologic map is included in this reference, along with stratigraphic descriptions of the bedrock formations at the site and a discussion of geologic structure.

2.2 SOILS

Investigations pertaining to soils at the SWSA 7 site have been reported in two documents. Rothschild et al. (1984b) present soil chemical, mineralogical, and hydrologic data; information on distribution coefficients for several radionuclides; and a broad-scale soil map. Appendix A of this report includes an addendum to the soil mapping at SWSA 7 by Lietzke (1988), which serves as an update to the previously published soil map of the site. The Lietzke (1988) soil map (Fig. 1 in Appendix A) supersedes the 1984 soil map of the SWSA 7 area.

2.3 GROUNDWATER

Groundwater data collected on the SWSA 7 site include measurement of aquifer properties, water table elevation data from wells, and results of chemical analyses performed on groundwater samples.

2.3.1 Aquifer Properties

Results of aquifer properties tests at the SWSA 7 site and other tests applicable to the site are reported in Rothschild et al. (1984a).

Tests performed to determine the hydraulic conductivity of the aquifer include slug tests in 14 wells on site and indicate that hydraulic conductivity values lie in the range of typical hydraulic conductivity for shallow wells elsewhere in the Conasauga Group on the Oak Ridge Reservation (ORR). These test results are reported in Rothschild (1984a).

In addition to aquifer hydraulic conductivity data, soil moisture release characteristics were measured for site soils. Soil moisture was determined by the hanging column method and results are reported in Rothschild et. al. (1984b).

2.3.2 Water Table Elevations

Piezometric data for the SWSA 7 site are available in the form of well hydrographs. Data are available for a total of 37 wells, 21 of which were constructed in 1983 and 16 in 1987. Well construction information for the 21 original wells is published in Rothschild et al. (1984a), and well construction data for the 16 additional wells are included as Appendix B of this report. Well locations, survey coordinates, and elevations are included on the SWSA 7 site map (Plate 1).

The period of water level measurement records for individual wells is somewhat variable. Sources of data are as follows: Well hydrographs for the 16 new piezometers for the period August 31, 1987, through July 1, 1988, at the SWSA 7 site are included in Appendix C of this report. Well hydrographs for the original 21 wells are published in two reports: data from periods of record varying from September 1, 1982, through April 30, 1984, are published in Rothschild et al. 1984a and for the period May 1, 1984, through March 31, 1988, are published in Clapp et al. 1988.

2.3.3 Groundwater Quality

Groundwater chemical data have been obtained from various wells on the SWSA 7 site over a period of time. In 1983, major anion and cation analyses plus gross alpha activity, tritium, strontium-90, cesium-137, and cobalt-60 analyses were performed on two samples from wells 7-1 through 7-18 and are reported in Rothschild et al. (1984a).

Clapp et al. (1988) report results of analyses for major anions, cations, and radionuclides on samples taken in April 1985 from wells 7-1 through 7-18.

In 1987, eight wells (7-4, 7-5, 7-7, 7-12, 7-13, 7-16, 1117, and 1126) were selected for quarterly sampling and analysis for field parameters (pH, temperature, specific conductance), dissolved anions and cations, gross alpha activity, gross beta activity, tritium, and volatile organic compounds. Analytical results for three quarterly samples are presented in Appendix D (Daniels 1988a,b) of this report.

2.4 SURFACE WATER

Data pertaining to surface water consist of daily total precipitation records, surface water discharge data, and surface water chemical composition data.

2.4.1 Precipitation

Daily total precipitation has been recorded at the SWSA 7 site raingage from late May 1984 to present. The location of the SWSA 7 raingage is shown in Clapp et al. (1988).

Rainfall data obtained from the Walker Branch Watershed for January 1, 1983, through March 31, 1984, are published in Rothschild et al. (1984a) as daily and monthly total rainfall. These data are approximations of the local rainfall in this portion of the ORR but may vary by 10 to 15% from actual rainfall at SWSA 7.

Data for the period April 1, 1984, through March 31, 1988, are published in Clapp et al. (1988) as daily and monthly total rainfall. Data obtained at the SWSA 7 raingage are reported beginning in June 1984.

2.4.2 Surface Water Discharge

Surface water discharge data are available from four stream gaging stations for various periods of record. The locations of the four surface discharge measurement stations are shown on the SWSA 7 site map (Plate 1).

Flow data from the Center 7 watershed station are reported in Rothschild et al. (1984a) for January 1983 through March 1984. These data were revised and republished in Clapp et al. (1988) because of revisions to estimates of contributing watershed area discharges, which resulted in revisions of the discharge-per-unit-area calculations.

Clapp et al. (1988) report daily discharge for each of the four discharge measurement stations from the initiation of data collection through March 31, 1988. Some data analyses and interpretations are also presented from the Center 7 station records.

2.4.3 Surface Water Quality

Surface water quality data for the SWSA 7 site consist of analyses for major dissolved anions and cations, selected radionuclides, and volatile organic compounds.

Rothschild et al. (1984a) report analytical data for major dissolved constituents and selected radionuclides for grab samples obtained on two dates from the Center 7 station and a location on Melton Branch.

Quarterly analytical data beginning in December 1987 for field parameters (temperature, pH, specific conductance), major and minor dissolved constituents, gross alpha activity, gross beta activity, tritium, and volatile organic compounds are reported in Appendix D of this report. Grab samples were collected quarterly from each of the four site discharge measurement stations.

2.5 ECOLOGY

2.5.1 Terrestrial Flora

The general description of vegetation for the ORR presented in Appendix O applies to the proposed SWSA 7 site. Abundance of community types on the ORR, on the proposed SWSA 7 site, and on the candidate disposal areas within the site (Lockwood Greene 1987) is given in Appendix O, Table 1.1. More specific information on site vegetation and comments on the rare or uncommon communities or species is presented in this section.

The proposed site was extensively surveyed for rare species from June 1 to July 13, 1988. Pine plantations and maintained fields were not visited; species diversity on such sites is typically low, and they are not likely to harbor the rare species now known or expected to occur on the ORR. Powerline rights-of-way were explored because these corridors host natural successional vegetation. Areas showing the greatest potential for rare species were revisited several times; different species are apparent at different times during the growing season. The chief limitation on the completeness of the rare plant survey is the relatively short portion of the growing season during which observations were made. In addition, extreme drought during this season, and the past 4 years, may have impacted visibility of some species (e.g., shoot dieback).

The proposed SWSA 7 site (Fig. 2.1) is mostly forested and includes some steep slopes and moist drainages. Kroodsma (1985) described the soils on the site and their associated vegetation. Natural pine forests, growing on formerly cultivated land, cover roughly 40% of the site. Upland hardwood is the most extensive community type on the site and is comprised primarily of oak and hickory associated with sweetgum and poplar. Distribution of forest community types within the site is shown in Fig. 2.2. The legend for Fig. 2.2 is presented in Table 2.1. Although no rare species were found during the survey period, appropriate habitat and physiography exist for Canada lily (Lilium canadense), a state listed rare species; and because it was observed in the nearby Freel's Bend area (Pounds 1987) in a Haw Ridge drainage similar to those at the proposed SWSA 7 site, the Canada lily may be present but not observable due to drought stress or herbivore predation.

Rare plants

No state or federally listed species were observed on the SWSA 7 site during the survey. For information on definitions of status for listing plants as threatened and/or endangered species see Appendix O, Tables 1.3 and 1.4.

2.5.2 Terrestrial Fauna

For information on definitions of status for listing plants as threatened and/or endangered species see Appendix O, Tables 1.3 and 1.4.

2.5.3 Aquatic Biota

The general description of aquatic biota for the ORR is presented in Appendix O. Loar, Soloman, and Cada (1981) summarized all previous studies

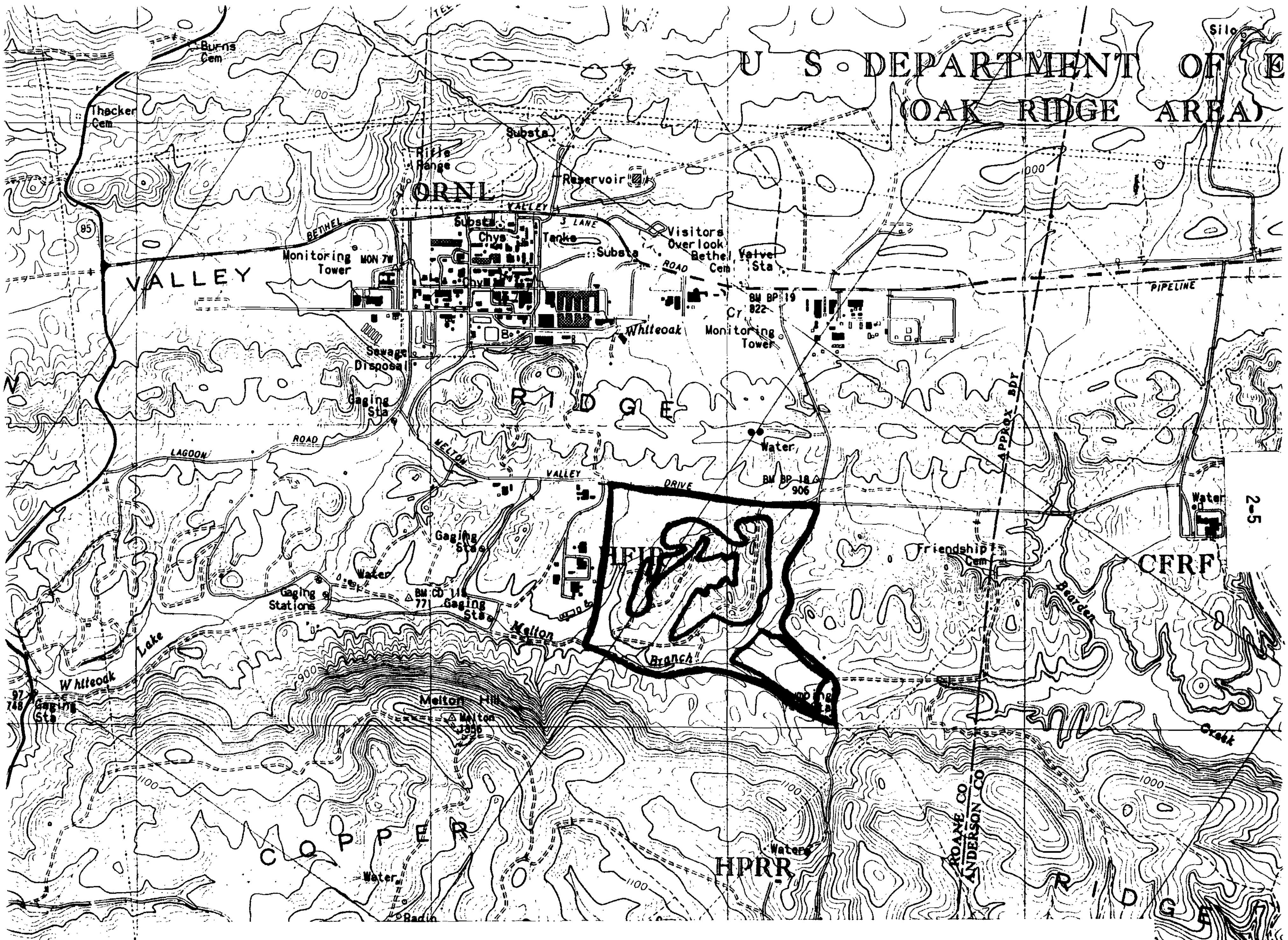

Fig. 2.1 Topographic map of the proposed Solid Waste Storage Area 7 site showing candidate disposal areas within the site.

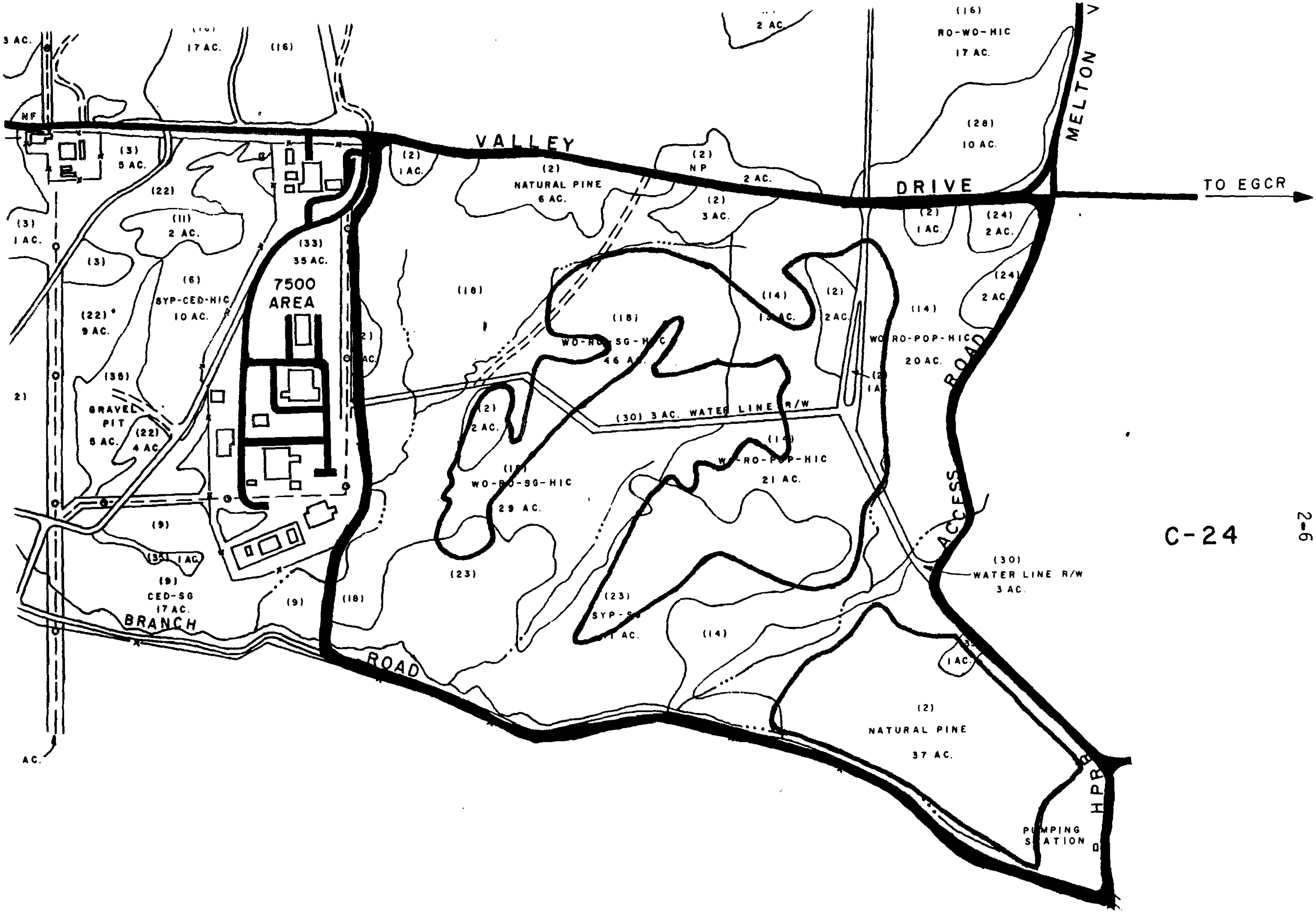

Fig. 2.2 ORNL forest management compartment map (Alt. Number 2) for the proposed Solid Waste Storage Area 7. Candidate disposal areas within the site are outlined. (See Table 2.1 for legend.)

Table 2.1. Legend for Fig. 2.2, ORNL forest management compartment map for the proposed Solid Waste Storage Area 7.

Stratum No.	Forest cover type[a]	Acreage
1	SLP plantations, 1955	40
2	NP	236
3	SYP-POP-WO	46
4	SYP-POP	3
5	SYP-WO	5
6	SYP-CED-HIC	10
7	Cedar	23
8	CED-RO-SYP	2
9	CED-SG	18
10	WP-VP	2
11	WP-WO	3
12	WP-WO-SYP	8
13	WO-WP	42
14	WO-RP-POP-HIC	169
15	CO-HIC-RO	64
16	RO-WO-HIC	147
17	WO-HIC-POP	66
18	WO-RO-SG-HIC	75
19	WO-RO-HIC	19
20	WO-SYP-HIC	12
21	RO-SYC-Elm	2
22	SYP-RO-POP	47
23	SYP-SG	41
24	POP-CO-HIC	4
25	POP-RM	3
26	SG-SYP-Ash	37
27	SG-SYC-SYP	22
28	SYP-RM-Regeneration	10
29	Bettle kill	8
30	Right-of-way	59
31	Roads	112
33	Buildings, facilities, construction	41
34	Cutover	21
35	Non-forested	41

[a]BIR	birch	SG	sweetgum
CED	red cedar	SLP	shortleaf pine
CO	chestnut oak	SRO	southern red oak
HIC	hickory	SYP	southern yellow pine
LOB	loblolly pine	VP	virginia pine
NP	natural pine	WO	white oak
NRO	northern red oak	YP	yellow poplar
POP	poplar		
RM	red maple		

of the aquatic biota of the White Oak Creek watershed (Fig. 2.3), and presented the results of a comprehensive biological sampling program carried out from March 1979 until June 1980. A single site on Melton Branch and two sites on White Oak Creek near the proposed SWSA 7 site were sampled for periphyton, benthic invertebrates, and fishes. A relatively diverse and abundant benthic invertebrate fauna was observed at the Melton Branch site, although no fish were collected in limited sampling.

Cada (1986) sampled fishes at four sites on Melton Branch between May 1985 and May 1986. Two species of fish were collected, the creek chub (Semotilus atromaculatus) and the blacknose dace (Rhinichthys atratulus). Both species are common and locally abundant throughout the region. Densities and standing crops of fish were probably limited at the upper Melton Branch sites by low discharge, whereas high water temperatures resulting from the High Flux Isotope Reactor discharge likely restricted fish at the lower sites. Lengths and weights were typical for these species and exhibited normal seasonal variations due to the changing age structure of the populations. Condition factors were not unusual and showed little seasonal or spatial variation (Cada 1986).

Sherwood and Loar (1987) presents results of a synoptic survey of the White Oak Creek watershed conducted in August and September 1985 to aid in developing a long-term monitoring plan. Since then, extensive studies (which include instream ecological monitoring, toxicity monitoring, radioecological studies, and bioaccumulation of nonradiological contaminants) of the aquatic communities of Melton Branch and White Oak Creek have been instituted. Results of the studies from March through December 1986 (Loar 1987) and from 1987 (Loar 1988) have been reported. Monitoring of the same sites is continuing and will continue to be reported annually (contact J. M. Loar, ORNL).

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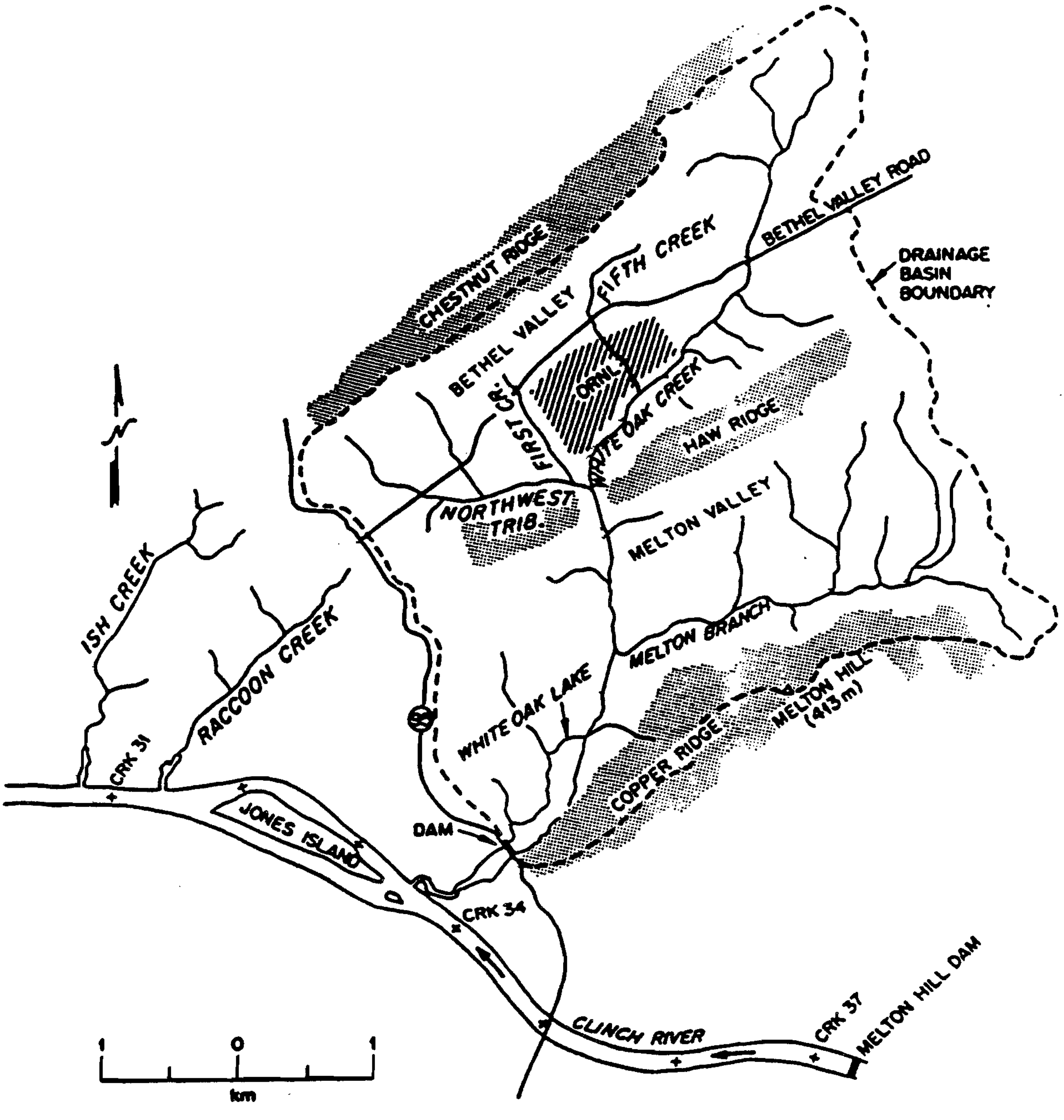

Fig. 2.3 Map of the White Oak Creek watershed above White Oak Dam.

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3. BEAR CREEK VALLEY

The LLWDDD Bear Creek Valley site is located about 5 miles west of the Y-12 Plant and 1 mile north of ORNL adjacent to Tennessee Highway 95 (Fig. 1.1). The site study area encompasses approximately 300 acres of relatively flat to gently sloping land.

A site topographic map included with this report (Plate 2) shows detailed site topography, locations of groundwater piezometers, and surface water discharge measurement station locations.

In the following sections, sources of published data and information and previously unpublished data pertaining to the Bear Creek Valley site are presented. Data sources and new data are organized by disciplinary field (e.g., geology, soils, groundwater).

3.1 GEOLOGY

The Bear Creek Valley site is underlain by bedrock of the Cambrian age Conasauga Group. Bedrock formations comprising the Conasauga are shown in Table 3.1. The geology of the Bear Creek Valley site is presented in Lee and Ketelle (1988). Data for the geologic study include rock core, geophysical logs, and saprolite mapping. A geologic map is included, as well as detailed stratigraphic descriptions and analyses of geologic structure.

3.2 SOILS

Soils are generally thin and overlie a variable thickness zone of weathered bedrock known as saprolite. Site investigations pertaining to soils include mapping the distribution of various soil types present on the site, describing soil profiles for each soil type, and sampling and analysis of soils for their mineralogical and geochemical characteristics, including sorption properties for selected radionuclides.

The principal source of data pertaining to Bear Creek Valley site soils is Lietzke, Lee, and Lambert (1988). This report includes a soil map of the site, as well as soil profile descriptions and site geomorphology. Soils were mapped according to their parent material, slope class, and erosional characteristics.

Site soils, general geology, geomorphology, and groundwater system aspects are discussed in Lee et al. (1988), which presents a generalized transect across Bear Creek Valley. Conasauga soils described along the transect are those studied in detail on the LLWDDD Bear Creek Valley site.

Table 3.1

STRATIGRAPHIC COLUMN OF CAMBRO-ORDOVICIAN ROCKS, WHITE OAK MOUNTAIN THRUST BLOCK, OAK RIDGE, TENNESSEE

Age	Group	Formation/Unit	Description	Thickness (ft)
MIDDLE ORDOVICIAN	CHICKAMAUGA (Och) [b]	Unit H[a]	Thin interbedded limestone and calcareous siltstone. Gray, olive, buff, and maroon.	>270
		Unit G	Limestone and siltstone in thick beds. Limestone fine- to medium-grained, nodular. Siltstone dark gray with vague limestone interbeds.	290
		Unit F	Laminated to thin-bedded calcareous and shaley siltstone. Maroon and olive gray.	20
		Unit E	Limestone and siltstone in thick beds. Limestone fine- to medium-grained, nodular and amorphous. Siltstone dark gray with limestone laminae.	300
		Unit D	Limestone. Medium-grained and stylolitic. Nodular and bedded chert.	140
		Unit C	Limestone and siltstone in thick beds. Limestone nodular and micritic. Siltstone calcareous and dark gray. Nodular chert.	95
		Unit B	Siltstone. Massive maroon and gray with limestone in thin, even beds.	250
		Unit A	Limestone and siltstone in thick beds. Dark to light gray, purplish to maroon. Nodular and bedded chert.	300
LOWER ORDOVICIAN	KNOX (OCk)	NEWALA Fm.	Medium-bedded dolostones and limestones with variable chert content, scattered chert matrix limestones. Abundant maroon mottling.	900 (est)
		LONGVIEW Fm.	Dense massive chert, bedded chert, and dolomoldic chert observed in residuum.	50–100 (est)
		CHEPULTEPEC Fm.	Dolostone, fine- to medium-grained, light to medium gray, medium to thick bedded, sandy near base.	500–100 (est)
UPPER CAMBRIAN		COPPER RIDGE Fm.	Dolostone, medium to thick bedded, fine to coarse crystalline, medium to dark gray. Chert varieties include massive, cryptopoan, and oolitic.	900–1300 est

Table 3.1 (continued)

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STRATIGRAPHIC COLUMN OF CAMBRO-ORDOVICIAN ROCKS, WHITE OAK MOUNTAIN THRUST BLOCK, OAK RIDGE, TENNESSEE (Continued)

Age	Group	Formation/Unit	Description	Thickness (ft)
MIDDLE CAMBRIAN	CONASAUGA (Ꞓc)	**MAYNARDVILLE Fm.**	Upper (Chances Branch Mbr.) – limestone and dolomitic limestone in thick massive beds.	140
			Lower (Low Hollow Mbr.) – dolomitic limestone in thick massive beds. Light gray to buff.	200
		NOLICHUCKY Fm.	Upper – shale and limestone in thin to thick beds. Shale dark gray or maroon. Limestone light gray, oolitic, wavy-bedded, or massive.	60–140
			Lower – shale and limestone in medium to thick beds. Shale dark gray, olive gray or maroon. Limestone light gray, oolitic, glauconitic, wavy-bedded, and intraclastic.	430–450
		MARYVILLE Fm.	Limestone and shale or siltstone in medium beds. Limestone light gray, intraclastic, or wavy-bedded. Shale or siltstone dark gray.	320–410
		ROGERSVILLE Fm.	Shale and argillaceous limestone. Laminated to thin-bedded, maroon, dark gray, and light gray.	80–110
		RUTLEDGE Fm.	Limestone and shale in thin beds. Limestone light to olive gray. Shale gray or maroon.	100–120
		PUMPKIN VALLEY Fm.	Upper – shale and calcareous siltstone. Laminated to very thin-bedded. Shale reddish brown, reddish-gray, or gray. Calcareous siltstone light gray or glauconitic.	130–150
			Lower – shale and siltstone or silty sandstone. Thin-bedded. Shale reddish-brown or gray to greenish gray. Siltstone and silty sandstone light gray.	175
LOWER CAMBRIAN		**ROME Fm. (Ꞓr)**	Sandstone with thin shale interbeds. Sandstone fine-grained, light gray or pale maroon. Shale maroon or olive gray.	Unknown

[a] Chickamauga Group stratigraphic subdivisions reflect those identified at the Oak Ridge National Laboratory site. Other formation names are consistent with regional stratigraphic nomenclature.

[b] Group name abbreviations are those commonly used on geologic maps and cross sections in the region.

Data pertinent to soil mineralogy and geochemistry are reported by Lee et al. (1988) and Ammons et al. 1988. Distribution coefficient data for selected site soils are reported in Ammons et al. 1988.

3.3 GROUNDWATER

Groundwater data collected on the Bear Creek Valley site include measurement of aquifer properties, water table elevation data from wells, results of chemical analyses performed on groundwater samples, and conceptual and computer models of the site flow system.

3.3.1 Aquifer Properties

Characterization of aquifer properties at the LLWDDD Bear Creek Valley site has required construction of a variety of wells at various locations and depths on the site. The locations of wells are shown on Plate 2, and well construction information is included in two primary documents: Golder Associates, Inc. (1988a) and Appendix G, Part 1 of this report.

Appendix G, Part 1, of this report contains drilling and well construction logs for 48 piezometers. Some of these wells were constructed as shallow and bedrock to evaluate vertical head gradients between the water table and the upper portion of bedrock. Additional wells were constructed in exploratory core holes and as individual rotary drilled wells, with completion intervals determined on the basis of straddle packer test results. Well construction details for these wells are included in Golder Associates, Inc. (1988a).

Tests performed at the site to determine aquifer properties include rising head tests (slug tests) in single wells, multiple-well/multiple-zone aquifer pump tests, and straddle packer testing in bedrock core holes. Results of aquifer property tests at the Bear Creek Valley site and other tests applicable to the site are contained in Golder Associates, Inc. (1988a).

3.3.2 Water Table Elevations

Piezometric data for the Bear Creek Valley site are available in digital form (which can be plotted as well hydrographs). Water level data for 44 wells at the Bear Creek Valley site for May 1987 through May 1988 are presented in Appendix G, Part 2 as well as hydrograph plots. Additional data are contained in Golder Associates, Inc. (1988b).

3.3.3 Groundwater Quality

Quarterly groundwater quality data were obtained from a total of 10 wells on site, including wells constructed in the shallow groundwater system (<100 ft depth) and the deeper groundwater system (>300 ft depth). Analytical parameters include major dissolved anions and cations, radiological screening parameters, priority pollutants, and selected stable isotopes. These data, and geochemical interpretation of their significance, are available in Golder Associates, Inc. (1988c).

3.4 SURFACE WATER

Surface water data collected at the Bear Creek Valley site include precipitation data, evaporation data, surface water discharge data, and surface water quality data.

3.4.1 Precipitation

Precipitation, evaporation, relative humidity, and barometric pressure data were collected at the Bear Creek Valley site for October 26, 1987, through June 9, 1988. Data are published in Golder Associates, Inc. (1988c). Other precipitation data applicable to the site (rainfall at the Walker Branch watershed and at the Bear Creek burial ground) are available from ORNL.

3.4.2 Surface Water Discharge

The Bear Creek Valley site is bounded on the northeast by Gum Branch and on the southeast and southwest by Bear Creek; one perennial stream bisects the site near its center. Surface water gauging stations have been constructed and instrumented for continuous stage height data collection at six locations on the Bear Creek Valley site to provide surface water discharge data (Plate 2). Daily discharge data summaries for all six stations are included in Appendix H of this report.

3.4.3 Surface Water Quality

Three quarterly surface water grab samples have been collected and analyzed at each of five surface water discharge stations at the Bear Creek Valley site. Sampling began in the fourth quarter of 1987 and continues through 1988. Parameters analyzed include major and minor dissolved anions and cations, screening radiological parameters, tritium, and volatile organic compounds. Data obtained to date are presented in Appendix D of this report.

3.5 ECOLOGY

3.5.1 Terrestrial Flora

The general description of vegetation for the ORR presented in Appendix O applies to the proposed Bear Creek Valley site. Abundance of community types on the ORR, on the proposed Bear Creek Valley site, and on the candidate disposal areas within the site (Lockwood Greene 1987) is given in Appendix O, Table 1.1. More specific information on site vegetation and comments on the rare or uncommon communities or species is presented in this section.

The proposed site was extensively surveyed for rare species from June 1 to July 13, 1988. Pine plantations and maintained fields were not visited; species diversity on such sites is typically low, and they are not likely to harbor the rare species now known to or expected to occur on the ORR. Powerline rights-of-way were explored because these corridors host natural successional vegetation. Areas showing the greatest potential for rare species were revisited several times; different species are apparent at different times during the growing season. The chief limitation on the completeness of the rare plant survey is the relatively short portion of the growing season during which observations were made. In addition, extreme drought during this season, and the past four years, may have impacted visibility of some species (e.g., shoot dieback).

The Bear Creek Valley site includes a portion of Bear Creek Valley and the south facing slope of Pine Ridge (Fig. 3.1). Although most of the valley area is managed pine plantations, the ridge slopes contain upland hardwood forest. The lower slopes are dominated by stands of yellow poplar, white oak, and red maple. Chestnut oak, white oak, hickory, northern red oak, and pine are present on the upper slopes.

Distribution of forest communities within the site is shown in Fig. 3.2. The legend for Fig. 3.2 is presented in Table 3.2.

Unusual communities or species

Several areas of interest shown in Fig. 3.1 are described in the following paragraphs.

Area 1. A ravine is present in the west end of Pine Ridge. Maidenhair spleenwort (Asplenium trichomanes) grows here on a rock outcrop in the ravine. This is the only known occurrence of this species on the ORR.

Area 2. A small stream dissects Pine Ridge. Wet bottoms around the stream provide habitat for many sedges and ferns, including Royal Fern (Osmunda regalis).

Area 3. A small population of ginseng (Panax quinquefolius) occurs in this wooded area. Ginseng is listed as threatened in Tennessee.

Rare plants

Ginseng (Panax quinquefolius), listed by the state as threatened in Tennessee, was observed on the proposed Bear Creek Valley site. Location of the population within the site is shown in Fig. 3.1.

Since public access to the ORR has been restricted, ginseng populations have been recovering from the extensive digging of the tubers that persists even today off the ORR. Most of the ginseng collected in the state is marketed in the Orient. The Tennessee Department of Conservation considers ginseng to be threatened with extinction only because it is so heavily collected (Milo Guthrie, Tennessee Dept. of Conservation, personal

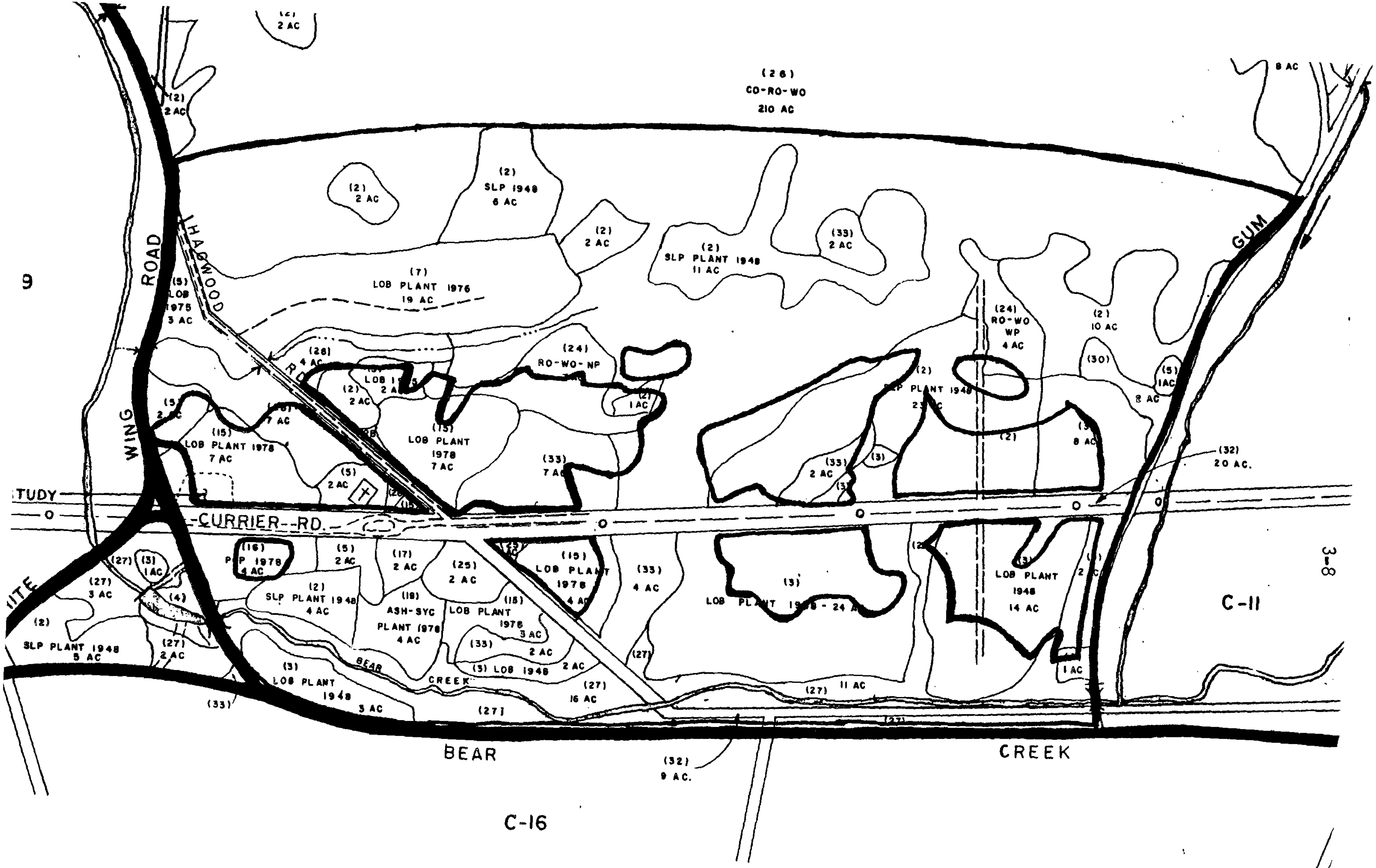

Fig. 3.2 ORNL forest management compartment map (Number 28) for the proposed Bear Creek Valley site. Candidate disposal areas within the site are outlined. (See Table 3.2 for legend.)

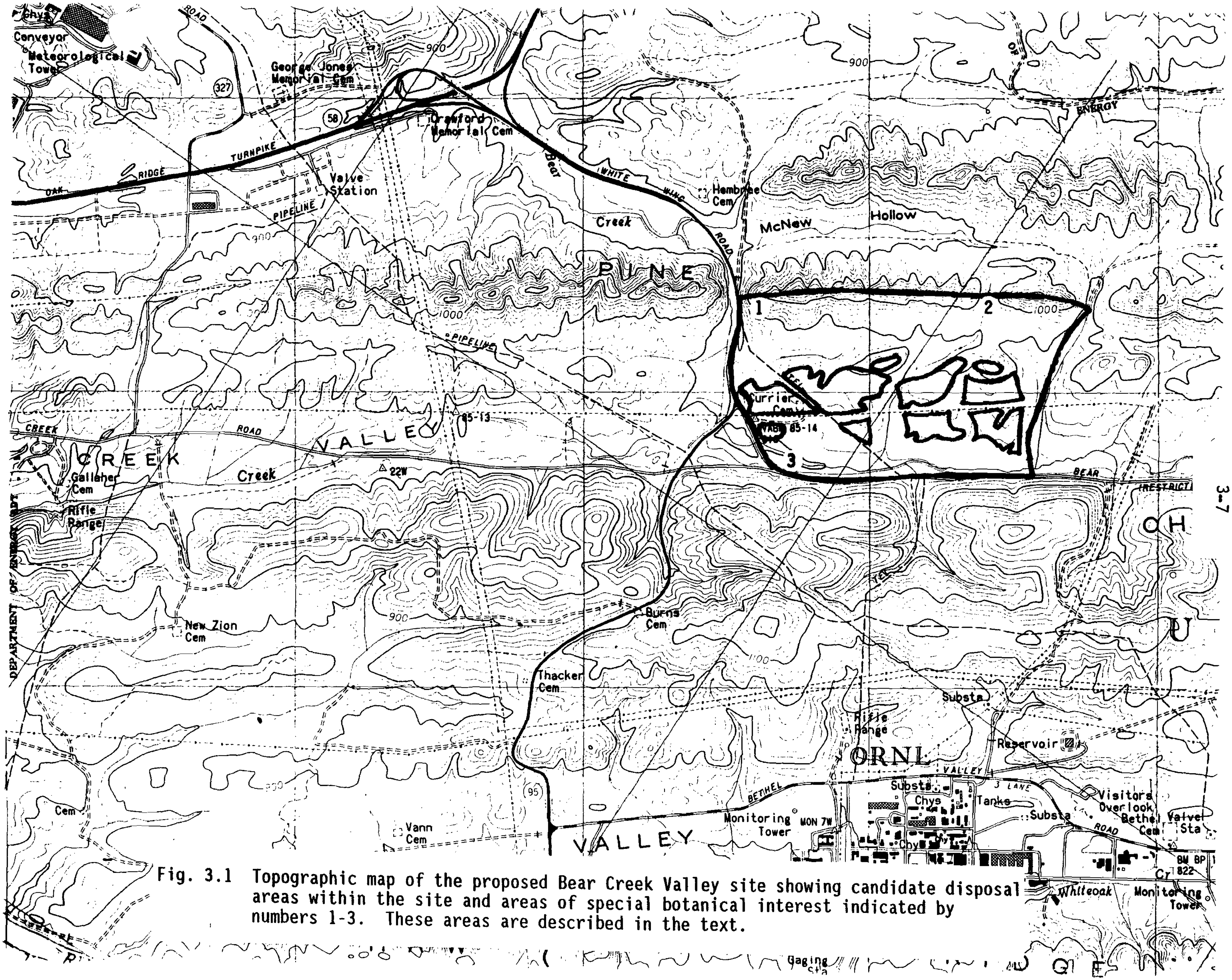

Fig. 3.1 Topographic map of the proposed Bear Creek Valley site showing candidate disposal areas within the site and areas of special botanical interest indicated by numbers 1-3. These areas are described in the text.

Table 3.2. Legend for Fig. 3.2, ORNL forest management compartment map for the proposed Bear Creek Valley site.

Stratum No.	Forest cover type[a]	Acreage
1	WP-SLP plantations 1948	16
2	SLP plantation 1948	297
3	LOB plantation 1948	52
4	LOB plantation 1973	2
5	LOH plantation 1975	14
6	Sweet gum plantation 1975	1
7	LOB plantation 1976	110
8	Long leaf plantation 1976	2
9	SYC plantation 1976	20
10	Walnut plantation 1976	3
11	Cottonwood plantation 1976	7
12	Black cherry plantation 1976	1
13	LOB plantation 1977	15
14	G. ash - pop plantation 1977	17
15	LOB plantation 1976	22
16	Yellow pop plantation 1978	4
17	Chestnut plantation 1978	2
18	ASH-SYC plantation 1978	4
19	LOB plantation 1971	3
20	SYC-BIR-SG-alder pawlonia plantation 1976	18
21	Ash plantation 1977	1
22	Chestnut RO plantation 1977	3
23	NP-POP-RO	48
24	RO-WO-NP	11
25	RO-POP-HIL	3
26	CO-RO-WO	390
27	SYC-SG walnut	32
28	WO-MAP-SG-elm	12
29	WO-WP	1
30	SG-POP-maple	30
31	Roads	30
32	Powerline right of ways	29
33	Cutover-bettle kill, scrub, non-forest	33
34	Streams	10
35	Cemetery	1

[a]BIR	birch	SG	sweetgum
CED	red cedar	SLP	shortleaf pine
CO	chestnut oak	SRO	southern red oak
HIC	hickory	SYP	southern yellow pine
LOB	loblolly pine	VP	virginia pine
NRO	northern red oak	WO	white oak
POP	poplar	YP	yellow poplar
RM	red maple		

communication, 1988) For example, in 1985 ginseng was collected in 92 of the state's 95 counties; 23,166 pounds (dry weight) were harvested. The number of plants necessary to make one pound dry weight is roughly from 100 to 300, depending on size.

For information on definitions of status for listing plants as threatened and/or endangered species see Appendix O, Tables 1.3 and 1.4.

3.5.2 Terrestrial Fauna

For information on terrestrial fauna for the Bear Creek Valley Site, see Appendix O.

3.5.3 Aquatic Biota

The general description of aquatic biota for the ORR is presented in Appendix O. The benthic invertebrates and fishes of Bear Creek have been repeatedly surveyed between 1972 and 1976 (McClain 1972; Reece 1973; ERDA 1975; Exxon Nuclear, Inc. 1976; Morton 1978). Loar et al. (1985) summarized the results of these studies. In general, these studies note an absence of fish and a paucity of benthic invertebrates above BCK 11.0 (11.0 km upstream from the mouth of Bear Creek). Further downstream, samples at BCK 4.3 and below indicate increasingly diverse and abundant fish and invertebrate communities with increasing distance from the headwater contaminant sources.

Loar et al. (1985) surveyed the fish and benthic invertebrates at nine Bear Creek sites between BCK 3.25 and BCK 12.29 (Figs. 3.3 and 3.4). In addition, benthic invertebrates were sampled at nearby reference sites, including two sites in Gum Hollow Branch and one site (BTK 0.3) in an unnamed tributary to Bear Creek near BCK 6.27. As in earlier studies, both fish and benthos communities of Bear Creek showed a trend toward higher numbers of species and greater abundance with increasing distance downstream. Benthic invertebrate densities, richness, and diversity were generally similar to those of uncontaminated reference sites below BCK 5.15. Compared with the earlier studies, Loar et al. (1985) noted that Bear Creek had substantially recovered; based on bioassay data, as well as the fish and benthic invertebrate surveys, the zone of acute toxicity in the Bear Creek headwaters has been greatly reduced. The mountain Redbelly Dace (Phoxinus oreas), which is listed by the state of Tennessee as in need of management, has been collected in NT14, a tributary to Bear Creek (Fig. 3.4; M. G. Ryon, ORNL, personal communication).

The results of ongoing studies of aquatic biota in Bear Creek are being incorporated into a report (Southworth et al., in preparation) which is expected to be available in draft form in September 1988. These studies are a continuation of the monitoring program reported in Loar et al. (1985) and will provide the most current data available on the ecological status of Bear Creek.

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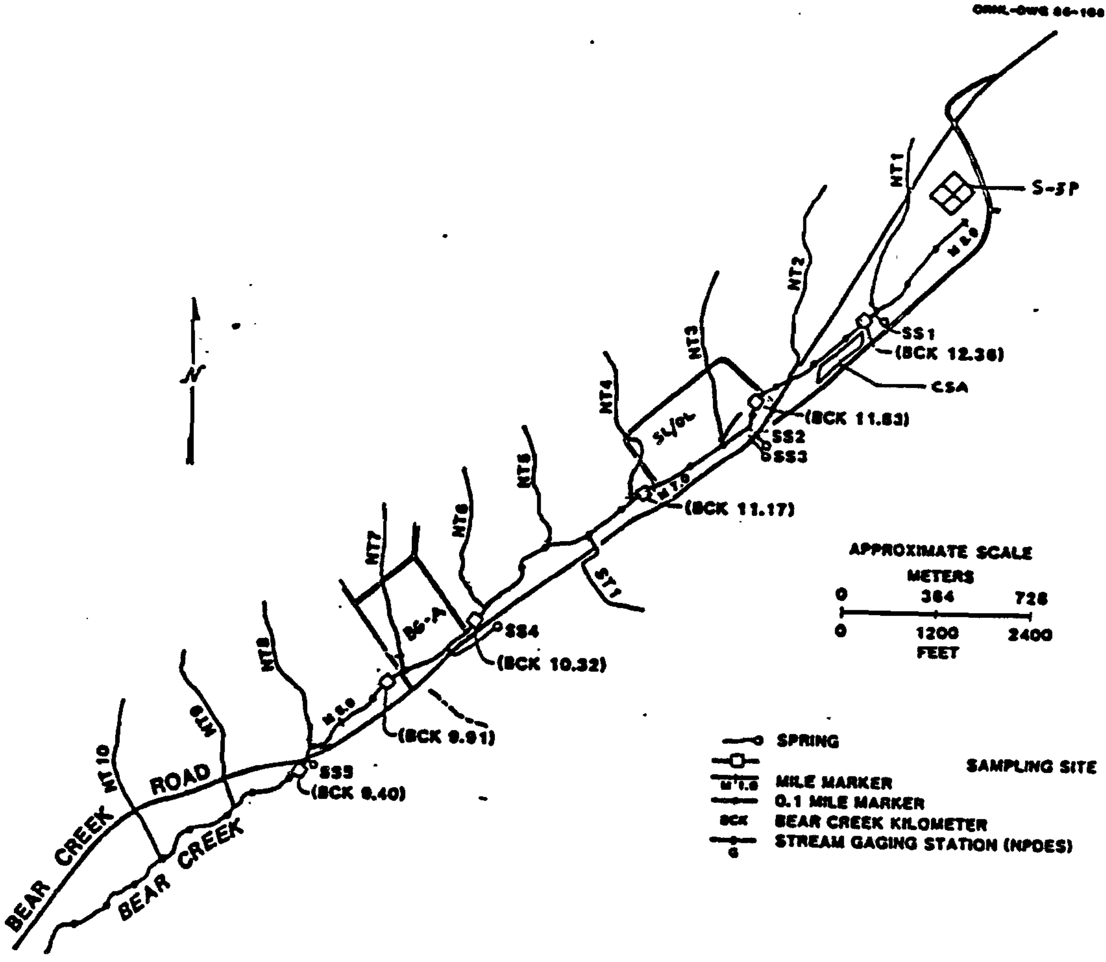

Fig. 3.3 Location of biological sampling sites (BCK) on upper Bear Creek. Distance in kilometers from the confluence with East Fork Poplar Creek is given in parentheses.

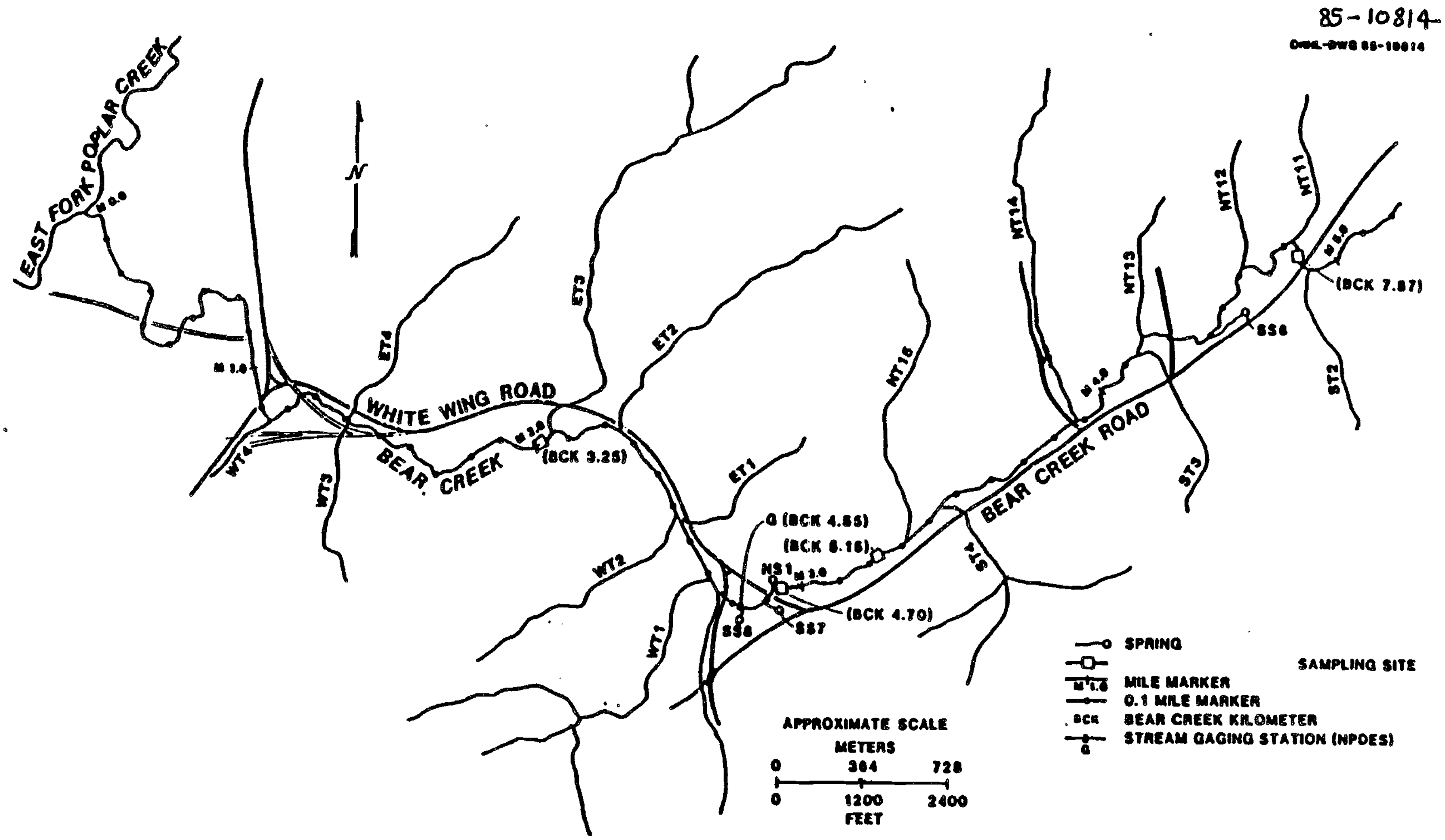

Fig. 3.4 Location of biological sampling sites (BCK) on lower Bear Creek. Distance in kilometers from the confluence with East Fork Poplar Creek is given in parentheses.

3.7 REFERENCES

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4. WEST CHESTNUT RIDGE

The LLWDDD West Chestnut Ridge site area is located west of the ORNL Main Plant facilities (Fig. 1.1). The site consists of three tracts, totalling about 150 acres, within a larger study area included in the site characterization effort. Topography within the characterization area is variable, and only portions of land with gentle to moderate slope are considered potentially feasible for development of low-level waste disposal facilities. Soils are generally thick and overlie weathered dolostone of the Knox Group. A site topographic map (Plate 3) shows detailed site topography, locations of groundwater piezometers, and surface water discharge measurement station locations.

In the following sections, sources of published and unpublished data and information and previously unpublished data are presented. Data sources and new data are organized by disciplinary field (e.g., geology, soils, groundwater).

4.1 GEOLOGY

Preliminary investigations pertinent to the site are published in Ketelle (1982). Ketelle and Huff (1984) give detailed information on site geology and geomorphology based on surficial mapping, soil drilling and testing, and rotary drilling and well construction at the site.

Results of an extensive subsurface investigation and geohydrologic site characterization effort are published in Woodward-Clyde (1984). This report includes drilling logs and well construction diagrams as well as results of numerous field and laboratory tests pertinent to site conditions.

Results of rock core drilling performed along a transect across a portion of the site, including a description of the stratigraphy of the Copper Ridge Dolomite and a conceptual model of groundwater flow based on rock core examination and geophysical log interpretation, are published in Lee and Ketelle (1987).

A key issue concerning use of the West Chestnut Ridge site for waste disposal is the potential for occurrence of sinkhole subsidence since the site is underlain by carbonate bedrock. Two studies were performed to evaluate the potential for karst activity on the site. To evaluate the site-specific soil stability, a soil mechanics analysis of soil stability over an idealized bedrock cavity, based on soil profile characteristics typical of the West Chestnut Ridge site, was performed by Drumm (1987). To understand the regional occurrence of active karst subsidence, a three-phase study was performed. This study included: (1) a regional inventory of karst activity in the Valley and Ridge Province of East Tennessee (Newton and Tanner 1987a), (2) an assessment of subsidence in karst terrains in selected areas in East Tennessee and comparison with the West Chestnut Ridge site (Newton and Tanner 1987b), and (3) an evaluation of sinkhole occurrence in the Valley and Ridge Province of East Tennessee (Newton and Tanner 1987c).

4.2 SOILS

Soils characterization studies performed for the West Chestnut Ridge site include soil mapping, mineralogical and geochemical analyses, and physical testing.

4.2.1 Mapping

Two reports document the mapping of site soils. Lee et al. (1984) present a site soil map and soil profile descriptions. Lietzke (1988) (Appendix I Addendum to ORNL/TM-9361, Soils of the West Chestnut Ridge Site) presents a refinement of the site soil map and more detailed soil profile descriptions. The map and descriptions presented in Lietzke (1988) supersede those of the earlier report.

4.2.2 Mineralogy and Geochemistry

Mineralogy and geochemical characteristics of the West Chestnut Ridge site are documented in several reports. University of Tennessee masters' theses by Monger (1986) and Crafts (1987) report mineralogical and geochemical characteristics of the residual soils which occur on the site. Lee et al. (1984) also reports soil chemical and mineralogical characteristics. A detailed study of soil geochemistry as it pertains to the sorbtion of radionuclides is reported in Seeley and Kelmers (1984).

4.2.3 Physical Properties

Data pertaining to physical properties of soils on the West Chestnut Ridge site are located in several reports. The primary source of soil physical and engineering properties is the subsurface characterization performed by Woodward-Clyde Consultants (1984). This report contains extensive data tabulations and test results for basic engineering properties of site soils as well as an evaluation of slope stability for cut slopes in the Knox residual soils. Selected data published by Woodward-Clyde were used by Drumm (1987) in performance of an analysis of the stability of West Chestnut Ridge soils overlying an idealized bedrock cavity. Reports previously referenced pertaining to mineralogical and geochemical studies also contain some soil physical properties data which are related to their mineral/chemical composition.

4.3 GROUNDWATER

Data pertinent to the groundwater system present at West Chestnut Ridge include measurements of hydraulic conductivities of various site materials, determination of aquifer properties for saturated zones on the site, results of a groundwater tracer test performed in a karst flow conduit within the site study area, piezometric data obtained over a 4-year period, and chemical analytical results on groundwater samples obtained from wells on the site.

4.3.1 Aquifer Properties

Data pertaining to hydraulic conductivity of soils, bedrock, and the aquifer at the West Chestnut Ridge site are reported principally by Woodward-Clyde Consultants (1984). Testing performed includes determination of unsaturated soil permeability, performance of soil infiltration tests in boreholes above the saturated zone, packer testing of bedrock in selected wells, and aquifer properties determination by performance and analysis of an aquifer pump test. In addition to the tests, a groundwater tracer test was performed in a karst groundwater flow system present in the site study area. This test and test results are described in Ketelle and Huff (1984) and Huff et al. (1984).

4.3.2 Water Table Elevations

Wells have been constructed at the West Chestnut Ridge site to measure water levels in soils overlying bedrock and in the upper portions of bedrock. Three generations of wells exist on the West Chestnut Ridge site as follows:

- Ten wells were constructed in a small area of the site in 1982 as part of an early siting study. Drilling logs and well construction information for these wells are included in Appendix J of this report. Well locations and water level data from these wells for the period of record January through September 1983 are published in Elmore et al. (1985).
- Thirty-nine wells distributed over the site study area were constructed in 1983. Drilling logs and well construction information for these wells are included in Woodward-Clyde Consultants (1984). Locations of these wells are shown on the site map (Plate 3).
- Five clusters containing four wells each were constructed in 1986 to detect ephemeral saturation at shallow depths (<~30 ft) in the upper portions of residual soils. Cluster well locations are shown on the site map (Plate 3). Well construction logs for these wells are included in Appendix J.

Well hydrographs for the 39 wells for the period October 1983 through September 1984 are published in Ketelle and Huff (1984). These data, and all subsequent water level data through June 1988, are included in well hydrographs in Appendix K of this report.

4.3.3 Groundwater Quality

Water samples from eight wells on site, sampling waters from three geologic formations, have been collected and analyzed on five occasions. Samples have been analyzed for major and minor dissolved anions and cations, gross radiological parameters, tritium, and volatile organic compounds. Analytical results from two sampling dates in 1984 are included in Appendix L of this report, and analytical results from December 1987, March 1988, and May 1988 are included in Appendix D of this report.

4.4 SURFACE WATER DATA

Surface water data collected at the West Chestnut Ridge site include precipitation, surface water discharge, and water quality data.

4.4.1 Precipitation

Precipitation data collection began at the West Chestnut Ridge site in December 1982. The station location is shown in Elmore et al. (1985). Precipitation data for December 20, 1982, through October 31, 1983, are published in Elmore et al. (1985). Precipitation data for November 1, 1983, through April 30, 1984, are published in Huff and Frederick (1984). Precipitation data for May 1, 1984, through September 30, 1984, are published in Huff and Frederick (1987). Precipitation data for October 1, 1985, through March 31, 1988, are published in Frederick and Clapp (1988).

4.4.2 Surface Water Discharge

Surface water discharge data have been obtained from streams on the West Chestnut Ridge site since July 1982. Initial measurements for July 1982 through September 1983 were made at temporary measurement stations, locations of which are shown in Huff et al. (1984). Periodic instantaneous flow measurements were made manually at these stations and are reported in Elmore et al. (1985). In September 1983, five permanent gaging stations were constructed and instrumented with stage height recorders to provide continuous discharge records on streams at the site. Locations of these stations are shown on the site map (Plate 3). Discharge data summaries from these stations are reported as follows:

Period of record	Information source
11/83 through 4/84	Huff and Frederick (1984)
11/83 through 9/85	Huff and Frederick (1987)
10/85 through 3/88	Frederick and Clapp (1988)

In addition to flow data summaries, these reports variously include rainfall/runoff ratios for each monitored watershed and water budget estimates based on the available record.

4.4.3 Surface Water Quality

The site surface water sampling schedule is similar to that for groundwater chemical characterization. Five surface water samples have been obtained at each of the five surface water discharge stations: two in 1984 and three in 1987/88. Analytical parameters have included major and minor dissolved anions and cations, radiological parameters, and volatile organic compounds. Analytical results for the 1984 samples are reported in Appendix L of this report and those for 1987/88 samples are reported in Appendix D.

4.5 ECOLOGY

4.5.1 Terrestrial Flora

The general description of vegetation for the ORR presented in Appendix O applies to the proposed West Chestnut Ridge site. Abundance of community types on the ORR, on the proposed West Chestnut Ridge site and on the candidate disposal areas within the site (Lockwood Greene 1987) is given in Appendix O, Table 1.1. More specific information on site vegetation and comments on the rare or uncommon communities or species is presented in this section.

The proposed site was extensively surveyed for rare species from June 1 to July 13, 1988. Pine plantations and maintained fields were not visited; species diversity on such sites is typically low, and they are not likely to harbor the rare species now known to or expected to occur on the ORR. Powerline rights-of-way were explored because these corridors host natural successional vegetation. Areas showing the greatest potential for rare species were revisited several times; different species are apparent at different times during the growing season. The chief limitation on the completeness of the rare plant survey is the relatively short portion of the growing season during which observations were made. In addition, extreme drought during this season, and the past 4 years, may have impacted visibility of some species (e.g., shoot dieback).

The proposed West Chestnut Ridge site (Fig. 4-1) is entirely within the NERP boundaries (Fig. 2.3). Upland hardwood is the most extensive community type on the site; pine forests are second in abundance. Distribution of forest communities within the site is shown in Fig. 4.2. The legend for Fig. 4.2 is given in Table 4.1.

The section of the ridge included in the site was intensively inventoried for forest community types about 10 years ago (Hedge 1979). The hardwood forests were found to vary in species composition depending on position on the ridge slope. On the lower slope were yellow poplar/white oak, yellow poplar/chestnut oak, and northern red oak communities. White oak/red oak, yellow poplar/white oak, and yellow poplar (mesic) communities occurred on the lower to middle slopes. Middle slopes contained white oak/hickory, yellow poplar/chestnut oak, and white oak/scarlet oak communities. The latter type exhibited the greatest number and diameter of chestnut stumps on the ridge. Middle to upper slopes were occupied by chestnut oak/black oak and black oak communities. Upper slopes contained white oak/black oak stands.

Unusual communities or species

Several areas of interest shown in Fig. 4.1 and are described in the paragraphs that follow.

Area 1. Calcareous barrens characterized by "pinkish" rock outcrops are scattered on the lower south slope of Chestnut Ridge. Uncommon species are false aloe (Manfreda virginica), Hypericum dolabriforme, and Gentiana quinquefolia.

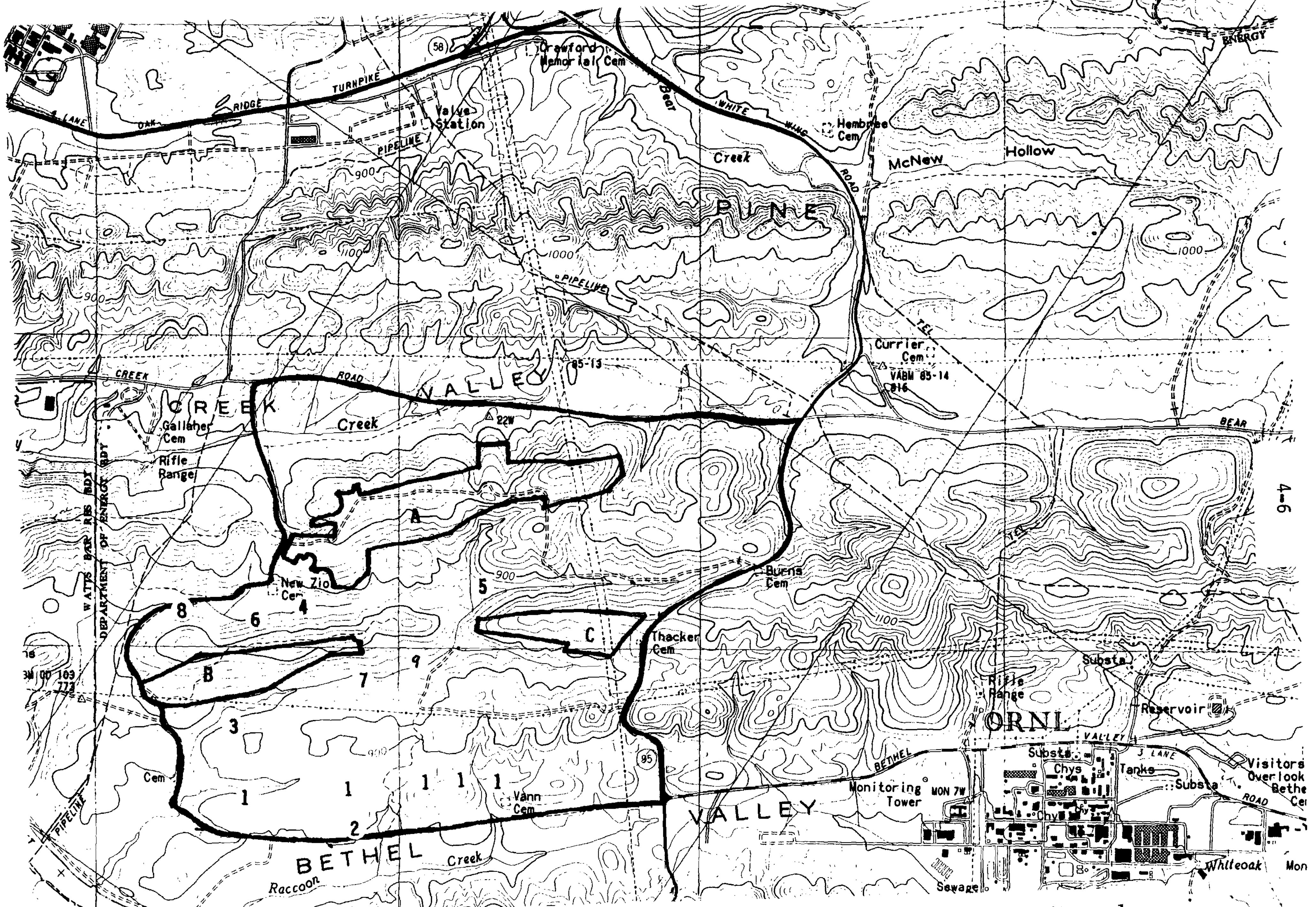

Fig. 4.1 Topographic map of the proposed West Chestnut Ridge site showing candidate disposal areas within the site (A, B and C) and areas of special botanical interest indicated by numbers 1-9. These are describe the text.

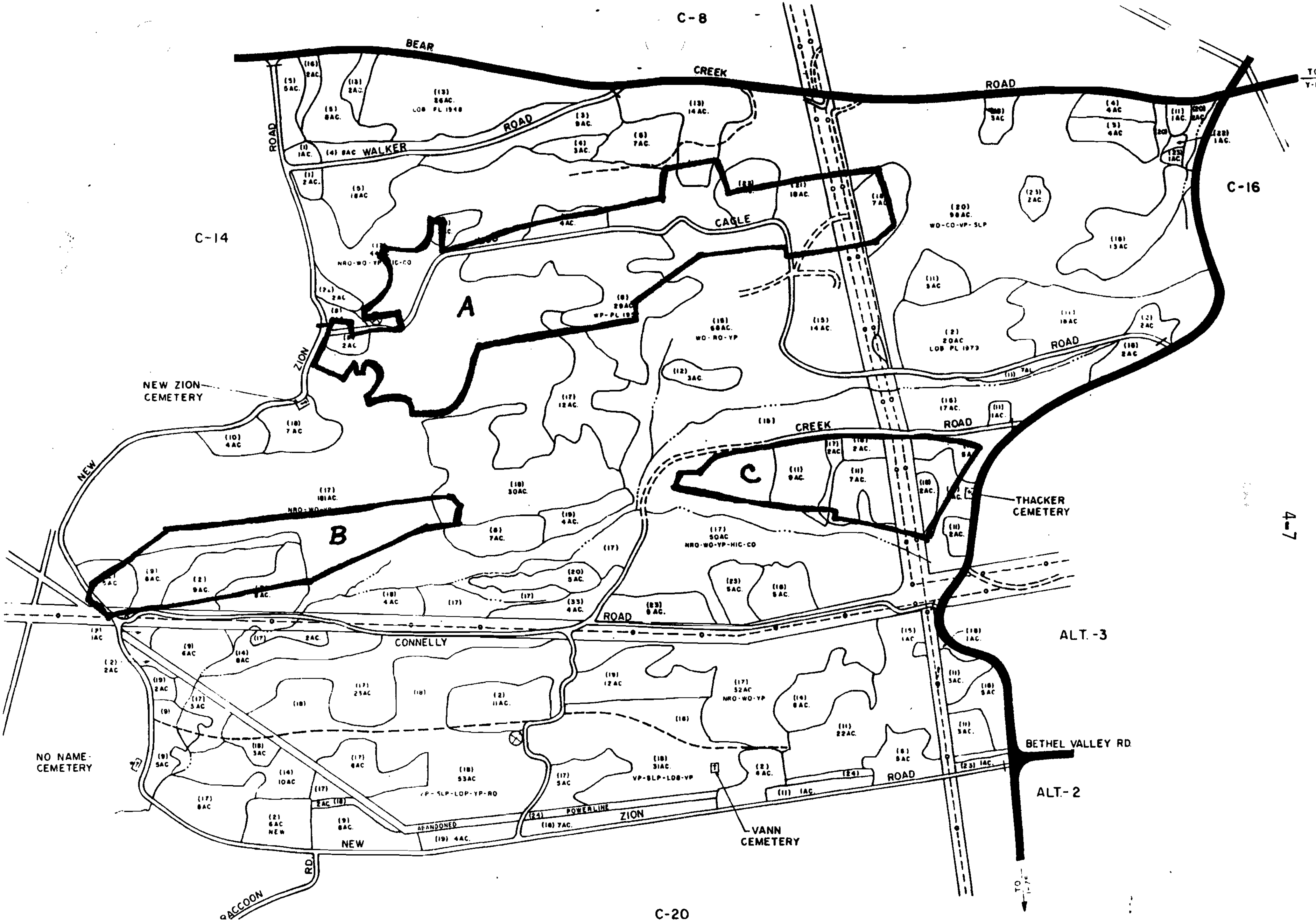

Fig. 4.2 ORNL forest management compartment map (Number 15) for the proposed West Chestnut Ridge site. Candidate disposal areas within the site (A, B and C) are shown. (See Table 4.1 for legend.)

Table 4.1. Legend for Fig. 4.2, ORNL forest management compartment map for the proposed West Chestnut Ridge site.

Stratum No.	Forest cover type[a]	Acreage
1	Loblolly plantation 1982	3
2	Loblolly plantation 1979	60
3	Poplar plantation 1978	13
4	Ash plantation 1978	15
5	Loblolly plantation 1978	30
6	Loblolly plantation 1972	5
7	Loblolly plantation 1969	8
8	White pine plantation 1952	3
9	Loblolly plantation 1951	27
10	White pine plantation 1951	4
11	LOB-SLP plantation 1950	80
12	White pine plantation 1950	3
13	Loblolly plantation 1948	42
14	VP-CED-NRO-WO	26
15	WO-RO-POP	84
16	HIC-WO-GUM-RO	25
17	NRO-WO-POP-HIC-CO	372
18	VP-SLP-LOB-POP-RO	180
19	VP-LOB-RO	20
20	WO-CO-POP-SLP	105
21	CO-HIC-GUM	18
22	POP-RO-WP	3
23	Clearcut	25
24	Abandoned powerline	9
25	Cemeteries	2
26	Powerlines	59
27	Roads	44

[a]

BIR	birch	SG	sweetgum
CED	red cedar	SLP	shortleaf pine
CO	chestnut oak	SRO	southern red oak
HIC	hickory	SYP	southern yellow pine
LOB	loblolly pine	VP	virginia pine
NRO	northern red oak	WO	white oak
POP	poplar	YP	yellow poplar
RM	red maple		

Area 2. Calcareous barrens along Bethel Valley characterized by white to gray limestone extend up the lower south slope of the ridge. Uncommon species include prairie dock (Silphium terebinthinaceum), false aloe (Manfreda virginica), and Psoralea onobrychis.

Area 3. A rocky, apparently calcareous woods occurs here. Arenaria patula (the only known site for this species on the ORR), Bumelia lycoides (a shrub of more southern distribution probably at the northern interior limit of its range here), and Manfreda virginica are present.

Areas 4 and 5. Wetlands along a stream host sedges and ferns including cinnamon fern (Osmunda cinnamomea), royal fern (Osmunda regalis), and chain fern (Woodwardia areolata). Only one other site for chain fern is known on the ORR. Sphagnum moss and Platanthera clavellata, a native orchid, are also present.

Area 6. A stream bed (dry during the summer 1988 drought) runs into a shallow sink with shallow hole. Numerous sinks are in the area where the stream bed should be evident but is not. It appears to be an active karst. The shallow sink is a unique habitat with a cool, moist microclimate that could support rare species. No rare species were detected during the survey period.

Area 7. A large spring and seep area occurs here. This site shows no evidence of homestead disturbance. Such sites are unusual on the ORR. Spring-fed wet areas are a more consistent habitat than those of ephemeral sources and thus provide a habitat for species requiring continual wetness. Shooting star (Dodecatheon meadia) is present near the spring.

Area 8. A limestone outcrop area supports a rich herbaceous flora, including shooting star (Dodecatheon meadia), Jacob's ladder (Polemonium reptans), green mandarin (Disporum lanuginosum), fly poison (Amianthium muscatoxicum), and Smilax ecirrhata.

Area 9. A small population of ginseng (Panax quinquefolius), state listed as threatened, is located here.

Rare Plants

Ginseng (Panax quinquefolius), listed by the state as threatened in Tennessee, was observed in the West Chestnut Ridge site. Location of the population within the site is shown in Fig. 4.1.

Since public access to the ORR has been restricted, ginseng populations have been recovering from the extensive digging of the tubers that persists even today off the ORR. Most of the ginseng collected in the state is marketed in the Orient. The Tennessee Department of Conservation considers ginseng to be threatened with extinction only because it is so heavily collected (Milo Guthrie, Tennessee Dept. of Conservation, personal communication, 1988) For example, in 1985 ginseng was collected in 92 of the state's 95 counties; 23,166 pounds (dry weight) were harvested. The number of plants necessary to make one pound dry weight is roughly from 100 to 300, depending on size.

Although uncommon species may not be state or federally listed for protection, they are of interest since most are restricted to uncommon habitats. Habitat loss results in the overall decline in number of individuals of such species and, if continued, leads to sufficient rarity for state or federal status. Protection of uncommon species on federal land before populations become dangerously reduced is good long-term planning. Mandated recovery efforts for endangered species are expensive to formulate and implement; taking steps to prevent the necessity of such action is cost effective and desirable. Recognition and protection of uncommon habitats on federal land has the added benefit of potentially preserving rare species not currently recognized in the habitat (e.g., insect populations of barrens on the ORR have not been inventoried).

For information on definitions of status for listing plants as threatened and/or endangered species see Appendix O, Tables 1.3 and 1.4.

4.5.2 Terrestrial Fauna

For information on terrestrial fauna for the West Chestnut Ridge site, see Appendix O.

4.5.3 Aquatic Biota

The general description of aquatic biota for the ORR is presented in Appendix O. The major permanent stream on the West Chestnut Ridge site is Ish Creek (Fig. 4.3) Six species of fish were collected at three sampling sites in Ish Creek between December 1983 and January 1984 (DOE 1984). The fish collected are all abundant in area streams, with the exception of the mountain redbelly dace (Phoxinus oreas), which is listed by the state of Tennessee as in need of management (Eager and Hatcher 1980). Such a listing does not mean that the species is threatened or endangered but rather that it should be managed to the optimum carrying capacity of the habitat. More recent surveys of Ish Creek (July and December 1987) also collected mountain redbelly dace, as well as striped shiners, creek chubs, blacknose dace, and Tennessee snubnose darters (M. G. Ryon and B. Harvey, Oak Ridge National Laboratory, unpublished data). The benthic invertebrates of Ish Creek are moderately diverse, and dominated by snails and chironomids (DOE 1984). Manipulative field experiments using periphyton, benthic invertebrates, and fish are currently being carried out in Ish Creek and are scheduled to continue through spring, 1989 (Bret Harvey and Walter Hill, Oak Ridge National Laboratory, personal communication). In addition, periphyton is monitored monthly at a site in Ish Creek as part of the ORNL Biological Monitoring and Abatement Program (H. L. Boston, Oak Ridge National Laboratory, unpublished data).

New Zion Creek is a disappearing stream (i.e., a stream which flows into a bedrock cavity system) within the West Chestnut Ridge site. Benthic invertebrates have not been sampled in New Zion Creek, but no fish were collected during surveys in December 1983 and January 1984 (DOE 1984).

Grassy Creek, a Clinch River tributary stream, originates from a series of springs on the north side of the West Chestnut Ridge site. The headwaters

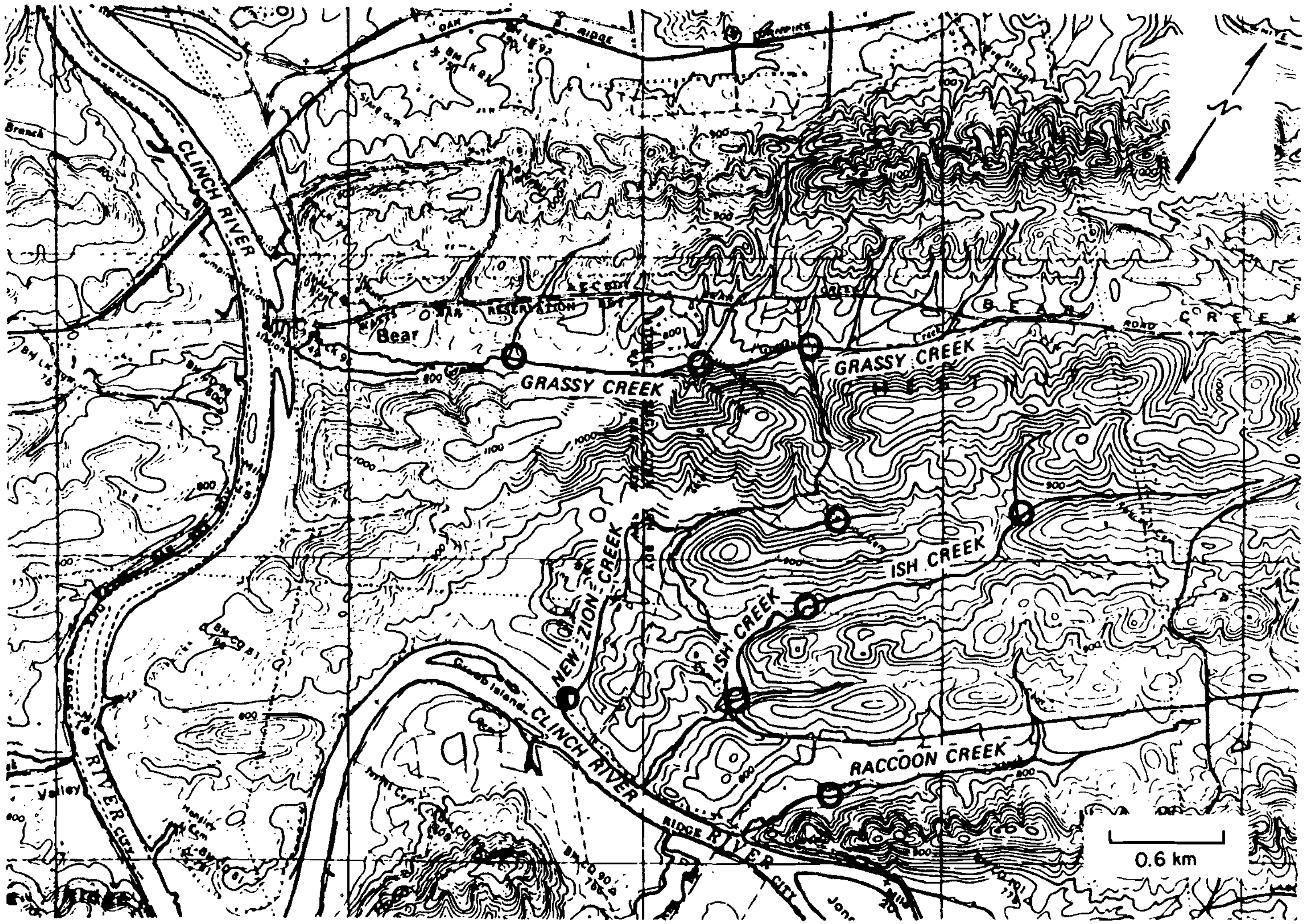

Fig. 4.3 Fish Sampling Sites on Grassy Creek, New Zion Creek, Ish Creek, and Raccoon Creek. Source: DOE (1984).

of Grassy Creek are similar to other small streams in the area, whereas the stream takes on many of the characteristics of a lake embayment near its confluence with the Clinch River. For example, three fish species (white sucker, blacknose dace, and creek chub) were collected in the upper reaches of Grassy Creek near the West Chestnut Ridge site (DOE 1984). The middle reach had 15 fish species and the lower reach had 31 fish species, 25 of which are common in the Clinch River. More recent surveys recorded five and seven species of fish at GCK 2.4 (Grassy Creek kilometer 2.4) and GCK 1.4, respectively; densities were dominated by minnows but suckers, bluegill sunfish, and sculpins were also collected (Loar et al. 1985).

The benthic invertebrates of two Grassy Creek sites, GCK 1.4 and GCK 2.4, were periodically sampled in 1984 (Loar et al. 1985). An abundant and diverse community was observed; some 91 taxa were identified, representing most of the organisms commonly found in streams of this size.

Monitoring of fish and benthic invertebrates at a single site in Grassy Creek continues; most recent survey information will be reported in Southworth et al. (in preparation).

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5. EAST CHESTNUT RIDGE

The LLWDDD East Chestnut Ridge site is located on the west side of the ORR (Fig. 1.1). Only ecological characterization of this site has been completed at this time (Sect. 5.5). Geologic, hydrologic, and water quality characterization activities began in July 1988. The report containing these characterization activities is due April 1, 1989.

5.1 GEOLOGY

5.2 SOILS

5.3 GROUNDWATER DATA

5.4 SURFACE WATER DATA

5.5 ECOLOGY

5.5.1 Terrestrial Flora

The general description of vegetation for the ORR presented in Appendix O applies to the proposed East Chestnut Ridge site. Abundance of community types on the ORR, on the proposed site, and on the candidate disposal areas within the site is given in Appendix O, Table 1.1. More specific information on site vegetation and comments on the rare or uncommon communities or species is presented in this section.

The proposed site was extensively surveyed for rare species from June 1 to July 13, 1988. Pine plantations and maintained fields were not visited; species diversity on such sites is typically low, and they are not likely to harbor the rare species now known to or expected to occur on the ORR. Powerline rights-of-way were explored because these corridors host natural successional vegetation. Areas showing the greatest potential for rare species were revisited several times; different species are apparent at different times during the growing season. The chief limitation on the completeness of the rare plant survey is the relatively short portion of the growing season during which observations were made. In addition, extreme drought during this season, and the past 4 years, may have impacted visibility of some species (e.g., shoot dieback).

Upland hardwoods is the most extensive community type on the East Chestnut Ridge site (Fig. 5.1). Roughly one-third of the area is in pasture. Distribution of forest communities within the site is shown in Fig. 5.2. The legend for Fig. 5.2 is presented in Table 5.1.

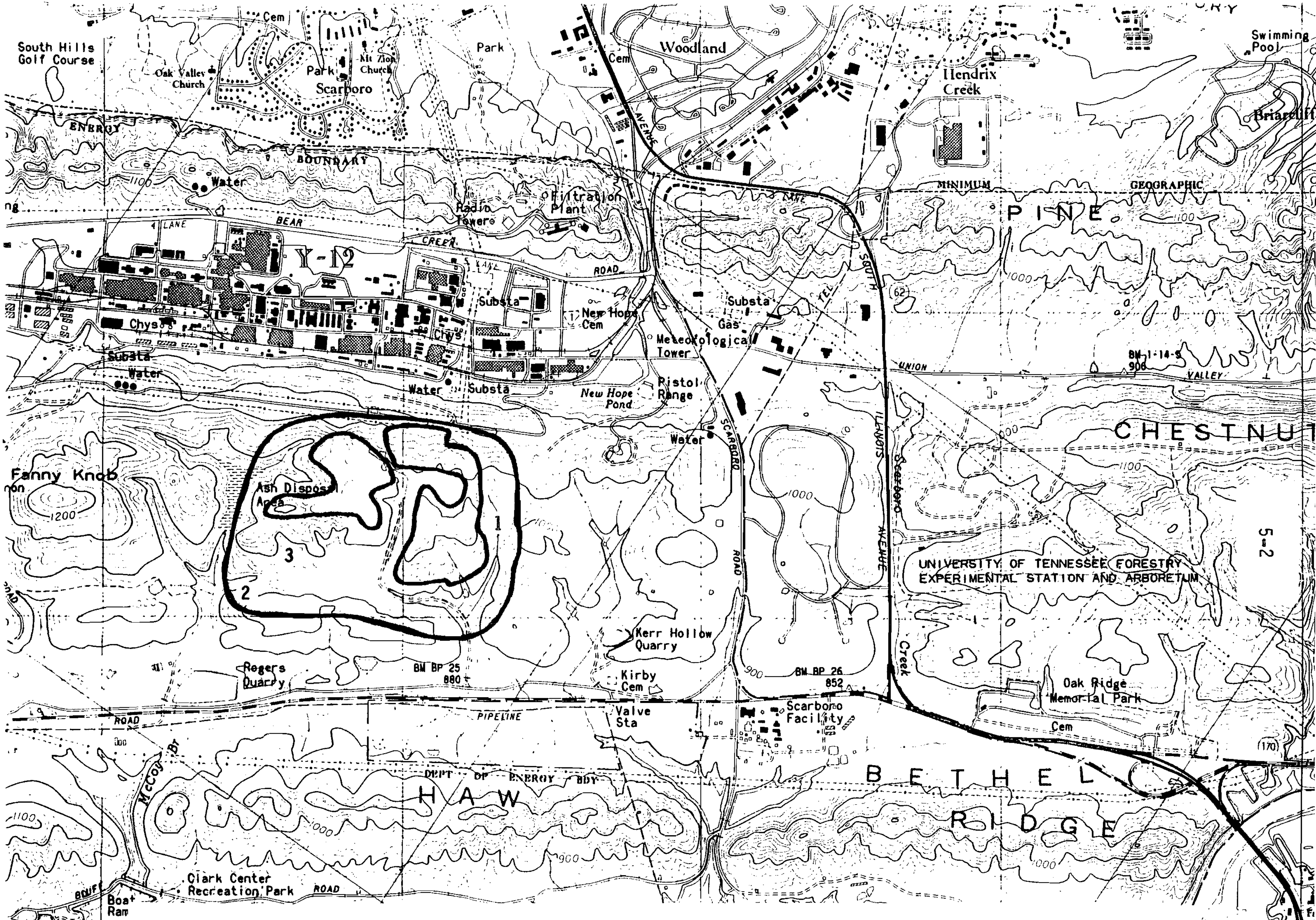

Fig. 5.1 Topographic map of the proposed East Chestnut Ridge site showing candidate disposal areas within the site and areas of special botanical interest indicated by numbers 1-3. These areas are described in the text.

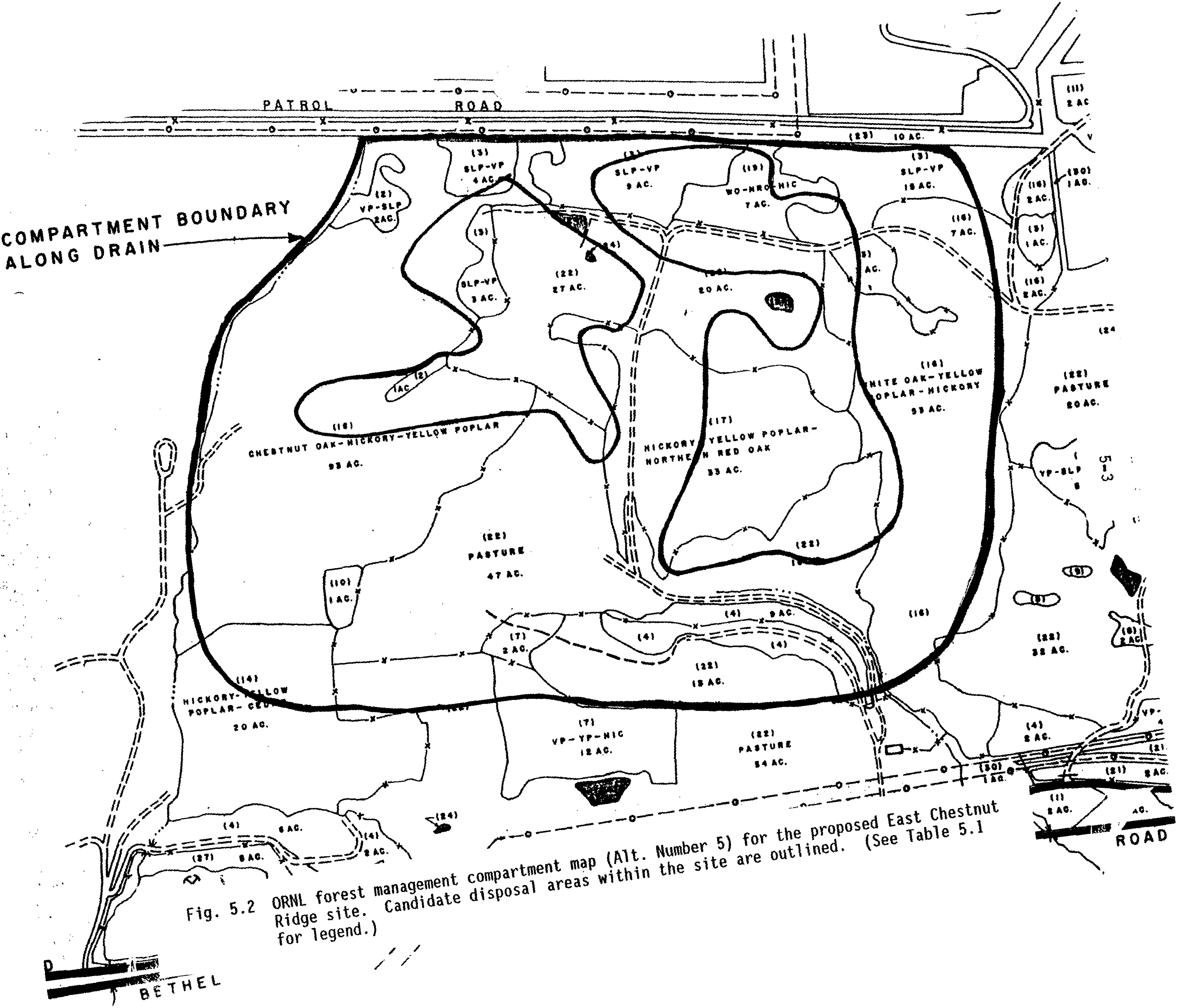

Fig. 5.2 ORNL forest management compartment map (Alt. Number 5) for the proposed East Chestnut Ridge site. Candidate disposal areas within the site are outlined. (See Table 5.1 for legend.)

Table 5.1. Legend for Fig. 5.2, ORNL forest management compartment map for the proposed East Chestnut Ridge site.

Stratum No.	Forest cover type[a]	Acreage
1	Loblolly pine plantation 1948	7
2	Virginia pine-shortleaf pine	10
3	Shortleaf pine-virginia pine	35
4	Virginia pine-cedar-yellow poplar	16
5	Virginia pine-cedar	2
6	Cedar-elm-ash	7
7	Virginia pine-yellow poplar-hickory	21
8	YP-SRO-cedar	2
9	YP-SLP-cherry	6
10	YP-SLP-SRO	1
11	YP-SRO-VP	51
12	SYC-cedar-SLP	8
13	VP-cedar-SRO	2
14	Hickory-YP-cedar	20
15	YP-hickory	31
16	WO-YP-hickory	64
17	Hickory-YP-NRO	33
18	CO-hickory-YP	93
19	WO-NRO-hickory	7
20	WO-SRO-elm	2
21	Cutover	6
22	Pasture	364
23	Powerline right-of-way	17
24	Ponds	7
25	Roads	73
26	Quarries	12
27	Nonforest	25
28	Ash pond	5
29	Water tank	3
30	Telephone right-of-way	2
31	Buildings	1
32	Cemetery	1

[a]BIR	birch	SG	sweetgum
CED	red cedar	SLP	shortleaf pine
CO	chestnut oak	SRO	southern red oak
HIC	hickory	SYP	southern yellow pine
LOB	loblolly pine	VP	virginia pine
NRO	northern red oak	WO	white oak
POP	poplar	YP	yellow poplar
RM	red maple		

Unusual communities or species

Several areas of interest shown in Fig. 5.1 are described here.

Area 1. An unusually mature moist deciduous forest with some white pine present occurs here. The understory is azalea (not in flower during survey period but likely Rhododendron periclymenoides). Associated herbaceous plants include fly poison (Amianthium muscaetoxicum) and featherbells (Stenanthium gramineum).

Area 2. A rocky calcareous woods with some tree canopy openings provides potential habitat for state-listed tall larkspur (Delphinium exaltatum), but none was observed during the survey. Herbaceous species identified include Salvia urticifolia, a sage mostly restricted to alkaline rock outcrops, and Carolina vetch (Vicia caroliniana).

Area 3. Panax quinquefolius, listed as threatened in Tennessee, occurs here in several groups.

Rare plants

Ginseng (Panax quinquefolius), listed as threatened in Tennessee was found on the East Chestnut Ridge site. Locations of the populations are shown in Fig. 5.1.

Since public access to the ORR has been restricted, ginseng populations have been recovering from the extensive digging of the tubers that persists even today off the ORR. Most of the ginseng collected in the state is marketed in the Orient. The Tennessee Department of Conservation considers ginseng to be threatened with extinction only because it is so heavily collected (Milo Guthrie, Tennessee Dept. of Conservation, personal communication, 1988) For example, in 1985 ginseng was collected in 92 of the state's 95 counties; 23,166 pounds (dry weight) were harvested. The number of plants necessary to make one pound dry weight is roughly from 100 to 300, depending on size.

For information on definitions of status for listing as threatened and/or endangered species see Appendix O, Tables 1.3 and 1.4.

5.5.2 Terrestrial Fauna

For information on terrestrial fauna for the East Chestnut Ridge site, see Appendix O.

5.5.3 Aquatic Biota

The general description of aquatic biota for the ORR is presented in Appendix O. There are few permanent waterbodies on the East Chestnut Ridge site, and only one study of the aquatic biota. Loar (1987) surveyed both the east and west tributaries of upper McCoy Branch for benthic invertebrates (Fig. 5.3). McCoy Branch is the disposal basin for Y-12 Plant fly ash; the survey was conducted in headwaters above the embayments which contain fly ash. The west tributary was dry at the time of sampling, although a spring draining into the tributary was found to contain salamanders and a hellgrammite. The east tributary of McCoy Branch was also dry for much of

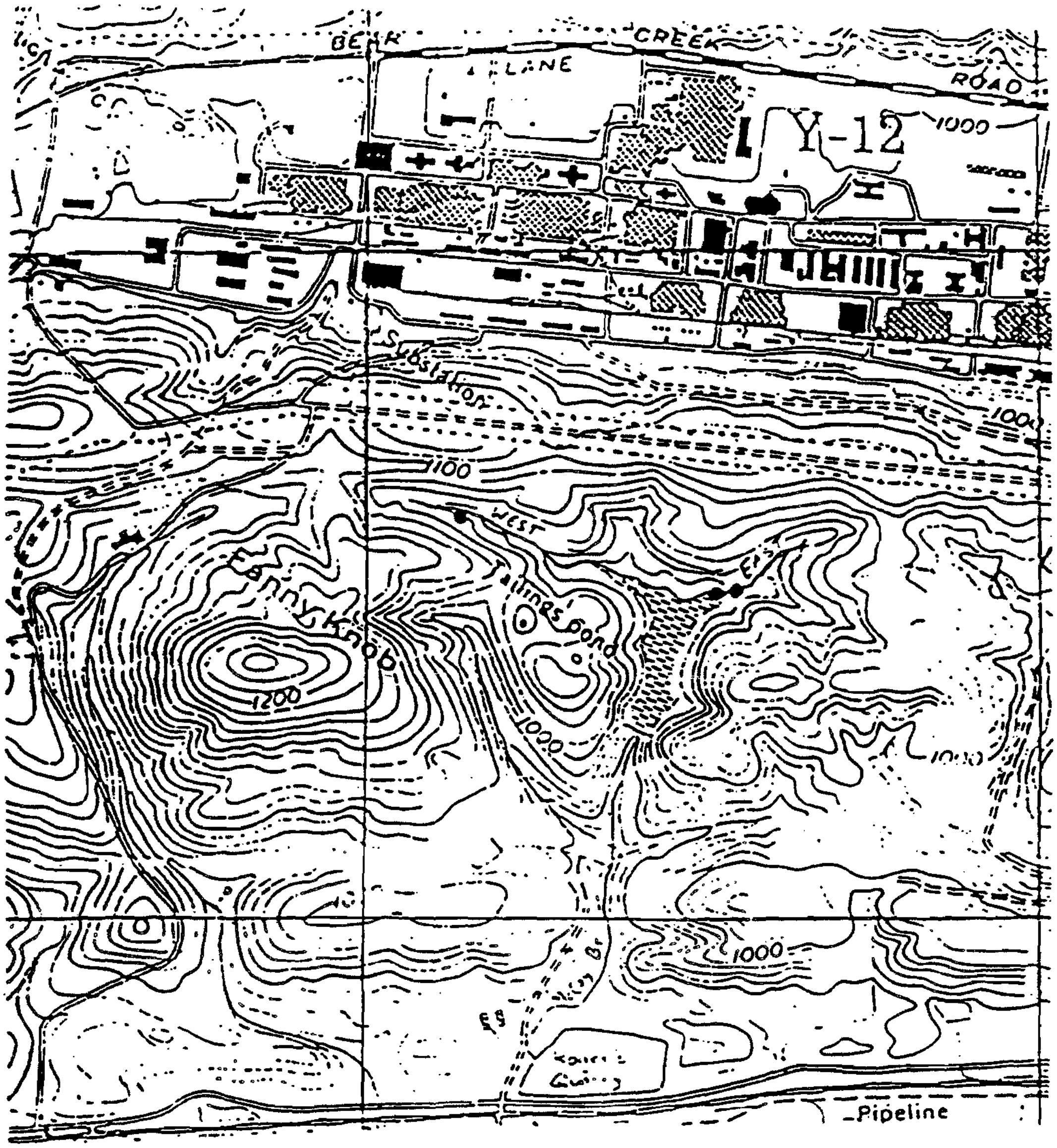

Fig. 5.3 Map of the East and West tributaries of upper McCoy Branch above the Y-12 Plant fly ash disposal basin on Chestnut Ridge. Locations of biological sampling sites ( ) are also shown. Source: Loar (1987).

its length, but the lower 25 m of shallow, standing water above the embayment had numerous benthic invertebrate taxa. Because of the dryness of the tributaries and difficult sampling conditions in the embayments, no attempt was made to sample fish.

Surveys of streams and embayments downstream from the East Chestnut Ridge site were reported in ERDA (1975). Fourteen benthic invertebrate taxa were identified from McCoy Branch below Rogers Quarry; the samples were dominated by hydropsychid caddisflies, mayflies, and chironomids. Eighteen fish species, numerically dominated by minnows, were collected in McCoy Branch (ERDA 1975). Farther downstream, in the McCoy Embayment of Melton Hill Reservoir, both the benthic invertebrate and fish collections were represented by lacustrine species.

Kerr Hollow Branch drains into the Scarboro Embayment of Melton Hill Reservoir from the east side of the East Chestnut Ridge site. Biological surveys collected four species of fish and a diverse benthic fauna typical of small rocky streams (ERDA 1975).

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6. LABORATORY CHARACTERIZATION AND LEACHING OF OAK RIDGE Y-12 PLANT WASTES CONTAMINATED WITH DEPLETED URANIUM

J. L. Collins, W. L. Pattison, and A. D. Kelmers

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6. LABORATORY CHARACTERIZATION AND LEACHING OF OAK RIDGE Y-12 PLANT WASTES CONTAMINATED WITH DEPLETED URANIUM

J. L. Collins, W. L. Pattison, and A. D. Kelmers
Chemical Technology Division

EXECUTIVE SUMMARY

Leaching tests were carried out in a radiochemical laboratory to study the solubilization or release of uranium from five wastes contaminated with depleted uranium. This work was conducted both to support the design, operation, and data analysis of the planned field-scale Uranium Lysimeter Demonstration Project and to aid in the evaluation of potential future waste disposal options. These five wastes result from production operations at the Oak Ridge Y-12 plant which involve depleted uranium. The wastes studied were: (1) production trash - waste generated by cleaning the buildings and general trash found on the floors, (2) mixed metal chips - machining turnings and chips of non-uranium metals such as steel, iron, brass, aluminum, etc., (3) combined waste - a mixture representative of the combined Y-12 Plant wastes for disposal which is composed of production trash, mixed metal chips, and other wastes from highly contaminated areas, (4) air filters from building ventilation systems, and (5) uranium oxide powder from the uranium chip oxidation facility where uranium metal machining turnings and chips are burned to form an oxide waste. Two leachants were employed in the tests. One leachant was a synthetic groundwater representative of Conasauga-formation shallow groundwater that could intrude into disposed wastes in Bear Creek valley or be employed in accelerated lysimeter tests. The other leachant was synthetic landfill leachate which simulated the acidic solution that forms as result of biodegradation of organic materials in a landfill. Two leaching test protocols were employed: (1) batch contact of the waste and leachant at either 2:1 or 20:1 leachant:waste ratios, and (2) a sequential contact which produced a cumulative leachant:waste ratio of 62:1. Both protocols employed leachate sampling at days 1, 2, 3, 4, and 7. Uranium analyses were performed by the ORNL Analytical Chemistry Division.

A novel leaching methodology was developed to allow leaching of bulk wastes on a large scale because meaningful, representative, small-size samples could not be prepared for more conventional 100-g-scale laboratory testing. The production trash, mixed metal chips, combined waste, and air filters were leached in fluorocarbon-lined 30-gal stain- less steel drums. The leachate was recovered by a suction-filtration technique. The uranium oxide powder was leached in 2-L borosilicate glass bottles generally following the proposed EPA Toxicity Characteristic Leach Procedure.

Significant findings which resulted from this work were:

Bimodal Uranium Release - A bimodal response of uranium leached as a function of time was observed in the batch contact tests. In some tests, the uranium concentration in the leachate or the fraction of the initial uranium leached increased with time and did not reach a steady-state limit or constant value in 7 days (the last time point). Such behavior could be consistent with slow leaching kinetics. In other tests, the uranium concentration or fraction released maximized on day 1 (the first data point) and then decreased to low values by day 7. Such behavior could result from sorption or precipitation of initially-solubilized uranium. (Sequential leach tests never showed a decreasing mode because the leachate was removed after each contact.) Bimodal uranium leaching behavior has been reported previously in tests to study uranium leaching from wastes at the Portsmouth Gaseous Diffusion Plant. The existence of bimodal uranium leaching behavior may complicated extrapolation of these 7-day tests to the longer times associated with the field lysimeters or the prediction of the performance of disposal options.

Possible Redox Control of Uranium Release Rate - A number of experimental observations are consistent with the development of reducing redox conditions in the leaching vessel. The most likely reductant for these tests is the mixed metal chips component of the various wastes. These metals can react with water to form strongly reducing conditions. Under such reducing conditions, any solubilized uranium would be reduced to the +4 valence state, and it is well known that the corresponding uranium(IV) oxide, UO_2, has a very low solubility in aqueous solutions. A reasonable working hypothesis is that the redox state of the leaching test (or waste disposal situation) may be the single most important variable in controlling the leaching or release of uranium from the waste. It would be interesting to test this hypothesis in a series of controlled leach experiments.

Rapid Release of Uranium from Air Filters - Of the five wastes tested, the air filters were unique in that large fractions (as much as 68 % in one test) of the uranium were rapidly leached by the synthetic groundwater or the synthetic landfill leachants. This finding suggests that air filters might be candidates for a more isolated disposal option that the other wastes.

Comparison or Uranium Leaching by Synthetic Groundwater vs Synthetic Land-fill Leachate - It was anticipated, based on a general knowledge of uranium chemistry, that the synthetic landfill leachant (a 0.1 M acetate buffer at pH 4.9) would be a more aggressive leachant for uranium, i.e., leach more uranium faster, than the synthetic groundwater (a very dilute Na^+, Cl^-, HCO_3^-solution at near-neutral pH). The test results indicated that the initial acidity (pH) or acid capacity (buffering) of the leachant was not important in controlling the leaching of uranium from most of the wastes. (The uranium oxide powder was the only waste which seemed to fulfill that anticipation.) This is a surprising finding and suggests that simple dissolution reactions involving higher-valence uranium oxides may not be controlling the release of uranium from most of the wastes. By default then, reactions involving other waste components may be dominating the solution chemistry, potentially slow reactions such as oxidation of uranium metal or insoluble UO_2 to soluble uranium(VI) species, and/or sorption/precipitation reactions involving uranium(VI) species may be the important release-rate controlling reactions.

6.1 INTRODUCTION

6.1.1 Purpose and Scope

The purpose of the Laboratory Characterization Task of the Uranium Lysimeter Demonstration Project was to develop data that will support the evaluation of disposal options and analysis of disposal scenarios for low-level radioactive wastes (wastes radiologically contaminated only with depleted uranium) generated by production operations at the Oak Ridge Y-12 Plant. The task had two overall goals: (1) to supply uranium leaching information for the Environmental Data Package (EDP), and (2) to support the field-scale activities by (a) characterizing the wastes which may be placed in the lysimeters, (b) aiding in the prediction of waste performance in the lysimeters over time, and (c) helping in interpretation of the lysimeter data when it becomes available.

The primary task milestone was the development of uranium leaching information on schedule for the EDP. The uranium content and leaching data will be used in the planned Environmental Impact Statement (EIS) and will subsequently be used to help evaluate, model, and/or select potential future waste disposal options for Y-12 Plant low-level wastes. Modeling or predicting the performance of future disposal options requires quantification of the uranium releases from the wastes over time for various potential disposal scenarios, and the task was designed to help generate such information.

The task also supports the Uranium Lysimeter Demonstration Project by providing information to assist in choosing wastes for field-scale testing, and to develop short-time laboratory data which are useful in interpreting the lysimeter test results. To this end, the wastes were chemically and physically characterized.

The task was primarily a laboratory-scale activity. Work on a relatively small scale (compared to field lysimeters or actual disposal operations) was essential in maintaining the task schedule and in allowing control of test parameters which could simulate accelerated time; i.e., allow the laboratory study in a few days of leaching to model events which will take longer times in the lysimeters. Because of the heterogeneous nature of most of the Y-12 Plant waste streams, much of the laboratory work was done on a 30-gal scale. The development of this 30-gal-scale leaching methodology is discussed below.

The Y-12 Plant Waste Transportation, Storage, and Disposal Department identified priority waste streams resulting from production operations involving depleted uranium for study in this task. Most of these waste streams are bulk- or trash-type wastes that are very heterogeneous, both in bulk waste components and in uranium contamination. Because much of the uranium contamination results from operations involving fabrication of uranium or uranium-alloy metal parts, it seemed likely that much of the contamination in the wastes consists of chips or turnings of elemental uranium rather than uranium oxides. Five wastes were investigated during this task. These were: production trash, combined waste, mixed metal chips, air filters, and uranium oxide powder from the Uranium Chip Oxidation Facility (UCOF). These wastes are described in detail in subsequent sections and in Appendix A (Sect. 6.7).

6.1.2 Literature Review

One of the first task activities was the selection of a uranium leaching methodology that would be applicable to the types of wastes generated by the Y-12 Plant. A literature search was undertaken to identify published information on methods for the leaching of uranium from low-level wastes or general methods for leaching contaminants from bulk-type wastes. Emphasis in the search was on prior laboratory work to predict long-term waste or waste facility performance.

The literature review was conducted by searching the DOE Energy Database in the Dialog computer-based information system (Dialog Information Services), and by scanning the indices for the last several years of appropriate journals such as Nuclear and Chemical Waste Management and Radioactive Waste Management and the Nuclear Fuel Cycle. The search was directed toward reports or papers that describe methods for characterization of the leaching of uranium from bulk wastes or trash. No articles describing investigations or methods relevant to the task work with Y-12 Plant wastes were identified. The literature review showed that little attention has been directed in the past to the study of the leaching of uranium from low-level radioactive wastes. Most studies of low-level wastes have tended to focus on fission products such as cesium, strontium, and cobalt, or on transuranics such as plutonium or neptunium. These elements are generally considered to be the more environmentally hazardous radionuclides. Studies of garbage or sanitary landfill wastes have focused on hazardous elements such as cadmium, lead, silver, etc., or on organic contaminants, and have not addressed uranium. Also, few laboratory-scale studies have attempted to deal with heterogeneous bulk or garbage wastes. Prior laboratory waste-leaching work has been primarily limited to prepared or monolithic waste forms; much of the work has been with cast concrete waste forms. Standard or generally accepted leach methods for heterogeneous or 'garbage-type' wastes do not seem to exist, and it was concluded that there is little prior experience with uranium leaching from low-level wastes to draw upon for the leaching and characterization of the Y-12 Plant wastes.

Four generally accepted leaching methods are designed either as pass/-fail regulatory tests or for the study of releases from monolithic waste forms. The Proposed EPA Toxicity Characteristics Leaching Procedure [Code of

Federal Regulations 1986], the EPA Solid Waste Leaching Procedure [EPA March 1984], the Materials Characterization Center Leach Test MCC-1 [Strachan et al. 1982], and the American Nuclear Society Leach Test ANSI/ANS-16 [ANS April 1986] have been developed by others and widely used to characterize hazardous and/or radioactive wastes with respect to the leaching of contaminants or radionuclides. Some of these methods are used to rate wastes on a relative scale and, by varying test parameters, to give indications of waste behavior under diverse disposal scenarios. However, pass/fail tests use a single test time and/or arbitrary test conditions to establish a regulatory screening criteria and, thus, will not yield leaching data which can be extrapolated over the times of interest for the Y-12 Plant waste lysimeters or disposal options. Also, test methods designed for monolithic solid specimens can not be applied to the Y-12 Plant bulk or powdered wastes.

Therefore, an early finding in the evolution of the task planning was the need for a methodology development phase and methods development become the first task activity.

6.1.3 Methodology Development

The heterogeneous nature of the bulk- or trash-type Y-12 Plant wastes precluded work with small samples in the laboratory such as the 100-g samples used in the 2-L-scale EPA proposed Toxicity Characteristic Leach Procedure and necessitated the development of a larger scale method of contacting wastes with leachants and subsequently recovering the leachates. After some experimentation, the following method was selected (the method is described in Sect. 2.2.1 and a detailed laboratory procedure is given in Appendix D). The use of 30-gal drums was chosen to allow working with substantial samples of given waste streams. Lined stainless steel drums were rotated on drum rollers to contact the wastes and leachants. A vacuum-filtration method was devised to recover clarified leachate after the desired contact time. After completion of the 30-gal-scale methodology phase of the task, the leach tests described in this report were carried out.

6.2 MATERIALS AND METHODS

A general description of the materials and methods used in this work is given in this section. Detailed records of the waste samples, formula for the leachates used in the various tests, and detailed laboratory procedures for both the 30-gal-size and 2-L-size leaching methods are given in Sect. 6.7 (Appendices).

6.2.1 Materials

6.2.1.1 Oak Ridge Y-12 Plant Wastes

Five wastes that contain depleted uranium were identified by the Y-12 Plant Waste Transportation, Storage, and Disposal Department as priority wastes for investigation. These wastes were:

(1) Production Trash - waste generated by the cleaners in cleaning and protecting the floors, resulting from efforts to minimize the spread of contamination, and general trash found on the floors. Production trash samples consisted of a very wide variety of components. Samples frequently contained floor sweepings, paper, metal scrap or parts, Hot Hogs (an adsorbent in a cloth tube), oily cloths, plastics, etc.

(2) Mixed Metal Chips - a mixture composed of metal turnings of aluminum, iron, stainless steel, copper, and/or brass. Mixed metal chip samples were primarily turnings and machining chips of various non-uranium metals. Most samples were quite oily.

(3) Composite Waste - an assortment of trash that contains 1/3 production trash, 1/3 mixed metal chips, and 1/3 general trash from highly contaminated areas. This composite waste is representative of the overall mixture of Y-12 Plant wastes for disposal. Composite waste samples were a mixture of the components in the first two waste types plus a wider variety of cloth, leather, and plastic materials. These components sometimes were coated with a red oily liquid.

(4) Air Filters - contaminated air filters from building ventilation systems throughout the Y-12 Plant. These samples were standard HEPA[a] air filters. The filter medium is constructed of fiberglass with aluminum separators and is supported on both sides by galvanized steel wire-guards inside a steel frame (2 x 2 x 1 ft). Appreciable amounts of an easily dispersed, olive green uranium-containing powder was observed on all filters. X-ray diffraction analysis of the powder revealed that it was primarily U_3O_8 with a trace of UO_2. The filter medium was cut from the metal frames and used in the leaching tests. The frames were discarded because they were too large to fit into the 30-gal leaching drums.

(5) Uranium Oxide Powder - powder from the uranium chip oxidation facility (UCOF) where uranium metal turnings and chips are burned to a mixture of uranium oxides [Childs 1987]. One sample was obtained and homogenized for use in all uranium oxide tests. The sample was primarily UO_2 with a small amount of U_3O_8.

Additional details about these wastes are given in Appendix A (Sect. 6.7).

6.2.1.2 Leach Solutions

Two leachants were used in the tests. They were chosen to bracket the acidity of solutions which might contact waste in various disposal situations. One solution was a synthetic groundwater which was prepared in the laboratory. The synthetic ground-water composition was adjusted to simulate the low Na^+, Cl^-, HCO_3^-content, and the acidity (pH 7.3) of a Conasauga

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[a] High Efficiency Particulate Absorber.

saprolite water sample. This composition represents near-surface groundwater which could enter waste emplaced in soil or in a tumulus in the Conasauga formation at the Y-12 site. The other solution was the synthetic landfill leachate specified in the proposed EPA Toxicity Characteristic Leach Procedure (TCLP) [Federal Register 1986]. The TCLP solution is a 0.1 M sodium acetate-acetic acid buffer at pH 4.9 which was specified by the EPA to simulate the carboxylic acid solution formed by the biological degradation of organic wastes in a sanitary landfill. Because the solubility of +6 valence uranium species is known [Krupka et al. 1985; Langmuir 1978; Sergeyeva et al. 1972; Smith et al. 1982] to be highly dependent upon solution pH, it was assumed that these two leachates would bracket the aggressiveness of potential leachants and that the synthetic landfill leachate would be much more aggressive (leach much more uranium) than the synthetic groundwater. (This assumption was not substantiated by the experimental results, as discussed in Sects. 6.3 and 6.4.) See Appendix B (Sect. 6.7) for additional details.

6.2.1.3 Well Water and Artificial Shallow Groundwater Samples

Samples of water from two wells in the Y-12 site were obtained and analyzed. These wells could be sources of water for the planned accelerated lysimeter tests. These two water samples were relatively high in pH and total alkalinity, and it was assumed that the waters were in communication with limestone or dolomite. It was decided not to use these well waters in the waste leaching work because their composition was representative of deep or standing groundwater rather than near-surface or shallow groundwater. Samples of three different types of soil from the Y-12 site were obtained and leached with deionized water to prepare artificial shallow groundwaters for analysis. Artificial waters were prepared because no samples of perched water table or shallow groundwater were available from the Y-12 site. The composition of the Conasauga saprolite sample was chosen to represent near-surface groundwater which could intrude into emplaced waste. See Appendix C (Sect. 6.7) for further details.

6.2.2 Methods

6.2.2.1 30-Gal-Size Leaching

The bulk wastes were leached in fluorocarbon-lined 30-gal stainless steel drums mounted on drum rollers. The waste sample and leachant selected for a given test were placed in the drum, and the drum was sealed and rotated for a specified contact time at ambient temperature. After contact, the drum was opened and the leachate was sampled and/or removed by a vacuum-filtration procedure. Laboratory measurements (pH and temperature) were promptly made, and analytical and archive samples of the leachate were stored in a refrigerator. Two types of leaching protocols were followed: sequential or batch. For the sequential leaches, the leachate was removed, sampled, and replaced with fresh leachant at 1, 2, 3, 4, and 7 days. In addition, the volume of leachant was geometrically increased to yield a series of liquid/solid ratios of 2, 4, 8, 16, and 32 for the five replacement times. This sequence yielded a cumulative liquid/solid ratio of 2, 6, 14, 30, and 62 for the sequential leach protocol. The leachate is removed after each contact period. For the batch leach protocol, a single leachant contact at a liquid/solid ratio of either 2 or 20 was employed. The leachate was sampled (but not replaced) on days 1, 2, 3, 4, and 7. All leachate samples were analyzed by the ORNL Analytical Chemistry Division (ACD) for uranium. All of the uranium data are included in this report. In addition, selected samples were analyzed by the ACD for hazardous materials (inorganic elements and organic compounds), anions, radioactivity (gross alpha and gross beta), alkalinity, and organic carbon. Additional procedural details can be found in Appendix D (Sect. 6.7).

6.2.2.2 2-L-Size Leaching

The uranium oxide powder was leached in 2-L-glass bottles with Teflon-lined lids. The bottles were rotated end-over-end to achieve contact of the powder and leachant. The same batch and sequential leaching protocols were followed as in the 30-gal-size tests with bulk wastes. After the desired contact time, the leachate was recovered by filtration through microfiberglass filter. The same laboratory measurements and analytical information were obtained as for the 30-gal-size experiments. All the uranium information obtained is included in this report. See appendix E (Sect. 6.7) for more procedural details.

6.2.2.3 Analytical Methods

All chemical analyses for the well water samples, artificial shallow groundwater samples, and test leachate samples were performed by the ORNL ACD in accordance with their standard laboratory procedures and quality assurance plan. Uranium was analyzed by Davis-Grey or fluorometric methods. Inorganic elements were determined by inductively coupled plasma spectrometry or atomic adsorption procedures. Organic compounds were analyzed by gas chromatography-mass spectrometry methods. Radioactivity was counted by alpha detectors or beta scintillation techniques. Miscellaneous chemical analyses included alkalinity and inorganic carbon.

The initial uranium content of the bulk waste samples was measured at the Y-12 Plant with their gamma counter, which is used to analyze truck-size loads of waste. Evaluation of this counter can be found in Appendix H (Sect. 6.7).

6.3 RESULTS

6.3.1 Selection of Synthetic Groundwater Composition

Because of our need to prepare large volumes (hundreds of liters) of synthetic groundwater for the 30-gal-scale waste leach tests, an approach to the selection of a synthetic groundwater composition was adopted that avoided an extensive laboratory development activity. Experience has shown that the exact duplication of all natural groundwater species in a solution prepared in the laboratory can be time consuming because saturation or near-saturation with carbonate, silica, or aluminosilicate phases can be difficult to achieve or to maintain in solution if achieved. Many of the groundwater components that are important in studying rock/groundwater chemistry, such as Al, Si, Na/K ratio, Fe(II)/Fe(III) ratio, or degree of saturation with calcite or dolomite, are probably unimportant (or at least a second- or third-level-importance parameter) in the uranium leaching tests. The important water composition parameters involved in uranium solubility are pH, PO_4^{3-}, SO_4^{2-}, F^-, and CO_3^{2-} because these control the U(VI) speciation and, in consort with the solid phases present, the uranium solubility [Langmuir 1978]. We, therefore, compared the leaching of uranium into several well waters and a simple synthetic groundwater.

A series of 2-L-size batch leach tests at 20:1 leachate:waste ratio was undertaken to compare the leaching of uranium from uranium oxide powder from the UCOF. Uranium oxide powder was chosen as the waste for these tests to ensure use of a reproducible waste material for the replicate tests. This test series was designed to compare the aggressiveness (ability to leach uranium) of two well waters, which could be used in the accelerated field lysimeter tests with a synthetic groundwater for the laboratory tests. The synthetic landfill leachate pH 4.9 buffer solution specified in the proposed EPA Toxicity Characteristic Leach Procedure [Federal Register 1986] was also included as a test leachant for comparison with the groundwaters. The tests were run in triplicate to explore the reproducibility of the laboratory procedure and analytical methods.

The uranium leaching data are presented in Table 6.1. A summary of the synthetic leaching solutions is described in Appendix B, and well water composition data are included in Appendix C (Sect. 6.7.3). Excellent - reproducibility of the uranium concentration values can be seen for the four sets of triplicate leach tests. The standard deviation values are only a small fraction of the uranium concentration values. This reproducibility results from several aspects of these tests: (1) the starting materials--both the uranium oxide powder and, of course, the solutions were well mixed--and replicate samples taken for parallel tests were highly reproducible, (2) the 2-L-size test procedure is relatively easy to carry out, and (3) the fluorometric analytical method for uranium is a well established method.

The data in Table 6.1 show that the well waters or synthetic groundwater solubilized much less uranium than did the synthetic landfill leachant. The synthetic groundwater was the least aggressive and leached the smallest amount of uranium. Thus, use of the synthetic landfill leachate and synthetic groundwater in the 30-gal-scale leach tests would bracket the ranges of aggressiveness exhibited by these potential leachants.

Based on the uranium leaching data and the general approach to synthetic groundwater preparation, a decision was reached to prepare synthetic groundwater containing only Na^+, Cl^-, and HCO_3^- at concentrations equivalent

Table 6.1. Comparison of uranium leaching from uranium oxide powder by two natural groundwaters, a synthetic groundwater, and a synthetic landfill leachate[a]

Leachant[b]	Uranium concentration (mg U/L) (mean ± 1 std. dev.)	Final pH (mean ± 1 std. dev.)
GW-84	77 ± 6	6.38 ± 0.06
GW-376	143 ± 1	6.82 ± 0.12
Synthetic groundwater	56 ± 1	5.74 ± 0.08
Synthetic landfill	1608 ± 23	4.92 ± 0.00

[a] All leach tests were run in triplicate for 24 h at 20:1 leachant: uranium oxide powder from the UCOF.

[b] GW-84 is water from well GW-84 located in the Maryville Formation of the Conasauga Group; GW-376 is water from well GW-376 (50 ft deep) which is located up-grade of the Y-12 lysimeter site in Bear Creek Valley; synthetic groundwater is synthetic groundwater prepared in the laboratory; synthetic landfill is synthetic landfill leachate prepared in the laboratory to the proposed EPA Toxicity Characteristic Leach Procedure formulation.

to Conasauga artificial shallow groundwater (see Appendic C, Sect. 6.7.3), and to adjust the pH to get the equivalent acidity. A composition equivalent to the Conasauga saprolite water was selected. The Conasauga saprolite water composition (Appendix C, Sect. 6.7.3) did not contain detectable amounts of F^-, SO_4^{2-}, or PO_4^{3-}. Also, Ca^{2+} was not detected and Mg^{2+} was very low. The synthetic groundwater formulation selected for the leaching tests was: Na^+, 0.10 mmol; Cl^-, 0.02 mmol; HCO_3^-, 0.08 mmol; pH, 7.3.

This synthetic groundwater composition was prepared by dissolving NaCl and $NaHCO_3$ in deionized water, and then adjusting the pH to 7.3 ± 0.1 with HCl as needed (see Appendix B, Sect. 6.7.2.1). This composition is a very dilute, very weakly buffered solution, and exact control of the pH at a predetermined value may be difficult to achieve and also may be unimportant with respect to the waste leaching tests because the acid/base capacity of the wastes likely will establish the leach test pH. This synthetic groundwater is a stable, easy-to-prepare water that avoids the difficulties often encountered with attempting to poise redox couples such as Fe(II)/Fe(III), or in dissolving and keeping silicates and aluminosilicates in solution.

6.3.2 Uranium Leaching

6.3.2.1 Production Trash

A summary of the uranium data for the four batch leach tests with production trash is given in Table 6.2 and in Fig. 6.1. A similar data summary and plot for the two sequential leach tests is given in Table 6.3 and Fig. 6.2.

The batch test protocol results all showed an increasing leach mode. When plotted as either the fraction of the initial uranium released or as the uranium concentration in solution vs time, there was generally a rapid increase by the first time point (day 1) and then a continuing but more gradual increase up to the last time point (day 7). In one case, about 1.6% of the initial uranium was leached, while in the other cases less than 0.8% was leached. The release of uranium from the waste did not seem to correlate with the liquid/solid ratio (L/S), the leachant composition, or the leachate pH. The greatest leaching occurred in the test at L/S of 2.0 with synthetic groundwater which terminated at a pH of 7.4. If the solution chemistry controlled the uranium leaching, then the greatest release might have been expected in the test at L/S of 20.0 with synthetic landfill leachate which terminated at pH 5.5. It seems that properties of the production trash and/or the form of uranium in the waste rather then the apparent solution chemistry may be controlling the uranium release rate in these tests.

The two sequential leach tests showed a rapid release of uranium in the early, low L/S ratio contacts, and then smaller releases into the later, high L/S ratio contacts. Surprisingly, more uranium was leached by the synthetic groundwater than by the synthetic landfill leachate. Perhaps the waste sample used in the synthetic groundwater test had a more soluble form of uranium than the other waste sample. A maximum of about 1% of the uranium was leached from this waste in these tests; little additional uranium was being solubilized in the final contacts with the larger volumes of leachant.

6.3.2.2 Composite Waste

A summary of the uranium data for the five batch leach tests (four planned tests and one partial duplicate test due to a plastic barrel failure) with composite waste is given in Table 6.4 and in Fig. 6.3. A similar data summary and plot for the two sequential leach tests are given in Table 6.5 and Fig. 6.4.

The batch test protocol results showed a more complex uranium release pattern than for production trash. When plotted as either the fraction of the initial uranium released or as the uranium concentration in solution vs time, there was generally an increase to the first time point (day 1). Subsequently, however, some tests showed a continuing but more gradual increase up to the last time point (day 7), while in other tests the uranium concentration in solution (and, therefore, the fraction released) decreased to low values by day 7, that is, uranium goes into solution and later

Table 6.2. Summary of batch leach data for production trash

	Test parameters							Results					
Sample no.	Leach vol. (L)	Leachant[a]	Solid waste (kg)	Uranium (g)	L/S[b]	Leach time (h)	Cum.[c] leach time (h)	Leachate uranium conc. (mg/L)	Total[d] uranium leached (g)	Initial uranium leached (%)	pH	Cond. (mmho)	Temp. (°C)
4FSA	71.2	TCLP	3.56	425	20.0	25.5	25.5	13.0	0.926	0.22	5.09	4.79	25.1
4FSB	71.2	TCLP	3.56	425	20.0	20.0	45.5	20.0	1.424	0.34	5.04	4.43	24.6
4FSC	71.2	TCLP	3.56	425	20.0	23.0	68.5	28.0	1.994	0.47	5.17	5.01	25.2
4FSD	71.2	TCLP	3.56	425	20.0	23.5	92.0	40.0	2.848	0.67	5.22	4.85	25.4
4FSE	71.2	TCLP	3.56	425	20.0	72.0	164.0	50.0	3.560	0.84	5.50	5.99	26.1
8FSAAA	42.6	SNGW	2.13	354	20.0	18.8	19.0	2.5	0.105	0.03	6.67	0.66	26.1
8FSBBB	42.6	SNGW	2.13	354	20.0	25.1	42.5	4.3	0.185	0.05	6.49	0.78	25.9
8FSCCC	42.6	SNGW	2.13	354	20.0	23.5	66.0	9.5	0.403	0.11	6.73	0.82	26.0
8FSDDD	42.6	SNGW	2.13	354	20.0	23.2	90.0	18.0	0.768	0.22	6.81	0.83	25.8
8FSEEE	42.6	SNGW	2.13	354	20.0	72.2	162.0	47.0	2.004	0.57	6.73	0.79	26.3
3FSA	18.3	TCLP	9.14	1224	2.0	26.5	26.5	210.0	3.839	0.31	6.70	7.23	25.2
3FSB	18.3	TCLP	9.14	1224	2.0	22.0	48.5	249.0	4.552	0.37	6.58	7.86	24.0
3FSC	18.3	TCLP	9.14	1223	2.0	24.0	72.5	377.0	6.892	0.56	6.77	7.21	25.5
3FSD	18.3	TCLP	9.14	1223	2.0	23.3	95.8	467.0	8.537	0.70	6.73	8.36	25.8
3FSE	18.3	TCLP	9.14	1223	2.0	69.0	164.8	458.0	8.372	0.68	6.63	8.02	26.4
7FSAAA	17.3	SNGW	8.62	876	2.0	19.8	19.8	168.0	2.903	0.33	7.09	3.77	25.9
7FSAAB	17.3	SNGW	8.62	876	2.0	24.8	44.58	476.0	8.228	0.94	7.04	4.16	26.0
7FSAAC	17.3	SNGW	8.62	876	2.0	21.5	66.08	592.0	10.562	1.21	7.05	4.36	25.5
7FSAAD	17.3	SNGW	8.62	876	2.0	25.8	91.91	656.0	11.714	1.34	7.15	4.14	25.8
7FSAAE	17.3	SNGW	8.62	876	2.0	72.1	163.99	796.0	14.097	1.61	7.40	3.00	25.9

[a] TCLP = synthetic landfill leachate; pH = 4.85 at 26°C; conductivity = 4.24 mmho; SNGW = synthetic groundwater; pH = 6.85 at 26°C; conductivity = 0.013 mmho.

[b] L/S = liquid/solid ratio.

[c] Cum. = cumulative.

[d] Corrected for analytical samples that were removed.

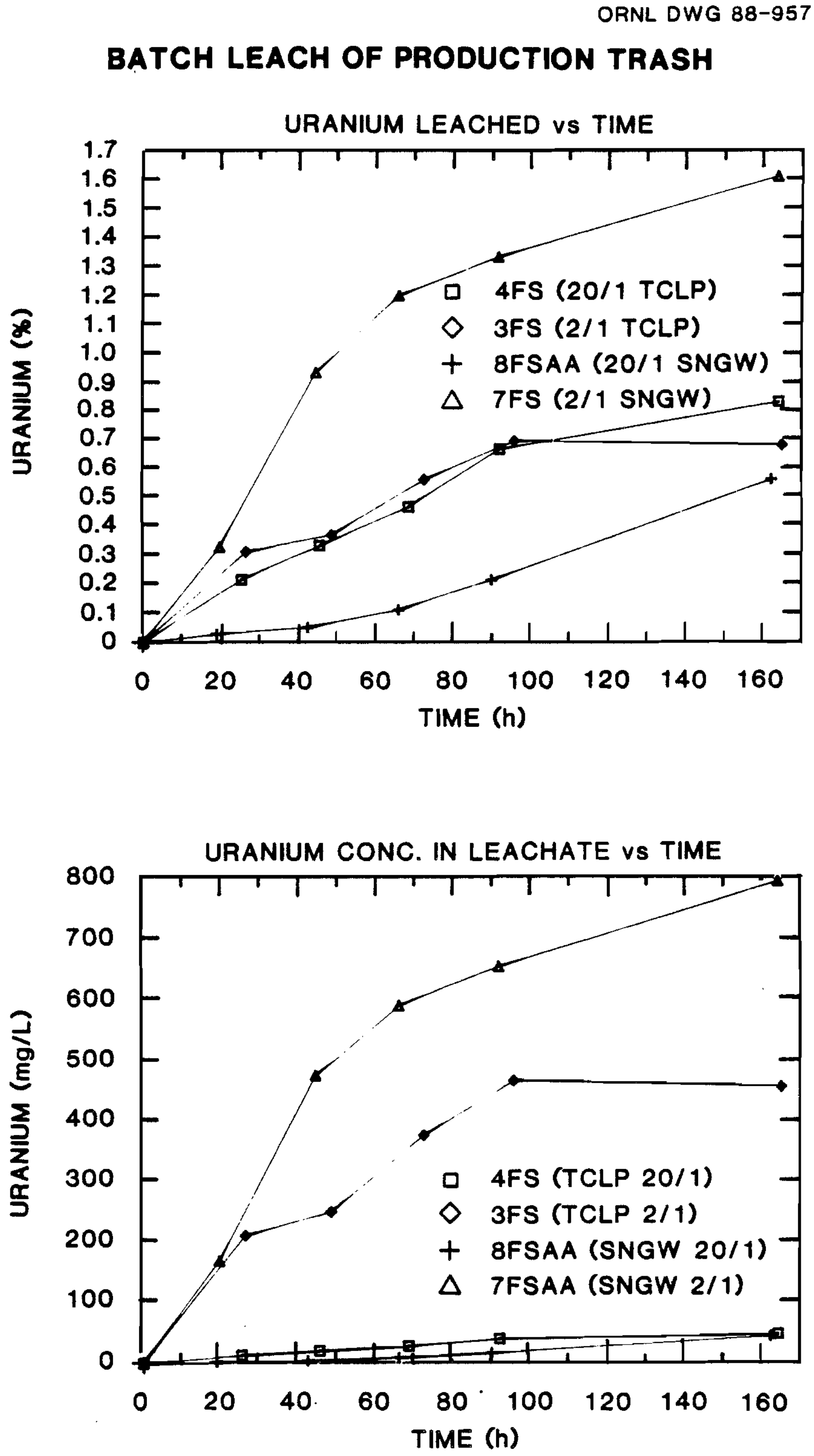

Fig. 6.1. Batch leach of production trash.

Table 6.3. Summary of sequential leach data for production trash

	Test parameters									Results							
Sample no.	Leach vol. (L)	Cum.[a] leach vol. (L)	Leachant[b]	Solid waste (kg)	Uranium (g)	L/S[c]	Cum. L/S	Leach time (h)	Cum. leach time (h)	Uranium conc. (mg/L)	Uranium in leachant (g)	Leached uranium (g)	Cum. uranium leached (g)	Initial uranium leached (%)	pH	Cond. (mmho)	Temp. (°C)
IFSA	7.2	7.2	TCLP	3.56	710.0	2.0	2.0	21.0	21.0	84.0	0.61	0.61	0.61	0.09	6.53	5.05	25.7
1FSB	15.9	23.1	TCLP	3.56	709.6	4.5	6.5	23.5	44.5	57.0	0.90	0.73	1.33	0.19	5.93	3.92	26.1
1FSC	28.5	51.6	TCLP	3.56	708.8	8.0	14.5	24.1	68.6	61.0	1.74	1.60	2.94	0.41	5.54	3.70	26.7
1FSD	57.0	109.0	TCLP	3.56	707.2	16.0	30.5	23.0	91.6	23.0	1.31	1.19	4.12	0.58	5.18	5.01	26.6
1FSE	99.7	208.2	TCLP	3.56	705.9	28.0	58.5	71.0	162.6	7.7	0.77	0.72	4.85	0.69	5.14	3.81	24.9
5FSA	7.4	7.4	SNGW	3.67	749.0	2.0	2.0	20.8	20.8	369.0	2.71	2.71	2.71	0.36	7.65	3.74	25.0
5FSB	14.7	22.1	SNGW	3.67	747.5	4.0	6.0	23.2	43.9	234.0	3.44	2.21	4.92	0.66	7.15	2.46	25.5
5FSC	29.4	51.4	SNGW	3.67	745.0	8.0	14.0	25.3	69.3	69.0	2.03	1.10	6.02	0.81	7.10	0.35	24.6
5FSD	58.8	110.2	SNGW	3.67	743.3	16.0	30.0	23.1	92.3	16.0	0.94	0.60	6.62	0.89	7.10	1.93	24.1
5FSE	80.8	191.1	SNGW	3.67	742.5	22.0	52.0	72.3	164.7	11.0	0.89	0.81	7.43	1.00	7.03	1.71	24.6

[a] Cum. = cumulative.

[b] TCLP = synthetic landfill leachate; pH = 4.85 at 26°C; conductivity = 4.24 mmho; SNGW = synthetic groundwater; pH = 6.85 at 26°C; conductivity = 0.013 mmho.

[c] L/S = liquid/solid ratio.

ORNL DWG 88-953

SEQUENTIAL LEACH OF PRODUCTION TRASH

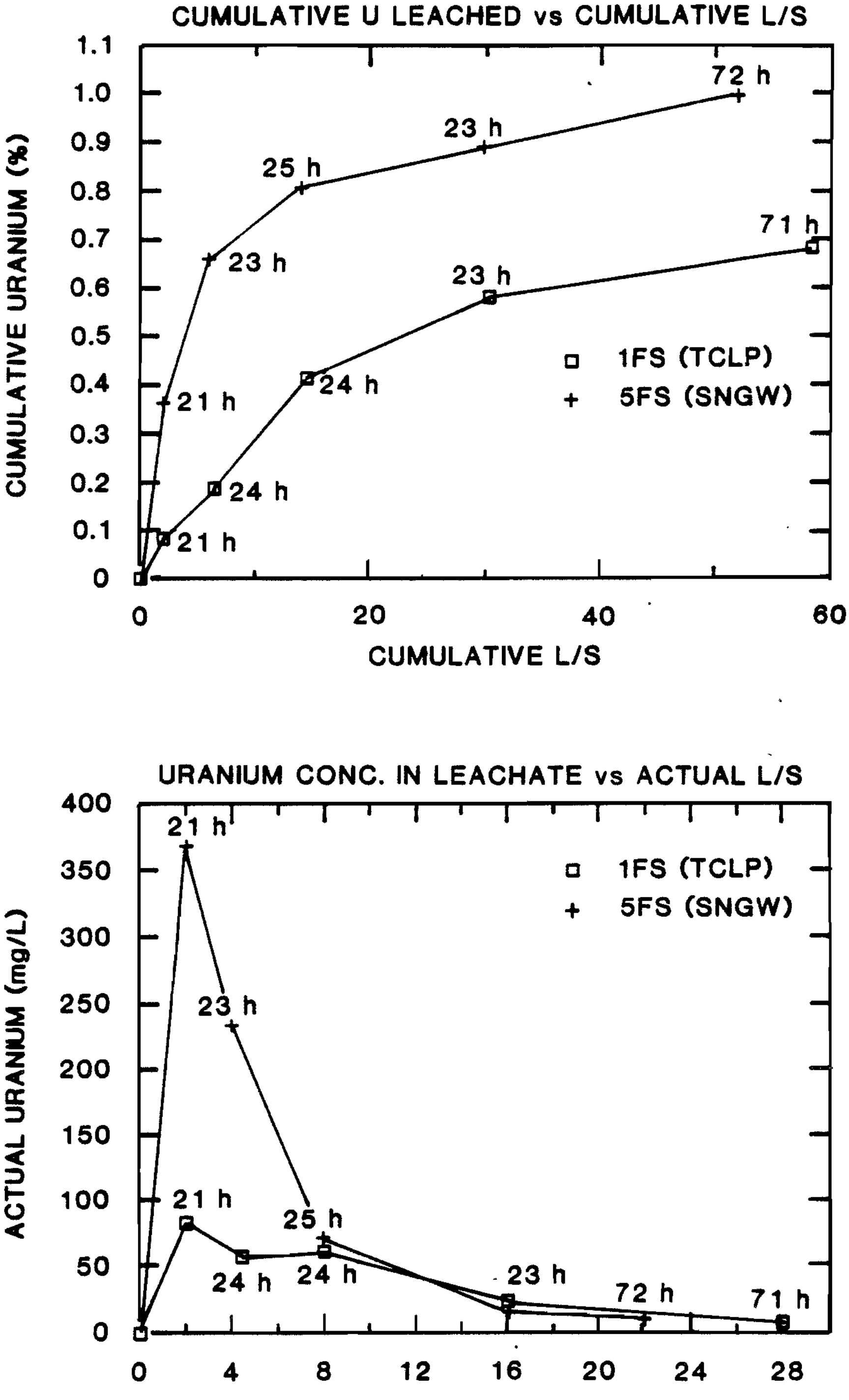

Fig. 6.2. Sequential leach of production trash.

Table 6.4. Summary of batch leach data for composite waste

	Test parameters							Results					
Sample no.	Leach vol. (L)	Leachant[a]	Solid waste (kg)	Uranium (g)	L/S[b]	Leach time (h)	Cum.[c] leach time (h)	Leachate uranium conc. (mg/L)	Total[d] uranium leached (g)	Initial uranium leached (%)	pH	Cond. (mmho)	Temp. (°C)
4BALAA	81.5	TCLP	4.08	220	20.0	22.6	22.6	16.0	1.304	0.59	6.28	5.12	25.5
4BALBB	81.5	TCLP	4.08	220	20.0	22.4	45.0	9.4	0.766	0.35	5.88	4.57	25.6
4BALCC	81.5	TCLP	4.08	220	20.0	23.8	68.8	4.0	0.328	0.15	5.73	4.30	25.8
4BALDD	81.5	TCLP	4.08	220	20.0	25.2	94.0	2.2	0.181	0.08	5.46	4.56	26.3
4BALEE	81.5	TCLP	4.08	220	20.0	71.1	165.1	0.3	0.024	0.01	5.47	5.67	25.9
8BALAAA	99.8	SNGW	8.10	194	12.3	20.9	20.9	1.6	0.157	0.08	6.77	0.52	26.1
8BALBBB	99.8	SNGW	8.10	194	12.3	23.7	44.6	14.2	1.418	0.73	6.49	0.78	25.9
8BALCCC	99.8	SNGW	8.10	194	12.3	24.9	69.5	20.2	2.017	1.04	6.47	0.60	26.0
8BALDDD	99.8	SNGW	8.10	194	12.3	23.1	92.6	25.4	2.536	1.31	6.47	0.62	25.8
8BALEEE	99.8	SNGW	8.10	194	12.3	70.7	163.3	27.9	2.785	1.44	6.40	0.64	26.4
3BALA	19.9	TCLP	8.96	317	2.0	19.5	19.5	8.8	0.174	0.06	6.16	5.51	25.2
3BALB	19.9	TCLP	8.96	317	2.0	24.0	43.5	2.7	0.053	0.02	6.56	5.08	25.3
3BALC	19.9	TCLP	8.96	317	2.0	23.0	66.5	1.1	0.022	0.01	6.62	5.49	25.7
3BALAA	21.8	TCLP	10.91	138	2.0	27.3	27.3	63.0	1.375	1.00	5.23	4.36	25.8
3BALBB	21.8	TCLP	10.91	138	2.0	21.4	48.7	73.0	1.593	1.15	5.50	4.43	25.8
3BALCC	21.8	TCLP	10.91	138	2.0	23.3	72.0	86.0	1.876	1.36	5.62	3.97	25.2
3BALDD	21.8	TCLP	10.91	138	2.0	23.4	95.4	143.0	3.120	2.26	5.66	4.18	25.3
3BALEE	21.8	TCLP	10.91	138	2.0	73.3	168.7	290.0	6.327	4.59	6.07	5.99	26.1
7BALAAA	21.9	SNGW	10.93	131	2.0	27.9	27.9	12.6	0.276	0.21	6.90	2.02	26.1
7BALBBB	21.9	SNGW	10.93	131	2.0	22.8	50.8	2.0	0.044	0.03	6.93	1.89	26.2
7BALCCC	21.9	SNGW	10.93	131	2.0	21.8	72.6	1.9	0.040	0.03	6.85	1.68	26.1
7BALDDD	21.9	SNGW	10.93	131	2.0	26.3	98.8	0.8	0.018	0.01	6.99	1.51	26.0
7BALEEE	21.9	SNGW	10.93	131	2.0	70.9	169.7	9.6	0.209	0.16	7.06	1.23	26.3

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[a] TCLP = synthetic landfill leachate; pH = 4.85 at 26°C; conductivity = 4.24 mmho; SNGW = synthetic groundwater; pH = 6.85 at 26°C; conductivity = 0.013 mmho.

[b] L/S = liquid/solid ratio.

[c] Cum. = cumulative.

[d] Corrected for analytical samples that were removed.

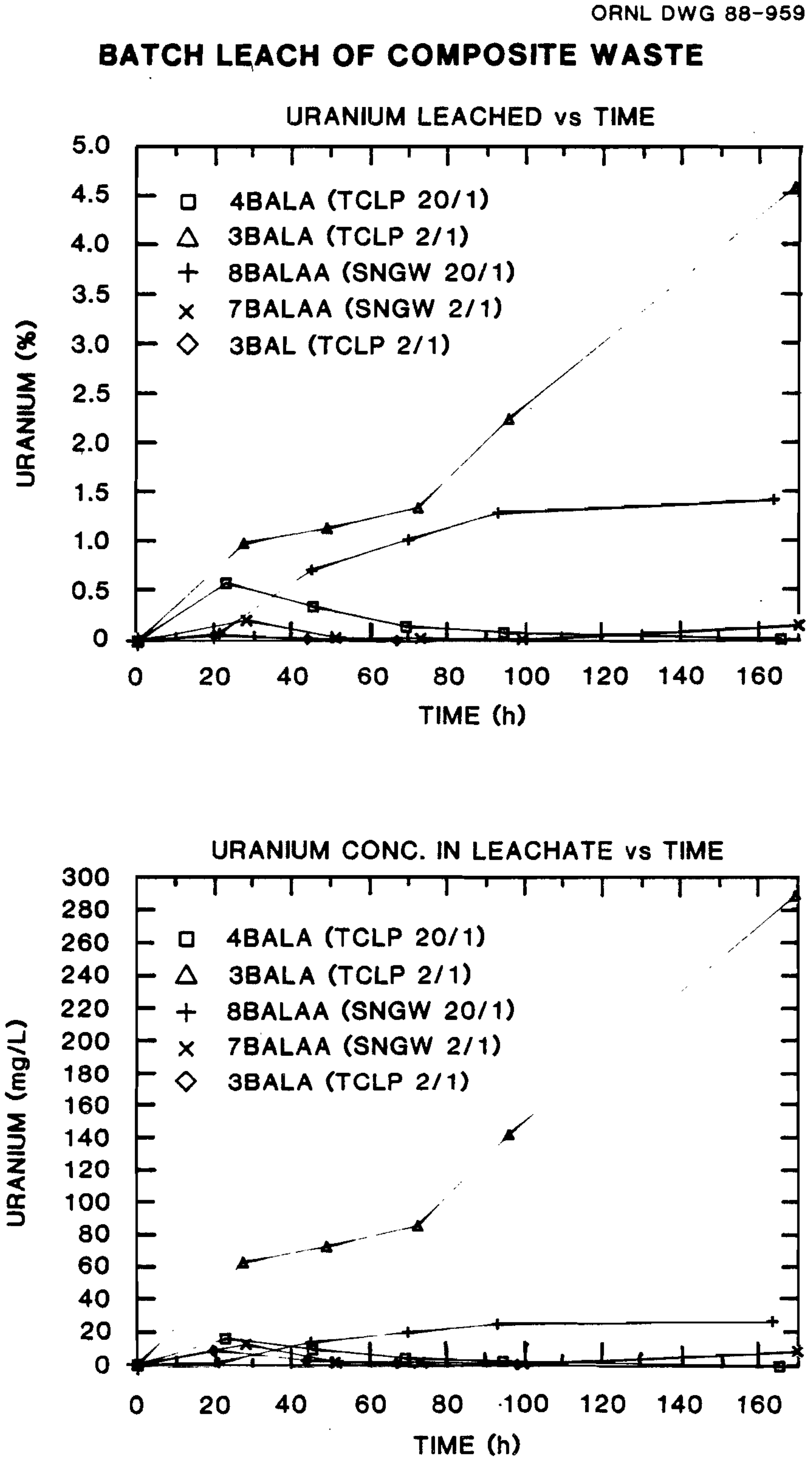

Fig. 6.3. Batch leach of composite waste.

Table 6.5. Summary of sequential leach data for composite waste

	Test parameters									Results							
Sample no.	Leach vol. (L)	Cum.[a] leach vol. (L)	Leachant[b]	Solid waste (kg)	Uranium (g)	L/S[c]	Cum. L/S	Leach time (h)	Cum. leach time (h)	Uranium conc. (mg/L)	Uranium in leachant (g)	Leached uranium (g)	Cum. uranium leached (g)	Initial uranium leached (%)	pH	Cond. (mmho)	Temp. (°C)
1BALA	7.2	7.2	TCLP	3.38	154.0	2.1	2.1	18.3	18.3	20.0	0.14	0.14	0.14	0.09	6.28	5.12	25.5
1BALB	20.7	27.9	TCLP	3.38	154.0	6.1	8.2	25.0	43.3	19.6	0.41	0.30	0.44	0.29	5.88	4.57	25.6
1BALC	31.0	59.0	TCLP	3.38	153.7	9.2	17.4	23.5	66.8	17.2	0.53	0.46	0.90	0.58	5.73	4.30	25.8
1BALD	58.2	117.1	TCLP	3.38	153.2	17.2	34.6	24.1	90.9	12.1	0.70	0.63	1.53	1.00	5.46	4.56	26.3
1BALE	118.0	235.1	TCLP	3.38	152.6	34.9	69.5	71.0	161.9	5.0	0.59	0.54	2.07	1.36	5.47	5.67	25.9
5BALA	5.9	5.9	SNGW	2.95	110.0	2.0	2.0	22.7	22.7	13.0	0.08	0.08	0.08	0.07	6.44	3.16	25.0
5BALB	11.8	17.7	SNGW	2.95	110.0	4.0	6.0	20.8	43.4	4.3	0.05	0.04	0.12	0.11	6.60	1.14	25.9
5BALC	23.6	41.3	SNGW	2.95	110.0	8.0	14.0	24.3	67.8	0.6	0.01	0.01	0.13	0.12	6.30	0.35	24.6
5BALD	47.2	88.5	SNGW	2.95	110.0	16.0	30.0	24.1	91.8	0.2	0.01	0.01	0.14	0.13	6.42	0.12	24.4
5BALE	64.9	153.4	SNGW	2.95	110.0	22.0	52.0	74.7	166.5	0.5	0.03	0.03	0.17	0.16	6.37	0.16	24.6

[a] Cum. = cumulative.

[b] TCLP = synthetic landfill leachate; pH = 4.85 at 26°C; conductivity = 4.24 mmho; SNGW = synthetic groundwater; pH = 6.85 at 26°C; conductivity = 0.013 mmho.

[c] L/S = liquid/solid ratio.

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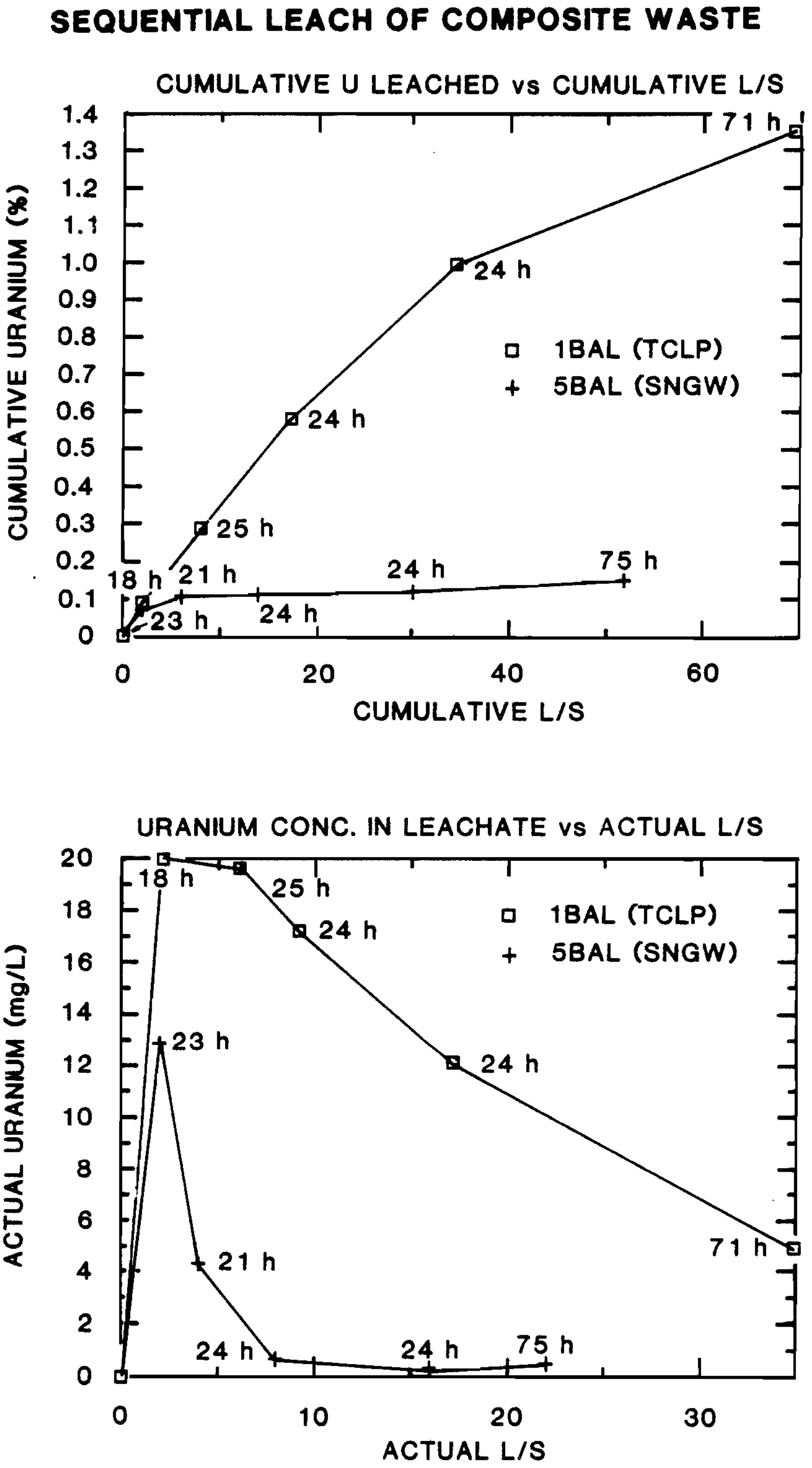

Fig. 6.4. Sequential leach of composite waste.

precipitates or is resorbed back out. The release of uranium from the waste did not seem to correlate with the liquid/solid ratio, the leachant composition, or the leachate pH. The greatest release (about 4.6%) occurred in the test at L/S of 2.0 with synthetic landfill leachate, while the lowest release (about 0.01%) occurred in the parallel synthetic landfill leachate test at L/S of 20.0. This latter test also had the lowest final pH. It seems that properties of the composite waste and/or the form of uranium in the waste rather than the apparent solution chemistry may be controlling the uranium release rate in these tests.

The two sequential leach tests with this waste showed markedly different behavior. Much larger amounts of uranium were leached by the synthetic landfill leachant than by synthetic groundwater. Even at the final L/S of 34.9, appreciable amounts of uranium were being released, and it was clear that the system had not reached steady state. As for the production trash sequential tests, a possible conclusion is that the different samples have uranium present in different forms--at least, insofar as leaching is concerned. An alternative explanation could be that other waste components could also be affecting the uranium leaching.

6.3.2.3 Mixed Metal Chips

A summary of the uranium data for the four batch leach tests with mixed metal chips is given in Table 6.6 and in Fig. 6.5. A similar data summary and plot for the two sequential leach tests is given in Table 6.7 and Fig. 6.6.

All of the batch leach tests showed similar decreasing-mode uranium release behavior. The fraction released or the concentration in solu- tion maximized by the first data point (day 1) and decreased at longer times (up to day 7, the last time point) to very low values. The final pH of both the synthetic groundwater and the synthetic landfill leachates were similar throughout the tests and ranged from about pH 5.8 to 6.5. A decreasing release mode can occur only if the uranium initially solubilized is subsequently removed from solution during extended waste/leachant contact. Either precipitation or sorption phenomena could produce such uranium behavior. As with the production trash and composite waste tests, the release of uranium appeared to be independent of the L/S ratio or the leachant composition. Again, it seems that properties of the mixed metal chips and/or the form of uranium in the waste, rather than the apparent solution chemistry may be controlling the uranium release rate in these tests.

The sequential leach tests showed uranium leaching behavior that was different from the sequential leaches of production trash or com- bined waste. As with the batch tests, only a small fraction of the total uranium was solubilized; the maximum was about 0.05%. The synthetic landfill leachant was more aggressive than the synthetic groundwater and was continuing to leach small but steady amounts of uranium even at the final, largest L/S ratio contacts. Because the leachate is removed after each

Table 6.6. Summary of batch leach data for mixed metal chips

	Test parameters							Results					
Sample no.	Leach vol. (L)	Leachant[a]	Solid waste (kg)	Uranium (g)	L/S[b]	Leach time (h)	Cum.[c] leach time (h)	Leachate uranium conc. (mg/L)	Total[d] uranium leached (g)	Initial uranium leached (%)	pH	Cond. (mmho)	Temp. (°C)
4CHIPA	73.48	TCLP	3.67	255	20.0	18.6	18.6	0.570	41.88	1.64E-02	6.20	5.61	25.8
4CHIPB	73.48	TCLP	3.67	255	20.0	23.7	42.3	0.180	13.23	5.19E-03	6.31	5.49	25.6
4CHIPC	73.48	TCLP	3.67	255	20.0	25.3	67.5	0.091	6.69	2.62E-03	6.40	5.77	25.5
4CHIPD	73.48	TCLP	3.67	255	20.0	22.9	90.5	0.077	5.66	2.22E-03	6.30	5.93	25.8
4CHIPE	73.48	TCLP	3.67	255	20.0	72.5	163.0	0.022	1.62	6.34E-04	6.45	5.72	25.6
8CHIPA	107.05	SNGW	9.07	236	11.8	17.0	17.0	1.360	145.59	6.17E-02	6.10	0.05	25.8
8CHIPB	107.05	SNGW	9.07	236	11.8	24.6	41.6	0.240	25.69	1.09E-02	6.37	0.06	25.7
8CHIPC	107.05	SNGW	9.07	236	11.8	23.3	64.9	0.091	9.74	4.13E-03	5.84	0.05	25.4
8CHIPD	107.05	SNGW	9.07	236	11.8	25.3	90.2	0.028	3.00	1.27E-03	6.47	0.06	25.8
8CHIPE	107.05	SNGW	9.07	236	11.8	73.2	163.4	0.013	1.39	5.90E-04	6.08	0.07	26.1
3CHIPA	5.67	TCLP	2.84	55	2.0	18.2	18.2	0.680	3.85	7.01E-03	6.09	4.46	25.9
3CHIPB	5.67	TCLP	2.84	55	2.0	24.2	42.3	0.035	0.20	3.61E-04	6.30	4.27	25.8
3CHIPC	5.67	TCLP	2.84	55	2.0	24.0	66.3	0.011	0.06	1.13E-04	6.46	4.18	25.8
3CHIPD	5.67	TCLP	2.84	55	2.0	26.0	92.3	0.006	0.03	6.18E-05	6.47	3.97	26.0
3CHIPE	5.67	TCLP	2.84	55	2.0	69.3	161.7	0.007	0.04	7.22E-05	6.45	3.92	26.1
7CHIPA	7.59	SNGW	3.79	103	2.0	19.0	19.0	0.003	0.02	2.21E-05	5.90	0.19	25.9
7CHIPB	7.59	SNGW	3.79	103	2.0	24.5	43.5	0.007	0.05	5.15E-05	6.15	0.19	25.8
7CHIPC	7.59	SNGW	3.79	103	2.0	23.6	67.1	0.003	0.02	2.21E-05	6.25	0.20	25.6
7CHIPD	7.59	SNGW	3.79	103	2.0	25.8	92.9	0.003	0.02	2.21E-05	6.25	0.20	26.1
7CHIPE	7.59	SNGW	3.79	103	2.0	73.2	166.1	0.003	0.02	2.21E-05	6.03	0.25	26.9

[a] TCLP = synthetic landfill leachate; pH = 4.85 at 26°C; conductivity = 4.24 mmho; SNGW = synthetic groundwater; pH = 6.85 at 26°C; conductivity = 0.013 mmho.

[b] L/S = liquid/solid ratio.

[c] Cum. = cumulative.

[d] Corrected for analytical samples that were removed.

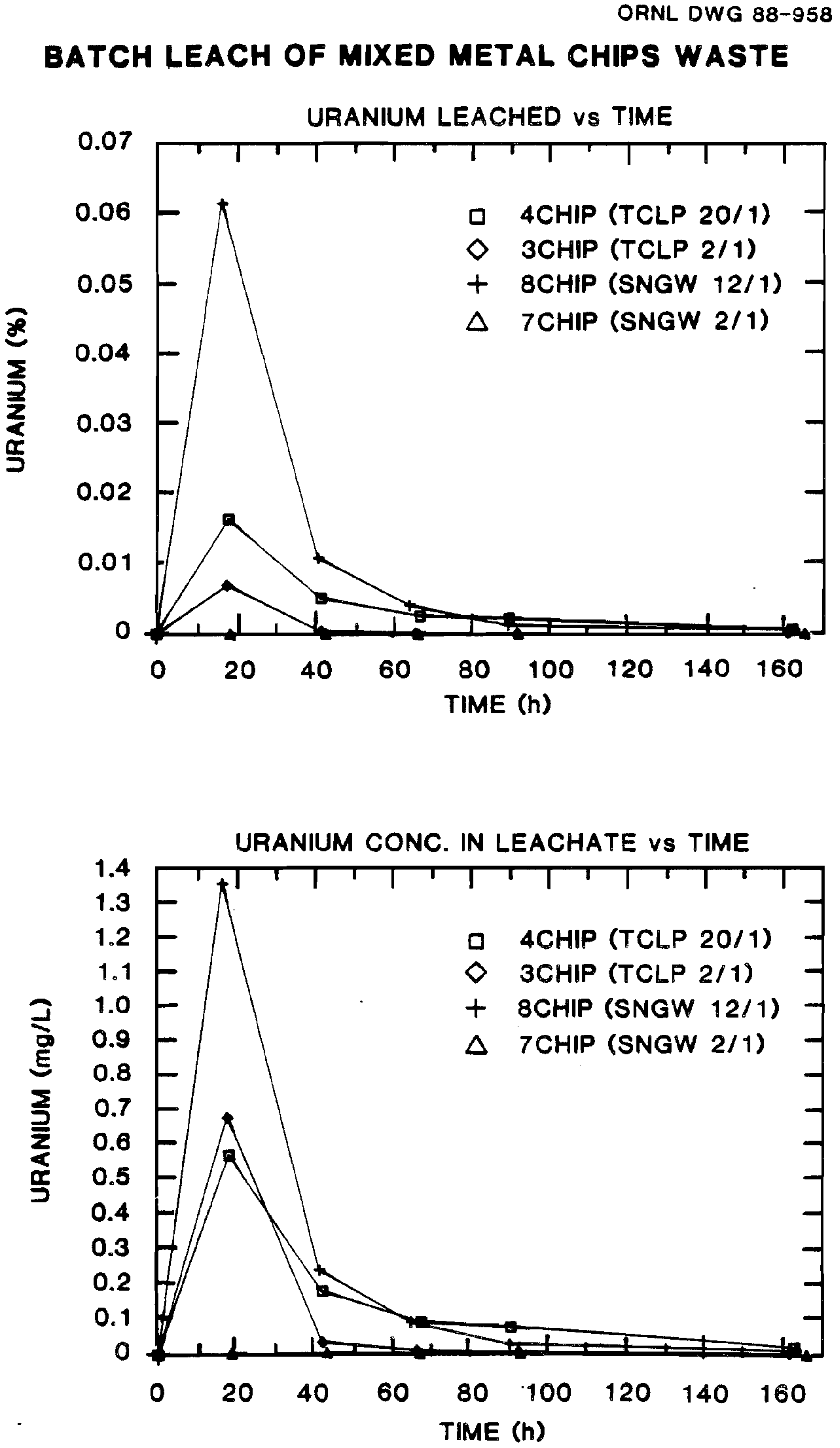

Fig. 6.5. Batch leach of mixed metal chips waste.

Table 6.7. Summary of Sequential leach data for mixed metal chips

	Test parameters									Results							
Sample no.	Leach vol. (L)	Cum.[a] leach vol. (L)	Leachant[b]	Solid waste (kg)	Uranium (g)	L/S[c]	Cum. L/S	Leach time (h)	Cum. leach time (h)	Uranium conc. (mg/L)	Uranium in leachant (g)	Leached uranium (g)	Cum. uranium leached (g)	Initial uranium leached (%)	pH	Cond. (mmho)	Temp. (°C)
1CHIPA	7.6	7.6	TCLP	3.81	119.0	2.0	2.0	22.6	22.6	0.95	0.0072	0.0072	0.0072	0.0061	6.18	5.35	26.1
1CHIPB	15.2	22.9	TCLP	3.81	119.0	4.0	6.0	20.2	42.8	0.48	0.0073	0.0065	0.0137	0.0115	6.09	5.66	26.1
1CHIPC	30.5	53.3	TCLP	3.81	119.0	8.0	14.0	27.5	70.3	0.45	0.0137	0.0133	0.0270	0.0227	6.11	5.61	25.5
1CHIPD	61.0	114.3	TCLP	3.81	119.0	16.0	30.0	24.8	95.0	0.15	0.0091	0.0084	0.0353	0.0297	6.31	5.34	25.9
1CHIPE	121.9	236.2	TCLP	3.81	119.0	32.0	62.0	67.2	162.2	0.18	0.0219	0.0218	0.0572	0.0480	6.17	5.72	25.9
5CHIPA	5.9	5.9	SNGW	2.90	93.0	2.0	2.0	23.1	23.1	0.064	0.0004	0.0004	0.0004	0.0004	6.48	0.24	25.5
5CHIPB	11.6	17.5	SNGW	2.90	93.0	4.0	6.0	23.0	46.1	0.022	0.0003	0.0002	0.0006	0.0006	6.42	0.07	25.8
5CHIPC	23.2	40.7	SNGW	2.90	93.0	8.0	14.0	21.0	67.1	0.035	0.0008	0.0008	0.0014	0.0015	6.60	0.04	25.7
5CHIPD	46.4	87.1	SNGW	2.90	93.0	16.0	30.0	24.0	97.1	0.016	0.0007	0.0007	0.0021	0.0023	6.80	0.03	28.6
5CHIPE	92.8	179.9	SNGW	2.90	93.0	32.0	62.0	71.0	162.1	0.009	0.0008	0.0008	0.0030	0.0032	7.95	0.03	25.7

[a] Cum. = cumulative.

[b] TCLP = synthetic landfill leachate; pH = 4.85 at 26°C; conductivity = 4.24 mmho; SNGW = synthetic groundwater; pH = 6.85 at 26°C; conductivity = 0.013 mmho.

[c] L/S = liquid/solid ratio.

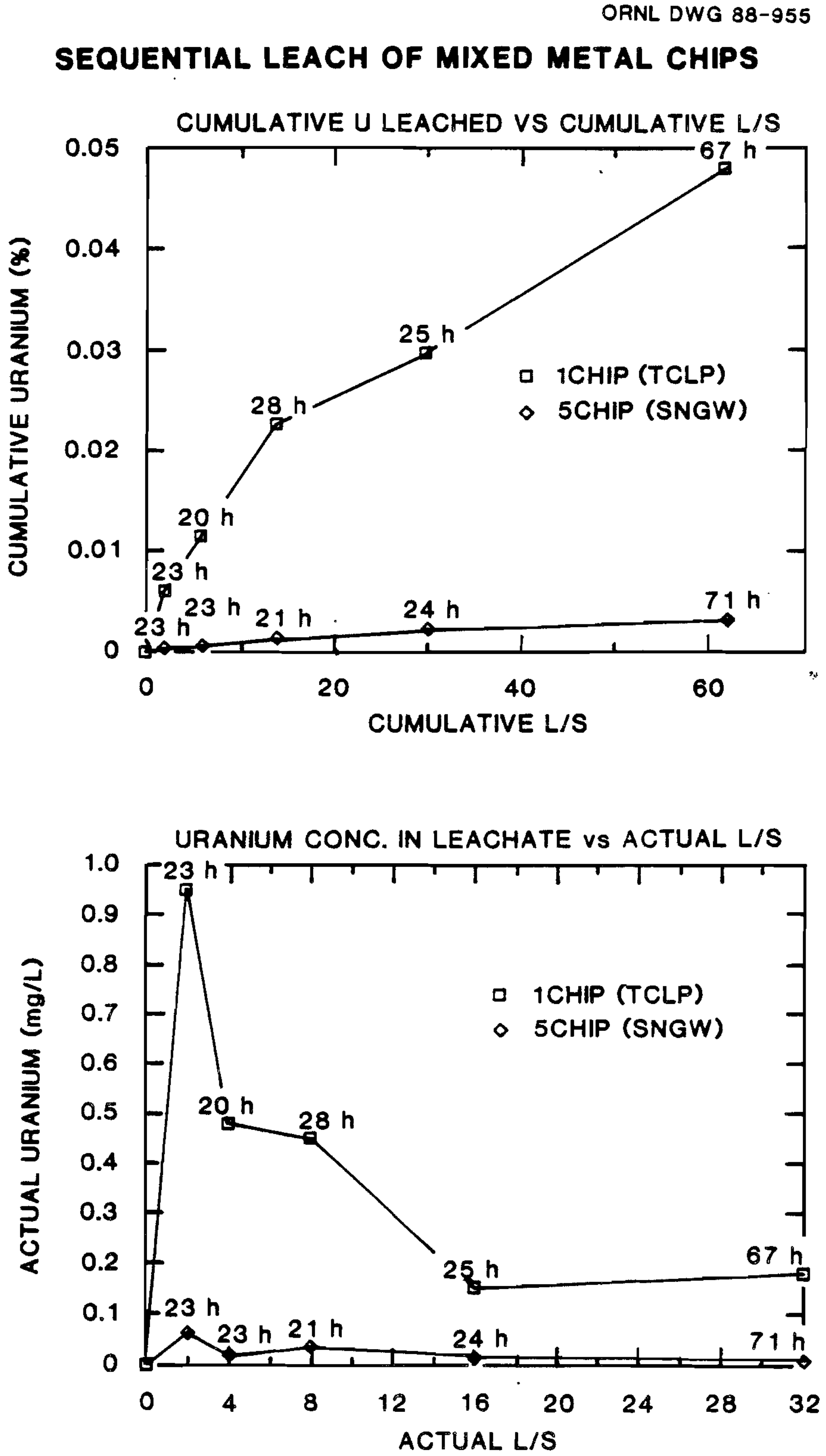

Fig. 6.6. Sequential leach of mixed metal chips.

contact, it is possible for the sequential tests to have a decreasing leach mode as was observed for the batch tests with mixed metal chips.

6.3.2.4 Air Filters

A summary of the uranium data for the four batch leach tests with the media cut from air filters is given in Table 6.8 and in Fig. 6.7. A similar data summary and plot for the two sequential leach tests is given in Table 6.9 and Fig. 6.8.

The uranium leaching data for the air filter samples showed two significant differences from the other wastes. First, and perhaps most important, was the high solubility of the uranium contaminant. The fraction leached by day 7 was as high as 66% in one batch test. In the sequential tests, less uranium was solubilized on day 7 than in the batch tests. In general, it appeared that the uranium leaching, at least on day 1, may have been constrained only by the solubility limit. High leaching of uranium from the air filters may be rationalized by assuming that only small particles of contaminant have reached the filters in the building ventilation systems and that these small particles may be readily oxidized to soluble uranium-containing solids.

A second, and surprising observation for the batch tests was the appearance of a decreasing leach mode in some cases. (In the sequential tests, of course, the uranium was removed after each contact and thus was not available for precipitation or sorption reactions if they could have occurred.) Particularly in the tests with a liquid/solid ratio of 2, much or nearly all of the uranium was removed from the leachate with extended time. Examination of the contact vessel for the synthetic landfill leachate tests showed bubbling and sludge formation. It appeared that the aluminum filter components were reacting with the leachate; this reaction would generate hydrogen and also a very strongly reducing redox condition. Thus, as in the case of mixed metal chips, uranium removal from solution could be due to reduction of soluble uranium(VI) species to insoluble uranium(IV) solids.

6.3.2.5 Uranium Oxide Powder From the UCOF

A summary of the uranium data for the four batch leach tests with uranium oxide powder from the UCOF is given in Table 6.10 and in Fig. 6.9. A similar data summary and plot for the two sequential leach tests are given in Table 6.11 and Fig. 6.10.

As in the case of the composite waste batch leaching tests, the batch leach tests of uranium oxide powder showed a somewhat more complex leaching pattern. As was expected, the uranium was more soluble in synthetic landfill than in synthetic groundwater leachant. These data show that a one day leach period was sufficient for each leachant to apparently become saturated with uranium when the L/S ratio was 2:0. The uranium concentration for the synthetic landfill leachate was 3.3 ± 0.3 mg/mL (mean ± 1 standard deviation). Although not shown in Table 6.10, seven separate one-day tests

Table 6.8. Summary of batch leach data for air filters

	Test parameters							Results					
Sample no.	Leach vol. (L)	Leachant[a]	Solid waste (kg)	Uranium (g)	L/S[b]	Leach time (h)	Cum.[c] leach time (h)	Leachate uranium conc. (mg/L)	Total[d] uranium leached (g)	Initial uranium leached (%)	pH	Cond. (mmho)	Temp. (°C)
4FILA	47.2	TCLP	2.36	218	20.0	18.4	18.4	3630	171.3	78.6	4.96	3.67	26.6
4FILB	47.2	TCLP	2.36	218	20.0	24.6	43.0	3480	170.3	78.1	4.95	3.70	26.8
4FILC	47.2	TCLP	2.36	218	20.0	23.8	66.8	3430	164.0	75.2	5.05	3.74	27.4
4FILD	47.2	TCLP	2.36	218	20.0	23.8	90.6	3260	155.7	71.4	5.05	3.41	26.0
4FILE	47.2	TCLP	2.36	218	20.0	70.8	161.3	3110	148.5	68.1	5.13	3.38	26.4
8FILA	47.2	SNGW	2.34	200	20.2	22.3	22.3	610	28.8	14.4	4.25	0.14	26.7
8FILB	47.2	SNGW	2.34	200	20.2	24.6	46.9	570	29.9	14.9	3.85	0.16	27.0
8FILC	47.2	SNGW	2.34	200	20.2	22.6	69.5	620	29.6	14.8	4.17	0.16	27.3
8FILD	47.2	SNGW	2.34	200	20.2	24.3	93.7	650	31.0	15.5	4.26	0.16	26.2
8FILE	47.2	SNGW	2.34	200	20.2	70.2	163.9	610	29.1	14.6	4.32	0.15	26.5
3FILA	4.5	TCLP	2.27	231	2.0	20.6	20.6	5760	26.1	11.3	4.92	3.53	26.7
3FILB	4.5	TCLP	2.27	231	2.0	23.0	43.6	3920	22.6	9.8	4.96	3.48	26.8
3FILC	4.5	TCLP	2.27	231	2.0	25.6	69.2	2130	11.8	5.1	5.07	3.48	27.1
3FILD	4.5	TCLP	2.27	231	2.0	23.3	92.4	1700	8.9	3.8	5.00	3.52	26.2
3FILE	4.5	TCLP	2.27	231	2.0	71.7	164.1	560	3.5	1.5	5.48	3.51	26.9
7FILA	5.2	SNGW	2.59	198	2.0	23.8	23.8	1740	9.0	4.5	3.92	0.67	26.8
7FILB	5.2	SNGW	2.59	198	2.0	24.2	48.0	510	4.2	2.1	4.10	0.47	26.9
7FILC	5.2	SNGW	2.59	198	2.0	24.7	72.7	240	1.5	0.8	4.46	0.34	27.0
7FILD	5.2	SNGW	2.59	198	2.0	20.6	93.3	40	0.3	0.2	4.69	0.23	26.0
7FILE	5.2	SNGW	2.59	198	2.0	73.0	166.3	140	0.8	0.4	5.37	0.16	26.9

[a] TCLP = synthetic landfill leachate; pH = 4.85 at 26°C; conductivity = 4.24 mmho; SNGW = synthetic groundwater; pH = 6.85 at 26°C; conductivity = 0.013 mmho.

[b] L/S = liquid/solid ratio.

[c] Cum. = cumulative.

[d] Corrected for analytical samples that were removed.

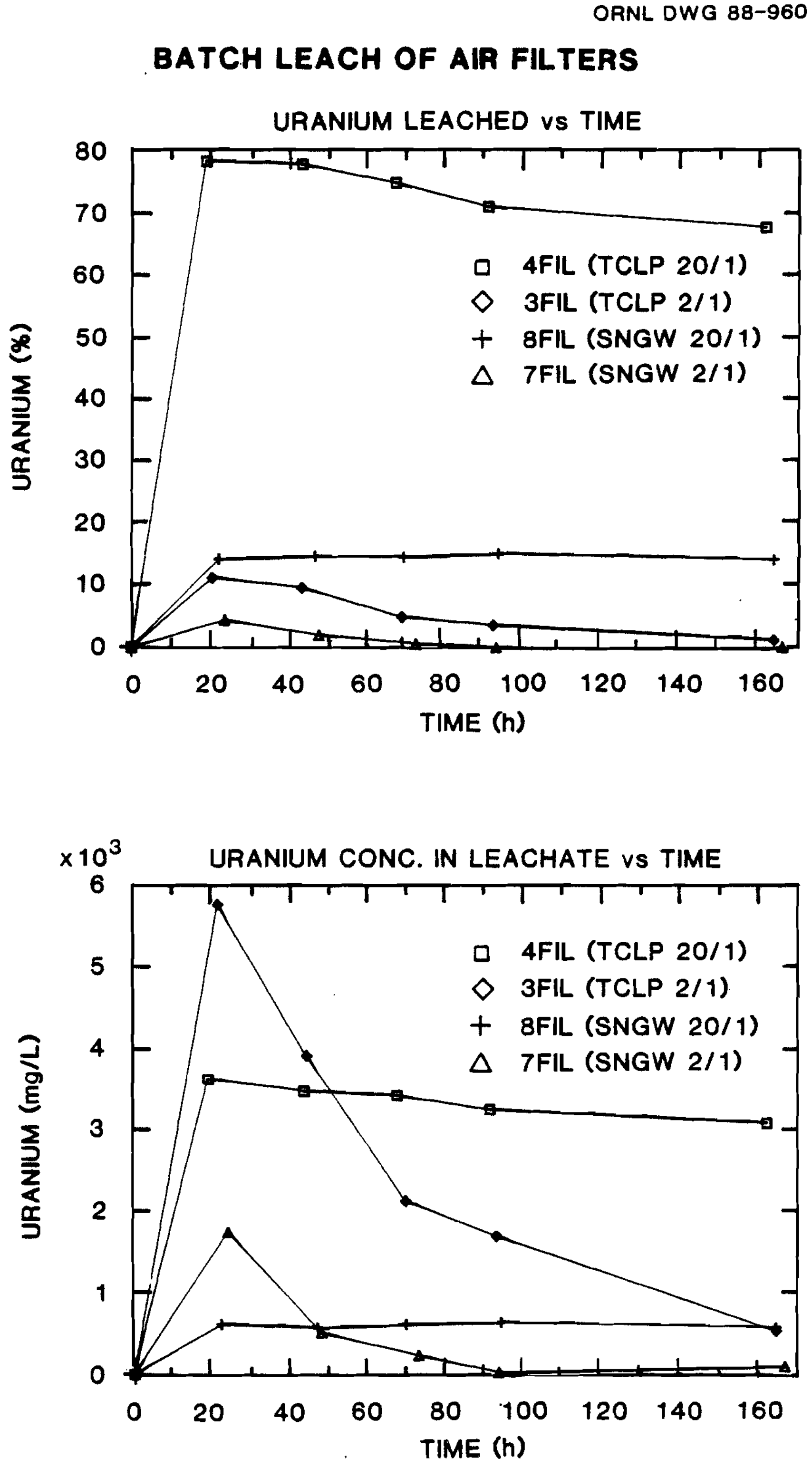

Fig. 6.7. Batch leach of air filters.

Table 6.9. Summary of sequential leach data for air filters

	Test parameters									Results							
Sample no.	Leach vol. (L)	Cum.[a] leach vol. (L)	Leachant[b]	Solid waste (kg)	Uranium (g)	L/S[c]	Cum. L/S	Leach time (h)	Cum. leach time (h)	Uranium conc. (mg/L)	Uranium in leachant (g)	Leached uranium (g)	Cum. uranium leached (g)	Initial uranium leached (%)	pH	Cond. (mmho)	Temp. (°C)
1FILA	5.8	5.8	TCLP	2.68	259.0	2.2	2.0	18.3	18.3	6840	39.74	39.74	39.74	15.3	4.81	2.99	26.9
1FILB	11.0	16.8	TCLP	2.68	259.0	4.1	6.0	24.3	42.6	3050	33.61	13.84	53.58	20.7	4.87	3.76	27.0
1FILC	21.4	38.2	TCLP	2.68	259.0	8.0	14.1	24.0	66.6	2320	49.67	38.20	91.78	35.4	5.09	3.79	26.9
1FILD	42.8	81.1	TCLP	2.68	259.0	16.0	30.6	24.8	91.3	930	39.82	30.08	121.86	47.1	4.82	3.70	27.1
1FILE	85.6	166.7	TCLP	2.68	259.0	32.0	64.1	71.0	162.3	170	14.56	10.55	132.41	51.1	4.90	3.71	26.7
5FILA	3.9	3.9	SNGW	1.91	198.0	2.0	2.0	20.0	20.0	1280	4.97	4.97	4.97	2.5	3.75	0.63	26.8
5FILB	7.6	11.5	SNGW	1.91	198.0	4.0	6.0	24.3	44.3	1130	8.61	4.23	9.20	4.6	3.75	0.37	27.0
5FILC	15.2	26.7	SNGW	1.91	198.0	8.0	14.0	26.1	70.4	430	6.55	2.17	11.37	5.7	4.08	0.14	27.0
5FILD	30.6	57.4	SNGW	1.91	198.0	16.0	30.0	22.7	93.1	230	7.04	5.47	16.84	8.5	4.20	0.05	27.1
5FILE	61.0	118.3	SNGW	1.91	198.0	31.9	62.0	70.5	163.6	290	17.68	16.82	33.66	17.0	5.01	0.02	26.8

[a] Cum. = cumulative.

[b] TCLP = synthetic landfill leachate; pH = 4.85 at 26°C; conductivity = 4.24 mmho; SNGW = synthetic groundwater; pH = 6.85 at 26°C; conductivity = 0.013 mmho.

[c] L/S = liquid/solid ratio.

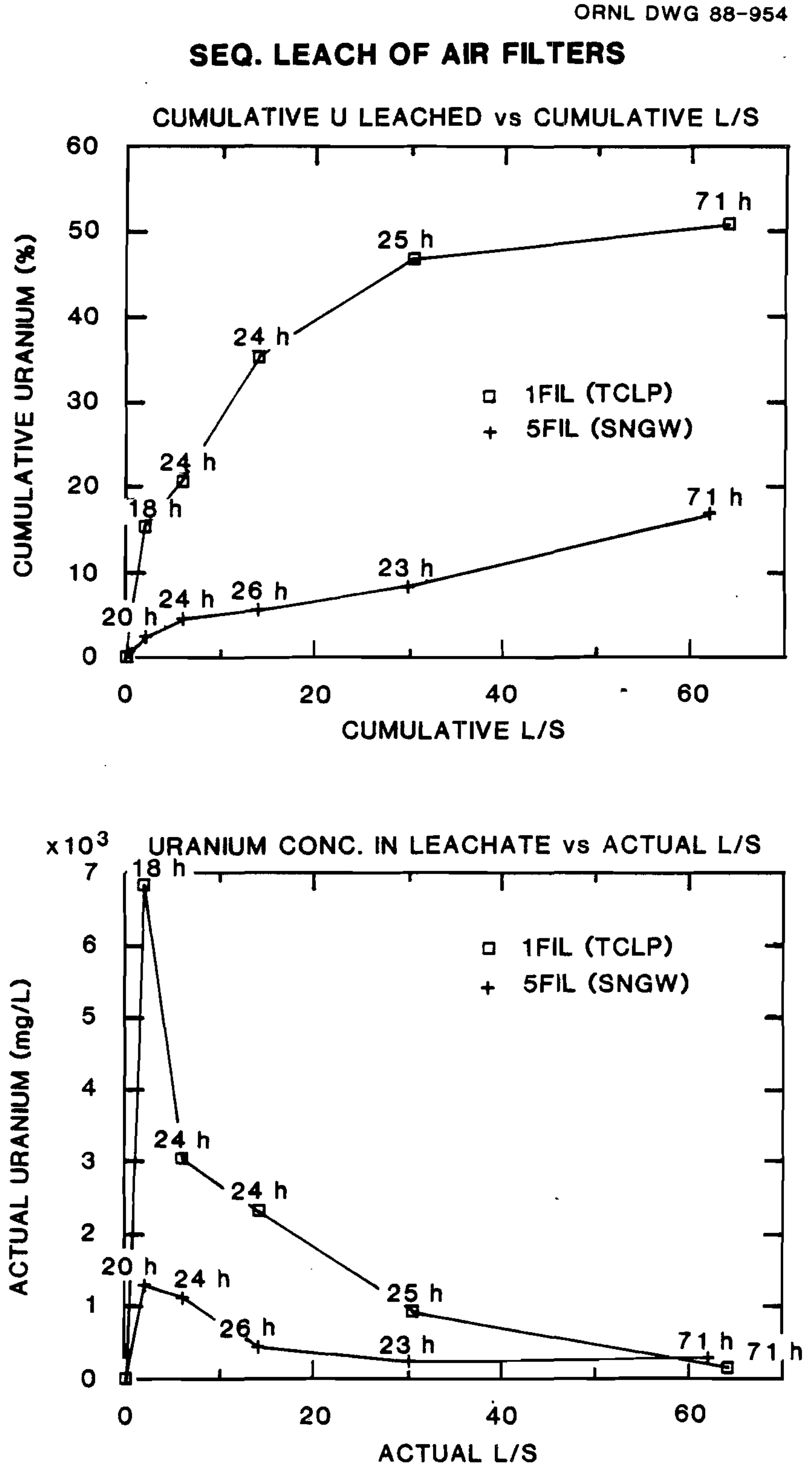

Fig. 6.8. Sequential leach of air filters.

Table 6.10. Summary of batch leach data for uranium oxide powder from UCOF

	Test parameters							Results					
Sample no.	Leach vol. (L)	Leachant[a]	Solid waste (kg)	Uranium (g)	L/S[b]	Leach time (h)	Cum.[c] leach time (h)	Leachate uranium conc. (mg/L)	Total[d] uranium leached (g)	Initial uranium leached (%)	pH	Cond. (mmho)	Temp. (°C)
31A	1700.2	TCLP	85.9	72.9	19.8	21.8	21.8	1480	2.52	3.45	5.08	3.65	26.2
31B	1700.2	TCLP	85.9	72.9	19.8	21.1	42.9	1640	2.87	3.93	5.09	3.70	26.1
31C	1700.2	TCLP	85.9	72.9	19.8	24.1	67.0	1850	3.21	4.40	4.98	3.59	26.3
31D	1700.2	TCLP	85.9	72.9	19.8	96.2	163.2	2880	4.97	6.81	5.20	3.59	26.3
31E	1700.2	TCLP	85.9	72.9	19.8	192.3	355.5	3050	5.29	7.25	5.10	3.62	25.7
31F	1700.2	TCLP	85.9	72.9	19.8	167.3	522.7	3300	5.76	7.90	5.10	3.85	25.8
31G	1700.2	TCLP	85.9	72.9	19.8	337.2	859.9	3800	5.88	8.07	5.13	3.74	25.4
32A	1701.6	SNGW	85.9	72.9	19.8	22.7	22.7	42.0	0.071	0.098	6.00	0.023	26.3
32B	1701.6	SNGW	85.9	72.9	19.8	21.1	43.8	37.0	0.065	0.090	6.13	0.019	26.1
32C	1701.6	SNGW	85.9	72.9	19.8	24.0	67.8	45.0	0.077	0.106	5.88	0.020	26.1
32D	1701.6	SNGW	85.9	72.9	19.8	96.0	163.8	54.0	0.092	0.127	5.81	0.019	26.3
32E	1701.6	SNGW	85.9	72.9	19.8	195.0	358.8	66.0	0.114	0.157	5.56	0.019	25.8
32F	1701.6	SNGW	85.9	72.9	19.8	167.3	526.1	71.0	0.124	0.171	5.92	0.016	25.8
32G	1701.6	SNGW	85.9	72.9	19.8	334.0	860.1	75.0	0.131	0.179	5.30	0.016	25.0
33A	1604.3	TCLP	799.8	678.8	2.0	22.7	22.7	3490	5.60	0.82	5.25	3.37	26.3
33B	1604.3	TCLP	799.8	678.8	2.0	19.9	42.6	3590	5.95	0.88	5.23	3.16	26.1
33C	1604.3	TCLP	799.8	678.8	2.0	24.3	66.9	3740	6.13	0.90	5.01	3.16	26.1
33D	1604.3	TCLP	799.8	678.8	2.0	96.0	162.9	3210	5.28	0.78	5.03	3.18	26.3
33E	1604.3	TCLP	799.8	678.8	2.0	192.5	355.4	2860	4.70	0.69	4.93	3.08	25.7
33F	1604.3	TCLP	799.8	678.8	2.0	167.5	522.9	3000	4.96	0.73	4.90	3.43	25.9
33G	1604.3	TCLP	799.8	678.8	2.0	337.5	860.5	3200	5.25	0.77	4.83	3.24	25.3
34A	1604.7	SNGW	799.3	678.3	2.0	21.8	22.7	193.0	0.310	0.046	5.17	0.077	26.4
34B	1604.7	SNGW	799.3	678.3	2.0	20.5	43.2	195.0	0.323	0.048	5.25	0.074	26.2
34C	1604.7	SNGW	799.3	678.3	2.0	24.2	67.3	190.0	0.312	0.046	4.90	0.082	26.2
34D	1604.7	SNGW	799.3	678.3	2.0	95.8	163.1	131.0	0.216	0.032	5.01	0.082	26.4
34E	1604.7	SNGW	799.3	678.3	2.0	196.1	359.2	30.0	0.053	0.008	5.00	0.094	26.1
34F	1604.7	SNGW	799.3	678.3	2.0	167.3	526.5	19.0	0.032	0.005	5.20	0.103	25.8
34G	1604.7	SNGW	799.3	678.3	2.0	334.3	860.8	7.0	0.013	0.002	5.30	0.100	24.8

[a] TCLP = synthetic landfill leachate; pH = 4.85 at 26°C; conductivity = 4.24 mmho; SNGW = synthetic groundwater; pH = 6.85 at 26°C; conductivity = 0.013 mmho.

[b] L/S = liquid/solid ratio.

[c] Cum. = cumulative.

[d] Corrected for analytical samples that were removed.

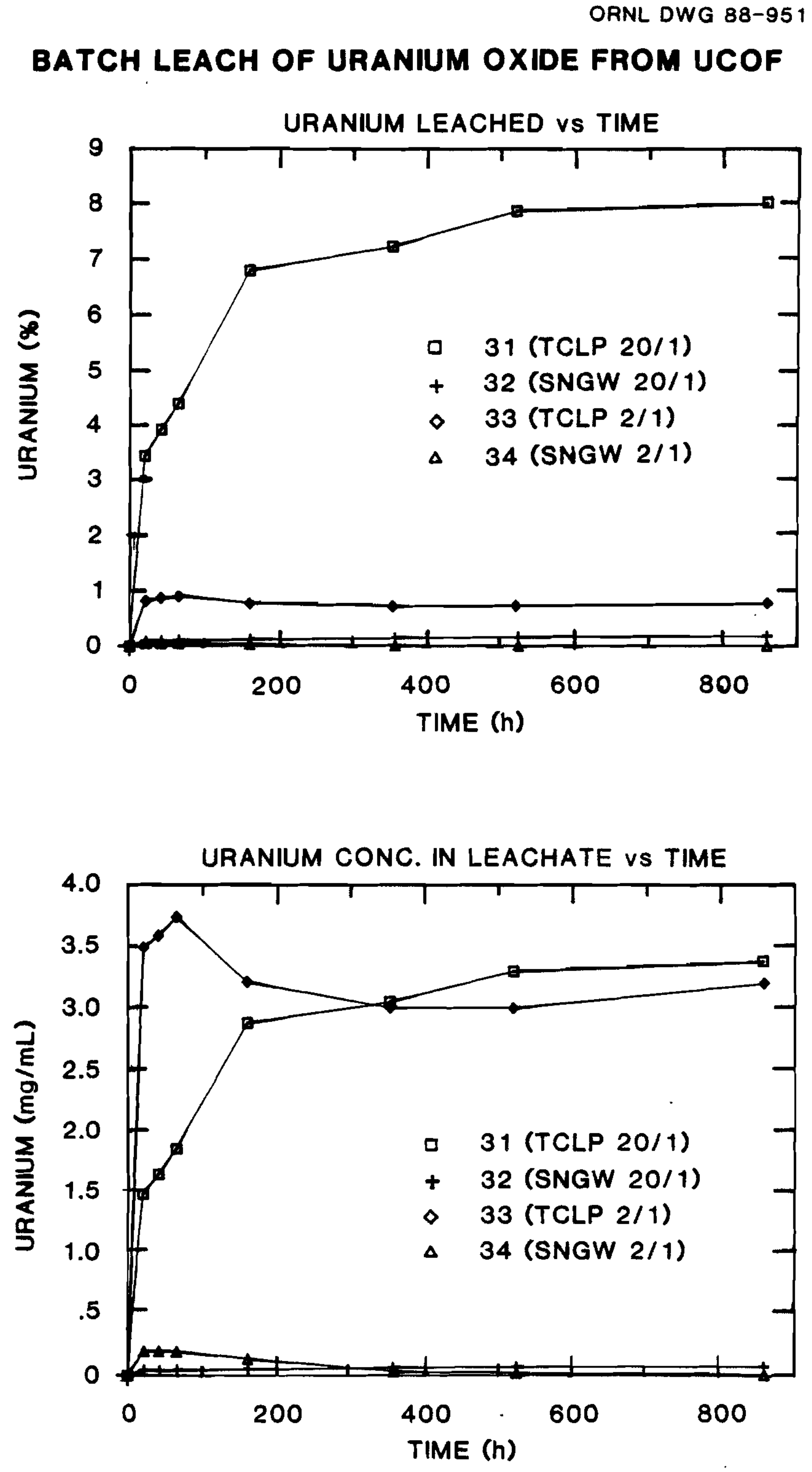

Fig. 6.9. Batch leach of uranium oxide from UCOF.

Table 6.11. Summary of sequential leach data for uranium oxide powder from the UCOF

	Test parameters									Results							
Sample no.	Leach vol. (L)	Cum.[a] leach vol. (L)	Leachant[b]	Solid waste (kg)	Uranium (g)	L/S[c]	Cum. L/S	Leach time (h)	Cum. leach time (h)	Uranium conc. (mg/L)	Uranium in leachant (g)	Leached uranium (g)	Cum. uranium leached (g)	Initial uranium leached (%)	pH	Cond. (mmho)	Temp. (°C)
35A	0.113	0.113	TCLP	0.0563	47.78	2.0	2.0	23.1	23.1	3400	0.383	0.383	0.383	0.80	4.85	3.37	26.0
35B	0.225	0.338	TCLP	0.0562	47.66	4.0	6.0	27.2	50.3	3300	0.743	0.481	0.864	1.81	4.96	3.88	25.7
35C	0.451	0.788	TCLP	0.0555	47.02	8.1	14.1	21.0	71.3	2200	0.991	0.885	1.749	3.66	4.75	4.03	25.7
35D	0.901	1.689	TCLP	0.0546	46.08	16.5	30.6	26.8	98.1	930	0.838	0.793	2.542	5.32	4.72	3.69	25.6
35E	1.802	3.491	TCLP	0.0538	45.25	33.5	64.1	71.9	170.0	830	1.495	1.463	4.005	8.38	4.74	3.77	26.1
36A	0.113	0.113	SNGW	0.0563	47.78	2.0	2.0	25.2	25.2	127	0.014	0.014	0.014	0.03	5.40	0.119	26.0
36B	0.225	0.338	SNGW	0.0563	47.77	4.0	6.0	24.0	49.2	64	0.014	0.012	0.026	0.05	5.70	0.033	25.7
36C	0.450	0.788	SNGW	0.0563	47.76	8.0	14.0	26.9	76.1	26	0.012	0.010	0.036	0.07	6.11	0.018	25.7
36D	0.901	1.689	SNGW	0.0563	47.75	16.0	30.0	23.8	100.0	16	0.014	0.013	0.049	0.10	5.72	0.013	25.6
36E	1.802	3.490	SNGW	0.0563	47.73	32.0	62.0	69.0	169.0	26	0.047	0.046	0.095	0.20	5.50	0.013	26.2

[a] Cum. = cumulative.

[b] TCLP = synthetic landfill leachate; pH = 4.85 at 26°C; conductivity = 4.24 mmho; SNGW = synthetic groundwater; pH = 6.85 at 26°C; conductivity = 0.013 mmho.

[c] L/S = liquid/solid ratio.

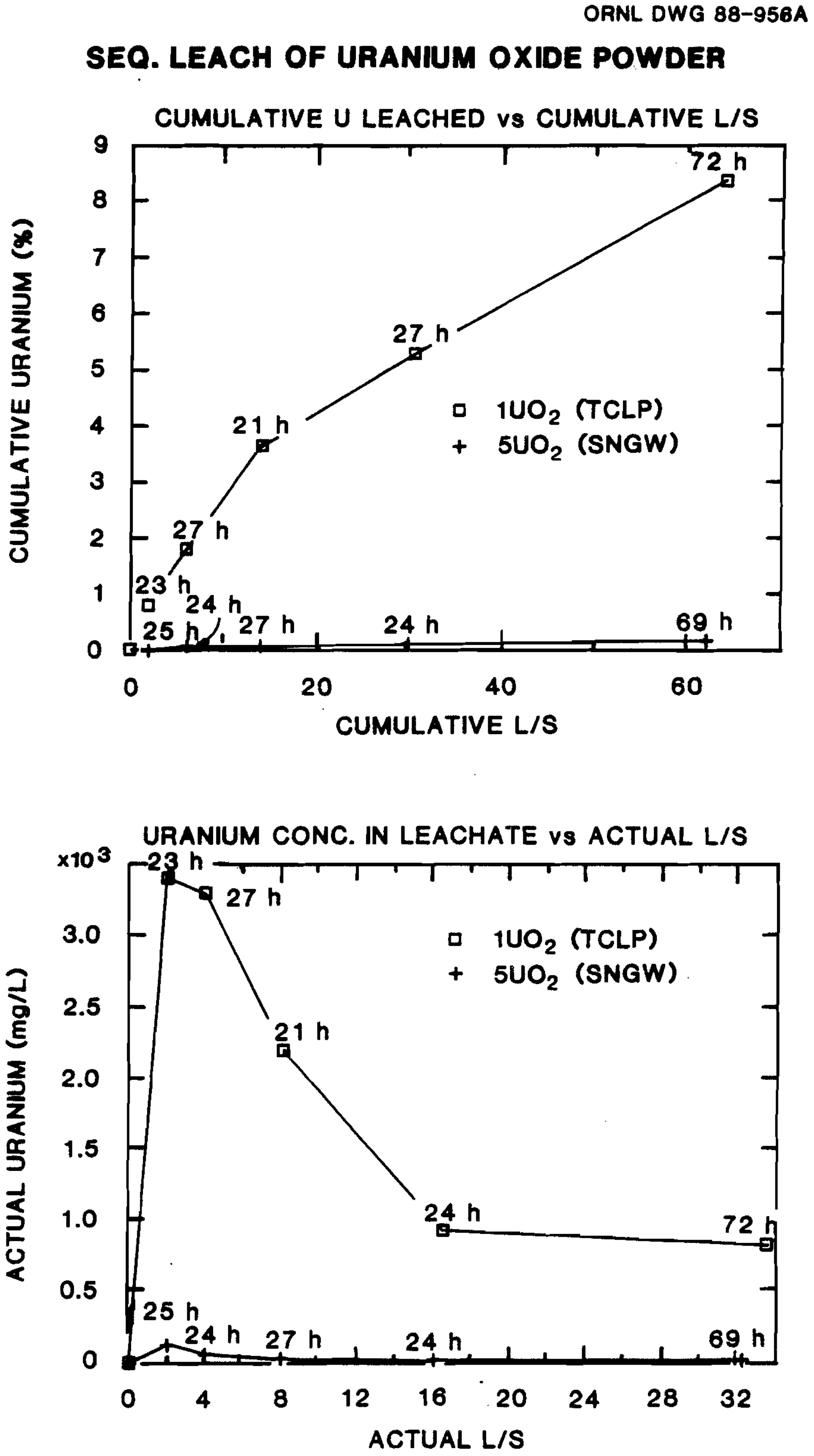

Fig. 6.10. Sequential leach of uranium oxide powder.

at a L/S ratio of 2.0 were also conducted with uranium oxide powder from the UCOF using synthetic land- fill leachant. The uranium concentration in the leachate for those tests was 3.3 ± 0.2 mg/mL. Lower uranium concentrations were observed for the synthetic groundwater leachates.

The two sequential tests further demonstrated that the synthetic landfill leachant was more aggressive in dissolving uranium than was the synthetic groundwater leachant. The first two leaches with synthetic landfill leachant (L/S ratios of 2.0 and 4.0) yielded leachates that appeared to be saturated with uranium. In the subsequent leaches, the concentration of uranium in the leachates decreased.

6.4 DISCUSSION

In this section, several aspects of the leaching of uranium are discussed in terms of various experimental parameters and conditions. An attempt is made to rationalize the uranium release data to aid in predicting waste performance in the lysimeters and to support analysis of potential disposal options. Because many of the test parameters and conditions interact in their effects on uranium leaching, the following division of the discussion into subsections is somewhat arbitrary and some repetition is unavoidable.

6.4.1 Effect of Waste Type

The first question addressed is identification of the differences (or similarities) in uranium leaching for the various Y-12 Plant wastes tested. The wastes studied in this work can be divided into two broad categories or classes: (1) large-volume trash-type wastes from Y-12 Plant production areas that are contaminated with relatively small proportions of depleted uranium, probably primarily present as uranium metal, and (2) small-volume wastes from specific Y-12 Plant sources that are composed of larger proportions of depleted uranium, primarily present as uranium oxides. The production trash, mixed metal chips, and composite waste fall into the first category, while the air filters and uranium oxide powder fall into the second category. Based on a general understanding of uranium chemistry, it might be anticipated that uranium leaching from these two different waste categories would be significantly different. This expectation was, at best, only partially confirmed by the results of the leach tests.

A comparison of the data for the fraction of the uranium leached by day 7 (the longest experimental time point) for the various wastes is shown in Table 6.12. The data for the longest experimental time were selected for comparison because the longest time might be expected to produce the greatest uranium release. Many tests had not reached steady-state after 7 days, and, therefore, the fraction uranium leached by day 7 does not represent a final or maximum value for these wastes. Also, in a number of tests the fraction uranium leached actually <u>decreased</u> over time from day 1 to day 7; clearly the

Table 6.12. Uranium leached by day 7 for different wastes

Waste	Leachant	Contacting protocol	Liquid/solid ratios	Uranium leached (%)
Production Trash	TCLP	batch	2.0	0.68
		batch	20.0	0.84
		seq.	58.5	0.69
	SNGW	batch	2.0	1.61
		batch	20.0	0.57
		seq.	52.0	1.00
Mixed Metal Chips	TCLP	batch	2.0	7.01E-03
		batch	20.0	6.34E-04
		seq.	62.0	4.80E-02
	SNGW	batch	2.0	2.21E-05
		batch	11.8	5.90E-04
		seq.	62.0	3.20E-03
Composite Waste	TCLP	batch	2.0	4.59
		batch	20.0	0.01
		seq.	69.5	1.36
	SNGW	batch	2.0	0.16
		batch	12.3	1.44
		seq.	52.0	0.16
Air Filters	TCLP	batch	2.0	1.5
		batch	20.0	68.1
		seq.	62.0	51.1
	SNGW	batch	2.0	0.4
		batch	20.0	14.6
		seq.	62.0	17.0
Uranium Oxide	TCLP	batch	2.0	0.69
		batch	19.8	7.25
		seq.	64.1	8.38
	SNGW	batch	2.0	0.005
		batch	19.8	0.17
		seq.	62.0	0.20

day 7 data for these tests do not represent a maximum uranium release but might represent an environmentally meaningful number.

Substantial data scatter can be seen in Table 6.12 for the fraction of uranium leached as a function of test parameters and conditions, and only very general observations or conclusions can be reached. Only a trivial portion (a tiny fraction of a percent) of the uranium was leached from mixed metal chips in any of the tests. In the case of the production trash, between about 0.6% and 1.6% of the uranium was leached in various tests. Composite waste, which is 1/3 production trash, 1/3 mixed metal chips, and 1/3 other wastes from contaminated areas, showed much more variable uranium leaching, with the fraction leached varying from 0.01% to 4.59%. Perhaps, in some tests, the composite waste performed like mixed metal chips, in other cases--like production trash, and in still other cases, possibly like uranium oxide. Such variable performance might be consistent with the possible heterogeneity of physical/chemical forms of the uranium contaminant in different composite waste samples.

The air filters and the uranium oxide powder gave greater releases (up to about 68% at day 7 in one test) which, at least in part, seemed to correlate primarily with the chemistry of the leachant used but not with the volume of the leachant. In some cases with the air filters and uranium oxide powder, it appeared that the leachate might be saturated with uranium.

The air filters were unique in that essentially all of the uranium was readily leachable. The release of uranium from the filter media seemed to be constrained only by the solubility limit. Such a relatively high leachability is consistent with the composition of the uranium powder in the air filters. An analysis of one sample of the powder by x-ray diffraction showed that it was $\geq 75\%$ U_3O_8 and $\geq 25\%$ UO_2. Several of the air filter tests suggested that a decreasing leach mode was being expressed. Thus, on extended time in the field lysimeters or other disposal modes, the uranium leached might be less than in these short-term laboratory tests.

The range and variability of the uranium leach data obtained with the trash-type wastes suggest that predictions of waste performance based solely on these waste-type classifications may be subject to some uncertainty. The uranium leaching likely reflects the chemical and physical properties of the uranium contaminant in the waste, rather than an arbitrary classification of waste based on Y-12 Plant waste collection categories. Also, the chemistry of other waste components, which are present in much greater quantities than uranium in the trash-type wastes, may also play a dominant role in determining uranium leaching. For example, the presence of oil in some samples could coat metal particles and inhibit oxidation and leaching, while in other cases, the presence of larger amounts of paper or plastics could adsorb oil which then could allow for acceleration of (or at least no longer inhibition of) oxidation and leaching reactions. Other adsorbents such as the Hot Hogs could also adsorb uranium which had been initially solubilized from the waste. It is well known (see Appendix F) that uranium solubility is pH dependent, and any waste components that alter the leachate pH could have a significant impact on the uranium leaching from the waste. Because few of the uranium leaching tests seemed to have reached steady-state conditions after 7 days, uranium leaching was continuing (or in some cases decreasing), and the fraction released was still increasing (or decreasing) for many tests. Thus, uranium leach data and a comparison of waste behavior taken at some other time period than 7 days might yield a somewhat different waste-type comparison.

6.4.2 Effect of Leachant Used

In the tests, two different leachants were used which were chosen to bracket the expected acidity of environmental disposal situations: (1) a synthetic groundwater that was a very dilute NaCl-$NaHCO_3$ solution at near-neutral pH, and (2) a synthetic landfill leachate that was an 0.1 $\underline{M}$ acetic acid-sodium acetate buffer at pH 4.9. Because the dissolution of U_3O_8 (the uranium oxide which might be present in oxidized uranium-oxide-containing wastes) consumes acid (see Appendix F) and because the solubility of U(VI) species is highly pH dependent and increases at lower pHs (see Appendix F), it often is assumed that more acidic solutions are more aggressive leachants for the dissolution of uranium oxides. Based on that assumption, the Y-12 Plant waste tests with synthetic landfill leachate were expected to show much higher uranium leaching than with the synthetic groundwater.

Examination of the fraction-uranium-leached values in Table 6.12 shows that this expectation was met only for the tests with uranium oxide powder and air filters. For production trash, the synthetic groundwater actually was a slightly more aggressive leachant than the synthetic landfill leachate. The values for uranium leached from mixed metal chips are too low to allow a meaningful comparison, and in the case of composite waste, the values are too scattered to reach any conclusion as to the relative aggressiveness of the two leachants.

The uranium concentration in the leach solutions for all wastes are compared as a function of leachate used in Fig. 6.11. In the cases of uranium oxide powder and air filters, both leachants dissolved appreciable amounts of uranium and the uranium release may be solubility limited. In the cases of trash-type wastes, high concentrations of uranium in solution were observed only for synthetic landfill leachate tests where the final sample pH was close to the initial pH of 4.9. The lower plot in Fig. 6.11 of log concentration vs pH clearly shows no correlation with leachate type for samples where the final pH was >5. (The question of pH control of leaching is examined further in Sect. 6.4.3.3.) The lack of correlation of uranium leaching for the trash-type wastes with the type of leachant used was unanticipated, based on the expected aggressiveness of the two leachants, and suggests that other waste components may be controlling the leaching chemistry.

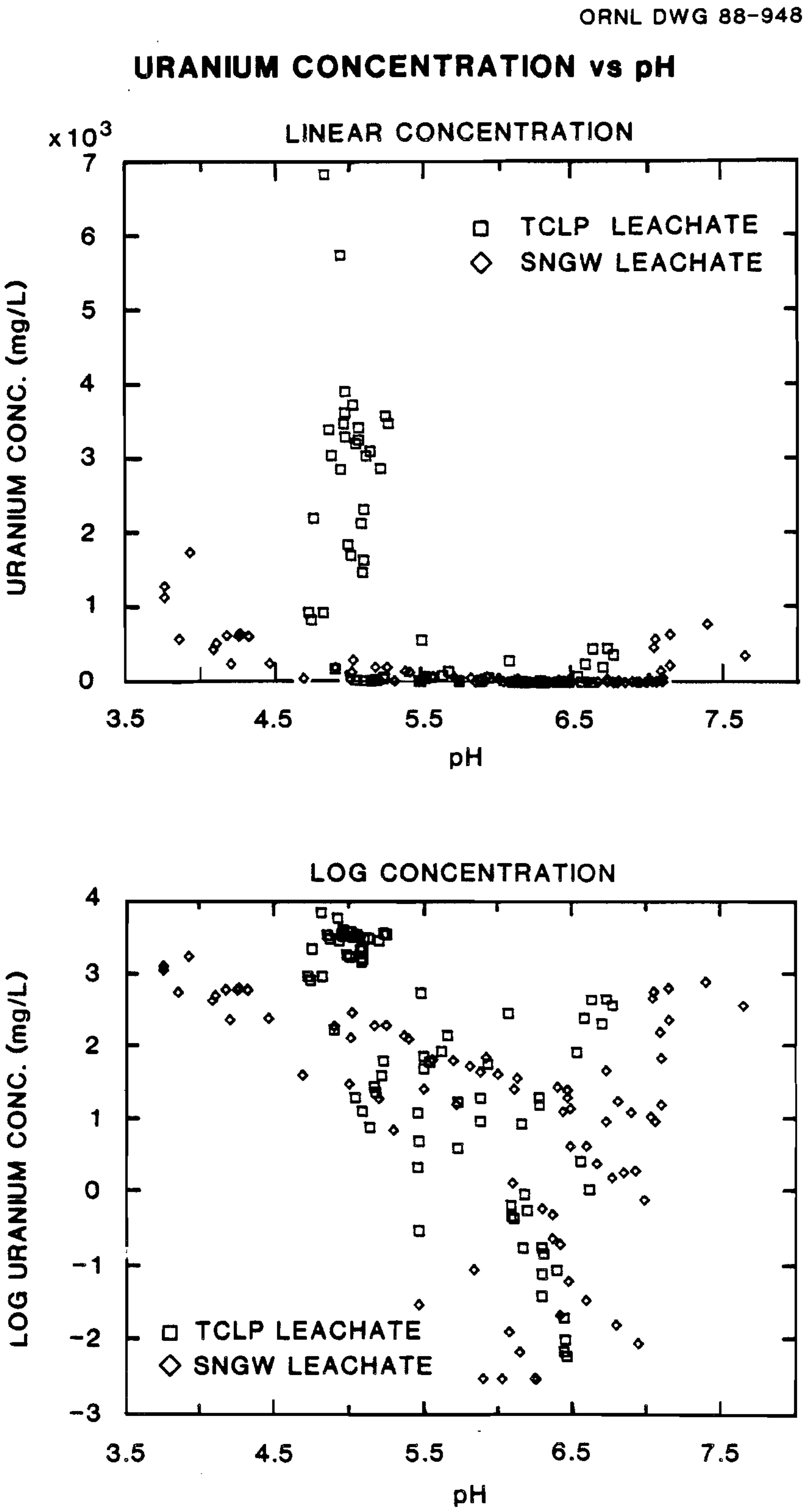

Fig. 6.11. Leachate uranium concentration vs pH.

The test results indicate that the initial acidity (pH) or acid capacity (buffering) of the leachant did not seem to be important in controlling the leaching of uranium from most of these Y-12 Plant wastes, with the exception of the uranium oxide powder and air filters. This is a surprising conclusion and suggests that simple dissolution reactions involving uranium may not be controlling the release of uranium from these wastes. By default then, reactions such as oxidation of uranium metal or insoluble UO_2 to soluble U(VI) species, or reactions involving other waste components, e.g., complex formation to increase uranium solubility or sorption/precipitation reactions which could decrease solubility, may be release-rate-controlling in some situations.

6.4.3 Effect of Leach Test Protocol

6.4.3.1 Batch vs Sequential

Two leaching experimental protocols were followed in these tests: (1) batch contact methodology at two liquid/solid ratios (~2 and ~20) to measure the uranium leaching as a function of time over a 7-day contact period, and (2) sequential contact methodology to measure uranium leaching as a function of the cumulative liquid/solid ratio (~62), also over a cumulative 7-day leaching period. Examination of the data from these tests could reveal several important aspects of uranium leaching and could help identify the release-rate-limiting reaction or process.

The batch contact data showed two important observations: (1) most of the tests had not reached steady-state during the 7-day period, and the uranium concentration in solution (or fraction released) had not achieved a constant value, and (2) uranium leaching exhibited bimodal non-steady-state behavior over time--in some tests the concentration (or fraction released) increased rapidly at first and then continued to increase more slowly with time, while in others, the concentration (or fraction released) maximized on day 1 and then decreased to very low values by day 7. Bimodal leaching behavior may make it difficult to extrapolate these one-week batch contact laboratory test results to predict uranium behavior over years or decades in the lysimeters or disposal options. A possible explanation of this bimodal behavior is discussed in Sect. 6.4.6.1.

The data for the sequential leach tests could only show an increasing total amount of leaching because the leachate and the uranium in the leachate were removed after each contact and, thus, could not precipitate or be sorbed in subsequent contacts. Depending on the kinetics of the reactions involved in uranium leaching and then removal-from-solution and the time the leachate may contact the waste in the field lysimeters or various disposal options, sequential test results might more realistically model uranium leaching in a lysimeter or leachant flowthrough situation than would batch contact tests. None of the curves of fraction released vs time for the sequential tests with trash-type wastes had leveled-off by day 7 (liquid/solid ratio of 62), and the question at issue is how to extrapolate these curves to times of years or decades. (Some of the curves for the air filter waste appeared to have leveled off because all of the uranium had been leached.) If the curves are assumed (or modeled) to level-off at only slightly greater liquid/solid ratios, say at a value of perhaps 2% uranium released, then 98% of the uranium will be modeled as insoluble or never released at any time. If, on the other hand, the final slope of these curves are extended over time at some finite rate, say 0.1% per day, then 100% of the uranium will be leached after about 3 years. Conversely, the curves could be extended over time as a function of the liquid/solid ratio and the uranium release predicted as a function of the groundwater flux in the lysimeters or other disposal options. In any case, if the rate is modeled as non-zero then 100% of the uranium will be calculated to be released at some future time. It is not clear that the data obtained from the tests described in this report are adequate to resolve this issue.

6.4.3.2 Liquid/Solid Ratio

The liquid/solid ratio in both the batch contact and sequential leach tests is an important experimental parameter that could have a major impact on the uranium leaching data. If uranium solubility (saturated solution concentration) is the release-rate controlling parameter, then the uranium leaching would be proportional to the liquid/solid ratio as long as sufficient uranium solids were present to achieve solution saturation. Such a situation might exist for wastes which contain appreciable amounts of higher-valence uranium oxides such as U_3O_8. The air filters and uranium oxide powder from the UCOF are possible examples of such wastes. A solubility-limited release situation is relatively easy to model because the uranium releases can be equated with the predicted groundwater flux. However, for many of the trash-type wastes it seems more likely that the uranium contaminant will be primarily present as chips of uranium metal. Uranium metal or lower valence oxides such as UO_2 are very insoluble in groundwater, and wastes containing uranium in these forms likely would not yield appreciable uranium release values unless (or until) the metal or UO_2 is oxidized. For such wastes (production trash, mixed metal chips, and composite waste), it seems less likely that solubility would be the release rate limiting process and more likely that the rate of oxidation could be the limiting reaction. For such wastes, it seemed doubtful that the uranium leaching would be proportional to the liquid/solid ratio in the experiments. The experimental results are briefly examined below with respect to this question.

Both the total fraction uranium leached by day 7, in percent, and the uranium concentration in the day 7 leachate are shown in Table 6.13 for all the tests. With the exception of the uranium oxide powder and air filters, no clear trends exist related solely to the experimental liquid/solid ratio. Many of the uranium oxide powder and air filter leachates may be saturated, or near saturation, for U(VI) species at the leachate pH (see Sect. 6.4.3.3). For the other wastes, the waste type seemed to be the dominant variable in controlling the fraction uranium leached and/or the leachate concentration of uranium. Little uranium was leached from mixed metal chips in any test,

Table 6.13. Fraction of uranium leached and uranium concentration in the leachate as a function of liquid/solid ratio

Liquid/solid[a]	Leachant[b]	Waste type	Leached[c] (%)	Conc.[d] (mg/L)
2 (batch)	TCLP	Production trash	0.68	458
		Mixed metal chips	7E-05	0.007
		Composite waste	4.59	290
		Air filters	1.5	560
		Uranium oxide powder	0.69	2860
	SNGW	Production trash	1.61	796
		Mixed metal chips	2E-05	0.003
		Composite waste	0.16	9.6
		Air filters	0.4	140
		Uranium oxide powder	2E-03	7
20 (batch)	TCLP	Production trash	0.84	50
		Mixed metal chips	6E-04	0.022
		Composite waste	0.01	0.3
		Air filters	68.1	3110
		Uranium wxide powder	7.25	3050
	SNGW	Production trash	0.57	47
		Mixed metal chips	6E-04	0.013
		Composite waste	1.44	27.9
		Air filters	14.6	610
		Uranium oxide powder	0.18	75
62 (seq.)	TCLP	Production trash	0.69	7.7
		Mixed metal chips	5E-02	0.18
		Composite waste	1.36	5
		Air filters	51.1	170
		Uranium oxide powder	8.38	830
	SNGW	Production trash	1.00	11
		Mixed metal chips	3E-03	0.009
		Composite waste	0.16	0.5
		Air filters	17.0	290
		Uranium oxide powder	0.20	26

[a] Nominal liquid/solid ratio; the value was slightly different in a few tests.

[b] TCLP = synthetic landfill leachate; SNGW = synthetic groundwater.

[c] The fraction of the initial uranium in the sample that was leached by day 7; total liquid/solid ratio of 2 or 20 for the batch contact tests and a ratio of 62 for the sequential tests.

[d] The uranium concentration in the final (day 7) sample for the batch tests and the day 7 sample at an actual liquid/solid ratio of 22 for the sequential contact tests.

while production trash and composite waste gave more variable results (see Sect. 6.4.1).

In the absence of additional information, it appears that the liquid/solid ratio for a given waste leaching test may not be a useful indication or guide to the amount of uranium to be released in that test. Thus, it would seem that predictions of future waste performance in the field lysimeters or other disposal options, which are based solely on knowledge of the cumulative liquid/solid ratio, may not be reliable or defensible.

6.4.3.3 Leachate pH

Because the solubility (saturated solution concentration) of U(VI) species is highly pH dependent (see Appendix F), it might be anticipated that the uranium concentration in solution for a given sample would correlate with the final sample pH if sufficient soluble uranium were present in the sample to achieve saturation. This hypothesis is explored in Fig. 6.12 where the log of the uranium concentration for all analytical samples (day 1 through day 7) is plotted vs sample pH for the two leachants used (synthetic landfill and synthetic groundwater) for each of the five waste types tested. Surprisingly, the figure revealed clusters of data points for the different waste types, but, as discussed in Sect. 6.4.2, showed that the initial leachant employed had only a minor or second-level effect on the uranium concentration. It is not clear why the sample pH values for the buffered synthetic landfill solution cover essentially as wide a range as the unbuffered synthetic groundwater samples. The chemistry involved here warrants further investigation.

Uranium oxide powder and air filter wastes gave the highest uranium concentrations, and the data points are clustered in the more acidic pH range. This is a logical result for leaching into the buffered landfill leachate but, because the dissolution reactions consume acid (see Appendix F), unbuffered solutions such as the synthetic groundwater were expected to become more basic, not more acidic during the test. The mixed metal chip data occupy a region in the plot at very low uranium concentrations. The data points for production trash and combined waste overlap to a considerable degree and generally show more scatter.

A possible conclusion that can be drawn from this plot (this conclusion has been reached several times previously in earlier sections of this report based on other data considerations) is that waste components other than the uranium contaminant or the leachant employed control the chemistry of the leaching system, and, in turn, the fraction uranium leached or the uranium concentration in the leachate.

6.4.4 Effect of Time

Because predictions of waste performance will be needed for periods of decades for the field lysimeters and centuries or millennia for final disposal options while this laboratory leaching data have been collected over

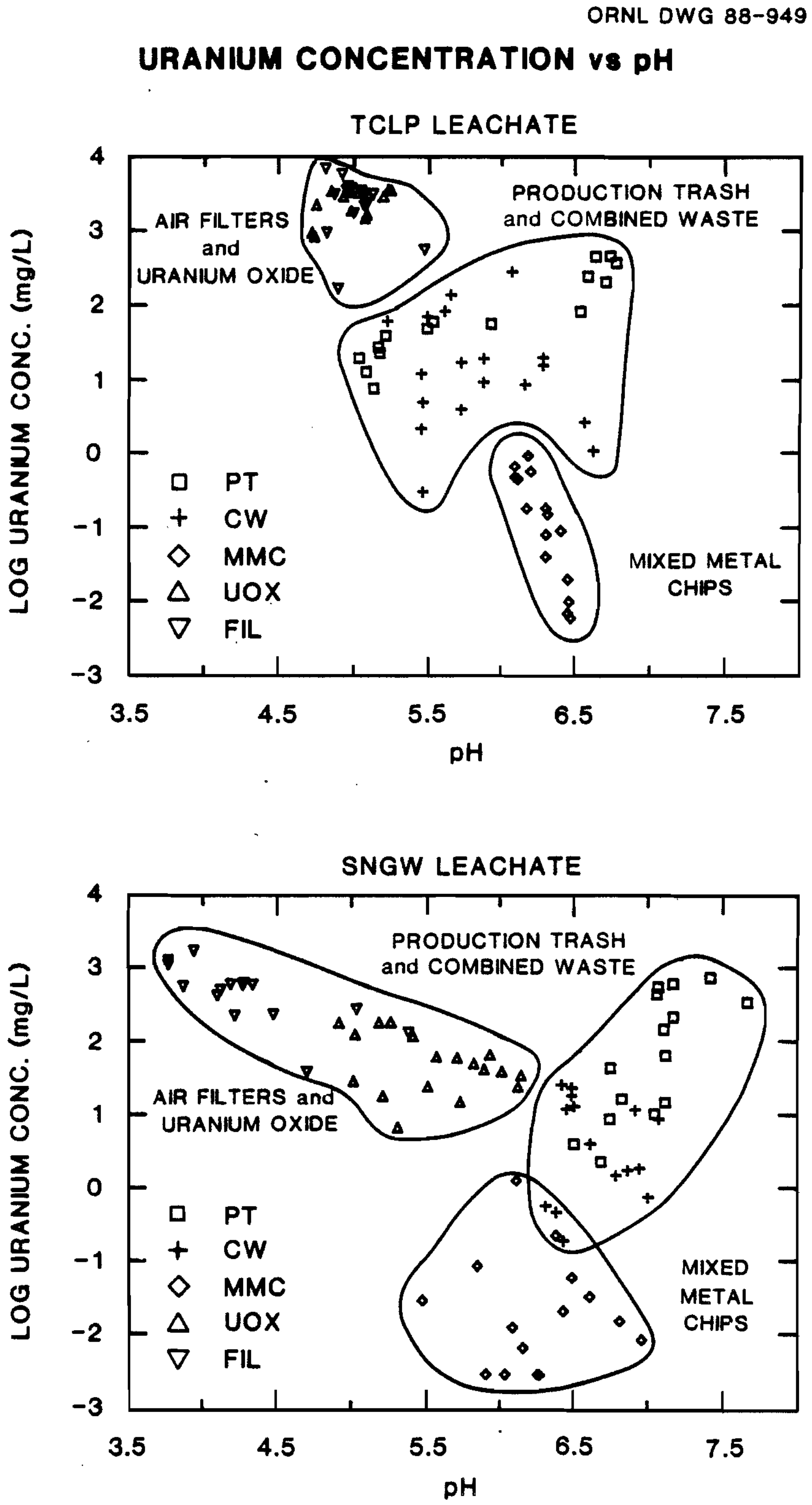

Fig. 6.12. Uranium concentration vs pH.

1 to 7 days, extrapolation of the laboratory data over time will be an important lysimeter or disposal option performance modeling aspect. Data for all leachate samples and waste types for both batch and sequential leach tests in both synthetic landfill leachate and synthetic groundwater are presented in Fig. 6.13 as a function of contact time. The data show very substantial divergence for different tests; i.e., both increasing and decreasing leach modes. In the absence of additional information, it seems that uranium leaching can not be predicted over time. An understanding of the release-rate-limiting reactions and processes and expression of these reactions and processes as a function of time may be necessary for useful or defensible predictions. An additional research program would be required to develop such information.

6.4.5 Leachate Sample Stability

Many of the synthetic landfill leachates and the synthetic landfill leachate analytical and archive samples from tests with combined waste, production trash, or mixed metal chips, but not from tests with uranium oxide powder, proved to be unstable (precipitates and sludges formed) on storage, and the analytical samples for uranium and inorganic elements for these samples were stabilized by acidification with HNO_3 to dissolve or prevent precipitation of the sludge. No precipitates or sludges formed in any of the synthetic groundwater leachates, and these were not acidified on storage.

The samples for analysis were filtered when they were prepared and were free of particulates or immiscible liquids/solids at that time. Excess leachate solutions were stored in drums in the laboratory until it was convenient to discharge them to the hot drain. Analytical samples and replicate archive samples were stored in a refrigerator until they were transferred to the Analytical Chemistry Division for analysis. After either refrigerated or room-temperature storage for about two weeks to a month, many, but not all, of the synthetic landfill leachate samples from production trash, mixed metal chip, or combined waste tests released a water-immiscible red oil that both floated to the top of the sample and/or adsorbed into the plastic sample bottles. In addition, some synthetic landfill leachate samples also formed a flocculent red-brown sludge, which settled to the bottom of the samples. In parallel synthetic groundwater tests, a thin film of clear oil was observed on the surface of some leachates in the 30-gal drum. Sample instability would represent a serious analytical problem because in the resulting heterogeneous samples, the uranium and other elements could be sequestered by the oils or sludges and be incorrectly analyzed. It is likely, but unproven, that the sludge is a ferric hydroxide precipitate resulting from the dissolution of soluble Fe(II) species during the leaching tests with synthetic landfill leachate and the subsequent precipitation of insoluble Fe(III) hydroxide dur to oxidation on sample storage. Ferric hydroxide is known to be a power adsorbent for uranium solution species [Seeley and Kelmers 1984]. The source or chemical identify

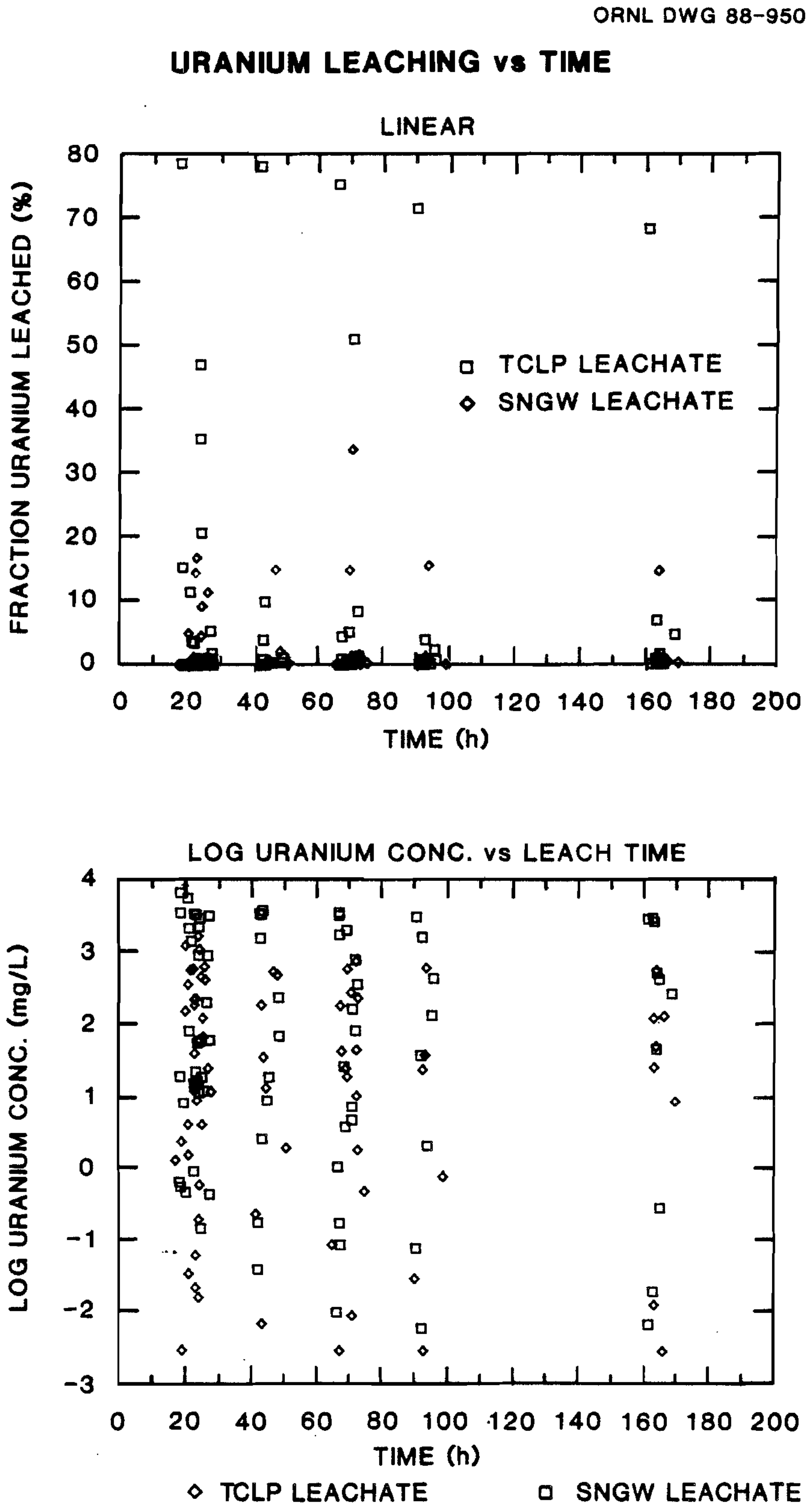

Fig. 6.13. Uranium leaching vs time.

of the oil is unknown at this time.[b] It is likely that some small amount of immiscible oil was present in many of the trash-type waste leach tests because oily material was observed in many of the as-received samples (see Appendix A), but the immiscible oil may have been readily observable only when a fine ferris hydroxide precipitate was also present to color the oil red. The problem of precipitate or sludge formation and analytical problems was alleviated by acidification of the appropriate samples to prevent or reverse the formation. The red oil, once it had been adsorbed into plastic, could not be redistributed into the sample.

Instability of the synthetic landfill leachate may have important implications for both the design and operation of the field lysimeters because the biodegradable material in some waste streams might be expected to generate a leach solution on extended contact in the field lysimeters which would be similar to the synthetic landfill leachate. Depending on whether the red oil and sludge adsorbs uranium, and whether the red oil is in turn absorbed by plastic components of the lysimeters or passes out of the lysimeters with the leachate, uranium retention by the lysimeters could be artificially accelerated or diminished, relative to various potential waste disposal options.

The air filter samples showed a different reactivity or instability with the synthetic landfill leachant. The mixture was bubbling after contact, and a fine precipitate had formed. A plausible explanation was that the aluminum filter separators were reacting with the leachant to release H_2 and forming aluminum hydroxide. The analytical and archive samples appeared to be stable on storage; this seems reasonable because after filtration, no aluminum metal remains to allow continued reaction and all aluminum hydroxide formed would also be removed because aluminum hydroxide is very insoluble near neutral pH.

6.4.6 Overview of Uranium Leaching from Y-12 Plant Wastes

Three of the more significant observations or findings that resulted from this laboratory leaching task are briefly highlighted in the following sections.

6.4.6.1 Bimodal Uranium Release

Perhaps the single most significant observation to come out of this laboratory investigation is the finding of bimodal uranium release curves as a function of time for the batch contact tests. In some tests, the uranium concentration in the leachate or the fraction of the initial uranium leached <u>increased</u> over time and did not reach a steady-state limit or constant value in 7 days (the last time point). Such behavior could be consistent with slow leaching kinetics; for example, reactions such as slow oxidation of uranium metal or reduced uranium oxides. In the other tests, the uranium concentra-

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[b] Dr. Roy Norman, Y-12 Plant, analyzed a sample of the red oil and found aliphatic oils present.

tion or fraction released maximized on the first day (the first data point) and then decreased steadily to very low values by day 7. Such behavior could be consistent with adsorption or precipitation of initially-solubilized uranium. It is possible that the redox state of the system controls the leaching mode observed (see Sect. 6.4.6.2) and is responsible for the different leaching modes.

Bimodal uranium leaching behavior has been reported previously in tests to study uranium solubilization from wastes at the Portsmouth Gaseous Diffusion Plant [Greiner and Deacon 1985]. Bimodality may complicate both interpretation of laboratory data and extrapolation of laboratory data to larger-scale, longer-time applications such as field lysimeters or other disposal options.

6.4.6.2 Possible Redox Control of Uranium Release Rate

The concept of leaching uranium from Y-12 Plant wastes presented in this section was developed to explain both the bimodal leaching characteristic and several experimental observations. A referenced discussion of the supporting uranium chemistry is given in Appendix F.

Important observations from batching leach tests were:

(1) A negative pressure (partial vacuum) developed in the leaching vessel for many, but not all, of the tests with trash-type wastes, but never with uranium oxide or air filter wastes.

(2) A brown sludge or precipitate formed upon storage of the synthetic landfill leachate or leachate samples for many, but not all, of the tests with trash-type wastes, but never with uranium oxide or air filter wastes. No sludges or precipitates formed in any synthetic groundwater leachates.

(3) The decreasing uranium leach mode was always observed for tests with mixed metal chips, sometimes for tests with composite waste, but never for production trash, uranium oxide powder, or air filters.

These observations are consistent with the development of reducing redox conditions in the leaching vessel. The most likely reductant for these tests is the reactive metal chips (aluminum, brass, iron, etc.) in the various wastes, as well as any uranium metal chips or turnings. These metals can react with water to form strongly reducing conditions. Under such reducing conditions, any solubilized uranium would be reduced to the +4 valence state, and it is well known that the corresponding U(IV) oxide, UO_2, has a very low solubility in aqueous solutions. Therefore, if strongly reducing redox conditions developed during the leach test, any uranium initially solubilized as U(VI) species would be precipitated (decreasing leach mode) and, of course, any undissolved uranium either as uranium metal or lower-valence oxides could not be solubilized (not leached) because no oxidant remains in the mixture to oxidize the uranium to the soluble +6 valence.

Anaerobic biological activity involving biodegradable carbon-containing components of the trash-type wastes could also lead to reducing redox conditions, if not in these short-time laboratory leaching tests, then probably in longer-time lysimeter studies or other disposal options. Sanitary landfills form reducing redox conditions due to anaerobic digestion, and similar performance could be anticipated for some of the Y-12 Plant wastes containing significant amounts of paper, cloth, wood, etc. after disposal.

The negative pressure observation supports this reducing redox theory because consumption of the strongest oxidant in the leaching vessel, the O_2 in the air, would produce a partial vacuum. Also, the sludge formation observation is consistent with this theory because under strongly reducing conditions, iron could be leached as soluble Fe(II) species in the acidic synthetic landfill leachate tests [but not in the synthetic groundwater tests because Fe(II) species are less soluble near neutral pH]. Then, oxidation of the dissolved Fe(II) species to very insoluble Fe(III) hydroxide precipitate would be expected to occur in the leachate samples after separation from the leach solids containing the reductant and storage or exposure to air.

A good example of this suggested mechanism can be seen by comparing two tests with production trash (see Table 6.2 and Fig. 6.1). The waste in test 3BALA had no iron turnings; a negative pressure did not develop, no brown sludge was formed, and an increasing leach mode was observed. The waste for test 4BAL contained a large amount of iron turnings, and in this case, the drum developed a negative pressure during leaching, the brown sludge formed, and a decreasing leach mode was observed. Further confirmation is seen in the fact that mixed metal chip wastes always gave a reducing leach mode, while combined waste sample (which had variable amounts of metal chips) sometimes gave the reducing mode. Production trash samples contained much smaller amounts of metal chips, and none of the samples tested exhibited a reducing mode. The uranium oxide and air filter samples contained no metal chips from machining operations and these leach tests never showed a decreasing mode.

Thus, a reasonable working hypothesis may be that the redox state of the leaching test or waste disposal situation may be the single most important variable in controlling the leaching or release of uranium from the waste. Wastes containing uranium metal (0 valence) or +4 valence uranium oxide (lower uranium valences are not stable in the presence of water) could release significant quantities of uranium to groundwater or landfill leachate-type aqueous solutions only after oxidation of the uranium to the +6 valence and formation of U(VI) solution species. Thus, the rate or time of oxidation and depletion of the reductant in the waste (metal chip and/or biodegradable material) could be the uranium release-rate-controlling process. For wastes which initially contain soluble +6 valence uranium compounds, if the rate of U(VI) reaction with the reductant exceeds the rate of groundwater movement through the waste, then little uranium may be released until the reductant is exhausted. It seems worthwhile to test this hypothesis in a series of controlled leach experiments with deliberate additions or deletions of specific waste components.

6.4.6.3 Air Filters

The air filters were unique among the wastes tested. The uranium contaminant was highly soluble, and release seemed to be constrained only by the solubility limit in the leachate sample. The potential for rapid release of uranium from this waste form may have important implications for disposal options.

6.5 ACKNOWLEDGMENTS

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6.7 APPENDICES

6.7.1 Appendix A - Description of Waste Samples

A detailed description of each of the waste samples received from the Y-12 Plant is included in this appendix. This description is based on a careful visual examination of each waste sample before it was placed in the 30-gal leaching drum. Large items such as sheets of plastic or paper, gloves, cloth, etc. were cut into smaller pieces with scissors to minimize trapping of uranium particles or leachant.

It should be pointed out that an attempt was made at Y-12 to minimize compositional differences between the same waste-strea-type samples used in the leach tests. This was accomplished by sorting the as-collected trash into piles of similar material type and placing proportional amounts of each type into plastic bags. Afterward, each bag was gamma counted to determine the uranium content.

6.7.1.1 Description of Production Trash

The Y-12 Plant definition[c] of production trash is any waste generated by the cleaners (a job classification for janitorial personnel) in cleaning and protecting the floors, resulting from efforts to minimize the spread of contamination, and/or general trash found on the floor. A visual description of the trash samples used in each leach test is given below by leach test number (see also Table 6.14). A typical sample in shown in Fig. 6.14.

Test 3FS (bags A, F, and H from drums 2 and 3)

The following items were identified: cotton rags, several kinds of plastic sheeting, screws, styrofoam-type drinking cups, candy bar wrappers, aluminum soda cans, chewing gum wrappers, kleenex-type tissues, industrial wipes, tubing, small amount of metal turnings (brass and stainless steel), copper electrical wire, dirt, large amount of oily floor sweepings compound, cigarette butts, section of newspaper, nylon mesh, sandpaper mesh screen, Hot

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[c] Personal communication from B. T. Butcher, Y-12 Plant, to A. D. Kelmers, ORNL.

Table 6.14. Production trash

Drum no.	Bag ID	Weight (kg)	Uranium (g)	Test no.
1 & 5[a]	A[b]	2.13	342 ± 11	828FSAA
B[c]	2.68	333		
C 2.09	232	8FS		
D 2.79	319			
E 1.92	253	4FS		
F 1.73	149	8FS		
G 3.05	452	7FSAA		
H 1.65	171	4FS		
2 & 3[a]	A	3.80	368	3FS
B	3.03	237	7FSAA	
C 2.42	399	7FS		
D[b]	3.01	616 ± 16	7FS	
E 2.55	197	7FSAA		
F 1.80	480	3FS		
G 3.47	132	7FS		
H 3.55	376	3FS		
16[d] A	3.56	710	1FS	
B	528			
C	458			
D 3.67	832	5FS		
E	749			
17[d] A		152		
B	156			
C	144			
D	109			
E	69			

[a] Received from Y-12 Plant on January 15, 1988.
[b] Mean ± 1 standard deviation for triplicate counts.
[c] Bags not assigned at test number were not used.
[d] Received from Y-12 Plant on April 15, 1988.

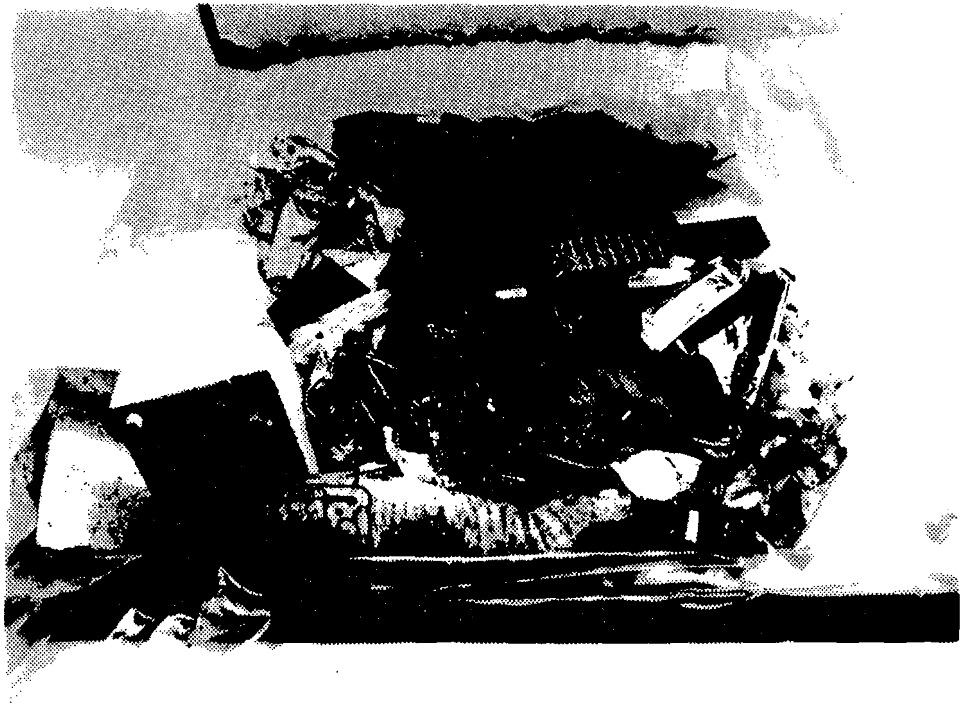

Fig. 6.14. Typical sample of production trash.

Hogs (an adsorbent in a cloth tube), blotter paper, memo correspondence, nails, nuts and bolts (brass and stainless steel), paraffin-coated milk cartons, peanuts and peanut shells, aluminum foil, a telephone directory, a can of rubbing compound, lens cleaning tissue, paper bag of sugar, and gloves (rubber, cloth, and leather).

Test 4FS (bags E and H from drums 1 and 5)

The following items were identified: cotton rags, several kinds of plastic sheeting, oily rope, styrofoam-type drinking cups, candy bar wrappers, aluminum soda cans, chewing gum wrappers, kleenex-type tissues, industrial wipes, tubing, small amount of metal turnings (brass and stainless steel), copper electrical wire, dirt, large amount of oily floor sweepings compound, cigarette butts, section of newspaper, nylon mesh, sandpaper mesh screen, Hot Hogs, blotter paper, memo correspondence, nails, screws, nuts and bolts (brass and stainless steel), paraffin-coated milk cartons, and gloves (rubber, cloth, and leather).

Test 7FSAA (bags B and E from drums 2 and 3 and bag G from drums 1 and 5

The following items were identified: cotton rags, several kinds of plastic sheeting, styrofoam-type and plastic drinking cups, candy bar wrappers, aluminum soda cans, chewing gum wrappers, kleenex box, industrial wipes, tubing, small amount of aluminum metal turnings, copper electrical wire, dirt, large amount of oily floor sweepings compound, cigarette butts, section of newspaper, nylon mesh, oily sandpaper, Hot Hogs, blotter paper, memo correspondence, nails, screws, nuts and bolts (brass and stainless steel), paraffin-coated milk cartons, peanuts and peanut shells, gloves (rubber, cloth, and leather), lint, brown paper lunch bags, rubber "O" rings, and small piece of wood.

Test 8FSAA (bag A from drums 1 and 5

The following items were identified: cotton rags, several kinds of plastic sheeting, styrofoam-type and plastic drinking cups, aluminum soda cans, industrial wipes, tubing, small amount of iron metal turnings, large amount of oily floor sweepings compound, cigarette butts, oily sandpaper, Hot Hogs, blotter paper, a few nails, screws, nuts and bolts (brass and stainless steel), paraffin-coated milk cartons, peanuts and peanut shells, and gloves (rubber, cloth, and leather).

Test 1FS (bag A from drum 16)

The following items were identified: several kinds of plastic sheeting, styrofoam-type and plastic drinking cups, aluminum soda cans, oily industrial wipes, large amount of aluminum metal turnings, small amount of oily floor sweepings compound, cigarette butts, oily sandpaper, Hot Hogs, blotter paper, memo correspondence, paraffin-coated milk cartons, gloves (rubber, cloth, and leather), brown paper lunch bags, and wooden pencil.

Test 5FS (bag D from drum 16)

The following items were identified: several kinds of plastic sheet, styrofoam-type and plastic drinking cups, aluminum soda cans, oily industrial wipes, large amount of aluminum, iron, and brass metal turnings, small amount of oily floor sweepings compound, cigarette butts, oily sandpaper, Hot Hogs, blotter paper, memo correspondence, paraffin-coated milk cartons, gloves (rubber, cloth, and leather), used steel-wool pad, and a small piece of copper wire.

6.7.1.2 Description of Composite Waste

The Y-12 Plant[a] definition of composite waste is an assortment of trash that contains 1/3 floor sweepings (production trash), 1/3 mixed metal chips, and 1/3 general trash from highly-contaminated areas. A visual description of the trash samples used in each leach test is given below by leach test number (see Table 6.15). A typical composite waste sample is shown in Fig. 6.15.

3BAL (bags A and L from drums 12, 13, and 15)

The following items were identified: several kinds of plastic sheeting, styrofoam and plastic cups, blotter paper, wipes, dirty and oily leather gloves, rubber gloves, loose liquid pipe-joint compound, cigarette butts, floor sweepings, medium amount of iron and brass tunings, Brillo™-type scouring pad, sandpaper, pieces of insulated copper and aluminum wire, oily cloth, yellow plastic tape, small piece of rubber tubing, oil-soaked paper towels, and a can of pipe-joint compound.

3BALA (bags A, D, and G from drums 11 and 14)

The following items were identified: moldy cotton rags, several kinds of plastic sheeting, styrofoam-type and plastic drinking cups, candy bar wrappers, aluminum soda cans, chewing gum wrappers, kleenex-type tissues and box, industrial wipes, tubing, small amount of large metal turnings (aluminum), large copper cable with PVC insulation, long piece of bare copper wire, moderate amount of oily floor sweepings compound, cigarette butts, section of newspaper, large ball of aluminum foil with lunch trash inside, lunch bag with rotten sandwich, sandpaper, Hot Hogs, blotter paper, memo correspondence, screws, nuts and bolts (stainless steel), gloves (rubber, cloth, and leather), yellow plastic tape, pasteboard box, paper fiber "egg container type," and a folded blue print.

4BALA (bag K from drums 12, 13, and 15)

The following items were identified: several kinds of plastic sheeting, styrofoam-type and plastic drinking cups, aluminum soda cans, industrial wipes, tubing, small amount of oily large metal turnings (iron), moderate amount of oily floor sweepings compound, cigarette butts, rubber gloves, oily leather gloves, pasteboard box, red plastic tape, and sheets of newspaper.

Table 6.15. Composite waste

Drum no.	Bag ID	Weight (kg)	Uranium (g)	Test no.
11 & 14[a]	A	2.19	40	3BALA
	B[b]		46	
	C		38	
	D	4.05	48	3BALA
	E	47		
	F	2.06	69	8BALAA
	G	4.66	50	3BALA
	H	2.99	35	8BALAA
12, 13 & 15[a]	A	9.75	184	3BAL
	B		117	
	C	3.38	154	1BAL
	D[c]	3.70	40 ± 6	7BALAA
	E		151	
	F	3.15	55	7BALAA
	G	3.06	90	8BALAA
	H	3.26	34	7BALAA
	I		195	
	J[c]		254 ± 20	
	K	4.08	220	4BALA
	L	10.00	133	3BAL
18[d]	A	2.95	110	5BAL
	B		39	
	C		24	
	D		32	
	E		29	
19d	A		65	
	B		45	
	C		70	
	D		76	
	E		32	

[a] Received from Y-12 Plant on February 4, 1988.
[b] Bags not assigned a test number were not used.
[c] Mean ± 1 standard deviation for triplicate counts.
[d] Received from Y-12 Plant on April 22, 1988.

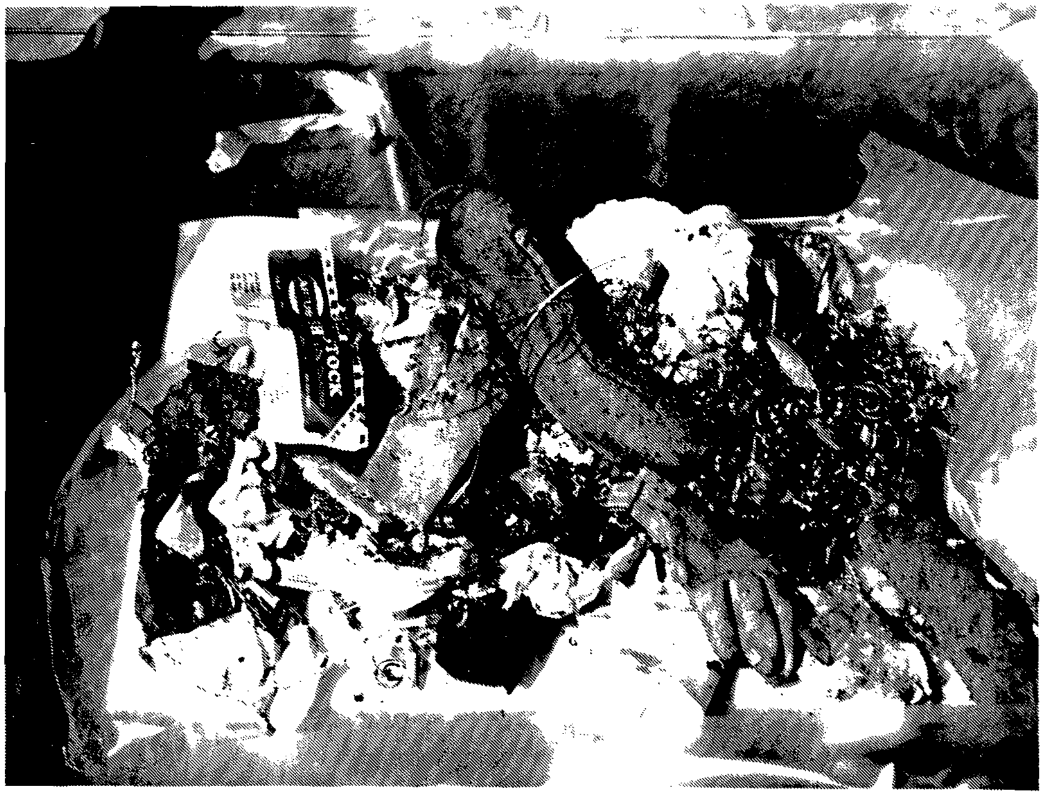

Fig. 6.15. Typical sample of composite waste.

There was a lot of red oil smeared on the surfaces of items in this bag of waste.

7BALAA (bags D, F, and H from drums 12, 13, and 15)

The following items were identified: plastic bags, polyvinyl chloride plastic, rubber gloves, oil-soaked paper, iron turnings, styrofoam-type and plastic cups, floor sweepings, aluminum turnings, cotton rags, oily leather gloves, paper coveralls, blotter paper, cigarette package and butts, tissue papers, cotton gloves, cotton short sleeve shirt, and a time card insert.

8BALAA (bag F from drums 12, 13, and 15 and bags F and H from drums 11 and 14)

The following items were identified: several kinds of plastic sheeting, styrofoam-type and plastic drinking cups, aluminum soda cans, industrial wipes, small amount of oily large metal turnings (iron aluminum), moderate amount of oily floor sweepings compound, cigarette butts, rubber gloves, oily leather gloves, pasteboard box, sheets of newspaper, cardboard packaging material, light bulb carton, broken light bulb, paraffin-coated milk carton, Hot Hog, empty plastic "Joy™" and "409™" bottles, cloth rags, and red plastic tape.

1BAL (bag C from drums 12, 13, and 15)

The following items were identified: several kinds of plastic sheeting, styrofoam-type and plastic drinking cups, aluminum soda cans, industrial wipes, large amount of oily metal turnings (iron and alumi-num) that varied in size from large to fine, moderate amount of oily floor sweepings compound, cigarette butts, rubber gloves, oily leather gloves, paper coveralls heavily stained with red ink, small piece of wood, meter-long piece of plastic insulated copper wire, and ~2 m^2 of nylon cloth and ~2 m^2 of cloth rags.

5BAL (bag A from drum 18)

The following items were identified: several kinds of plastic sheeting, styrofoam-type and plastic drinking cups, aluminum soda cans, industrial wipes, large amount of oily metal turnings (iron and aluminum) that varied in size from large to fine, moderate amount of oily floor sweepings compound, cigarette butts, rubber gloves, oily leather gloves, and paper coveralls heavily stained with red ink.

6.7.1.3 Description of Mixed Metal Chips

The Y-12 Plant definition[a] of mixed metal chips is a mixture composed of metal turnings of aluminum, iron, stainless steel, copper, and/or brass. A visual description of the trash samples used in each leach test is given below by leach test number (see Table 6.16). A typical sample of mixed metal chips is shown in Fig. 6.16.

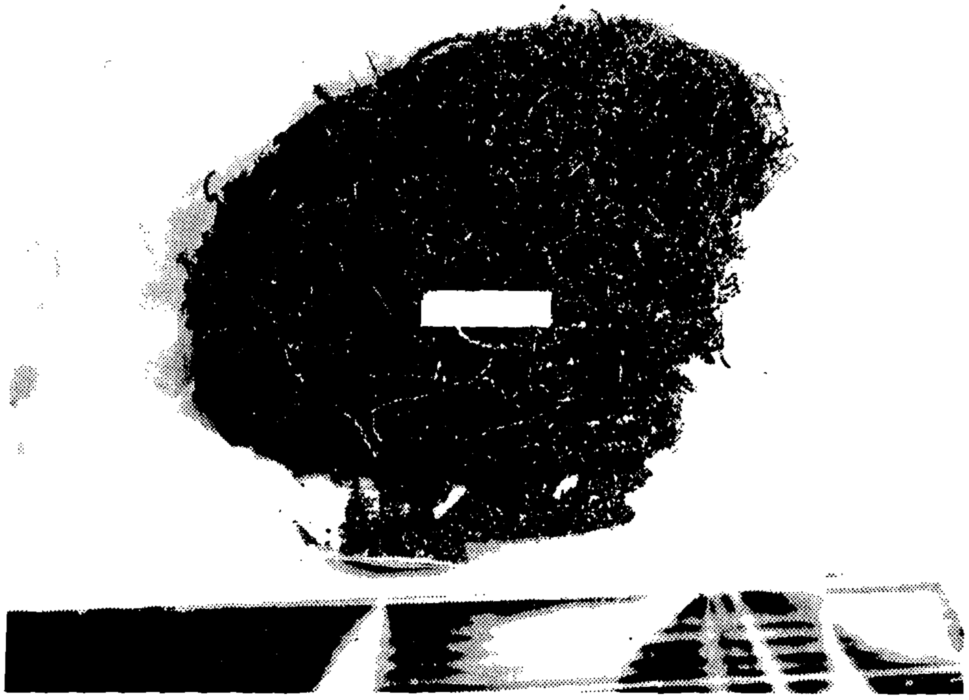

Fig. 6.16. Typical sample of mixed metal chips.

Table 6.16. Composite mixed metal chips.

Drum no.	Bag ID	Weight (kg)	Uranium (g)	Test no.
8[a]	A	2.84	55	3CHIP
	B[b]	3.67	255 ± 5	4CHIP
	C	3.79	108	7CHIP
	D	5.35	217	8CHIP
6[c]	A[d]		34	
	B	3.81	119	1CHIP
	C		70	
	D		72	5CHIP
	E	2.90	93	5CHIP

[a] Received from Y-12 Plant on February 22, 1988.
[b] Mean ± 1 standard deviation fro triplicate counts.
[c] Received from Y-12 Plant on April 1, 1988.
[d] Bags not assigned a test number were not used.

Test 3CHIP (bag A from drum 8)

The plastic bag contained fine metal turnings of brass and iron. There was a heavy coating of rust on the surface of the bag, and the turnings were damp.

Test 7CHIP (bag C from drum 8)

The contents of this bag were similar in appearance to those in Test 3CHIP; however, these turnings were more greasy.

Test 4CHIP (bag B from drum 8)

The contents appeared to be fine turnings of copper and iron which were greasy.

Test 8CHIP (bag D from drum 8)

The contents of this waste was like that for Test 4CHIP.

Test 1CHIP (bag B from drum 6)

A large fraction of this waste was large-sized turnings of stainless steel; the remainder was fine, rusty iron turnings. Also, there was lots of oil on the surface of the bag and larger-sized turnings.

Test 5CHIP (bag E from drum 6)

Similar to waste in Test 1CHIP.

6.7.1.4 Description of Air Filters

The air filters were standard High Efficiency Particulate Absorber (HEPA) filters from building ventilation systems in Y-12 Plant areas working with depleted uranium. The filters are constructed of a fiberglass filter medium with aluminum separators and are supported by galvanized steel wire face guards on both sides. The filtering medium is sealed with gaskets on both sides into steel frames which measure 24 x 24 x 11.5 in. Appreciable amounts of an easily dispersed olive green powder were observed on all filters. The filter medium had to be cut from the steel frames because the HEPA filters were too large to fit into the 30-gal leaching drums. It also turned out that the volume of the filter media was too large to fit into a 30-gal leaching drum consequently, the filter media of five of the seven HEPA filters used were halved. These, along with the two that were not divided, were placed into plastic bags, packaged, and sent back to Y-12 where they were gamma counted for uranium content. A listing of the air filter medium samples used in each leach test is given in Table 6.17. An air filter is shown in Fig. 6.17.

6.7.1.5 Description Of Uranium Oxide Powder

An approximately 13-kg sample of uranium oxide from the Y-12 Uranium Chip Oxidation Facility (UCOF) was received from J. E. Cline (Y-12 Plant) and chemically and physically characterized. The sample was a mixture of black powder and intact larger hulls or residual chips and turnings (see Fig. 6.18). Representative samples of the powder and hulls were examined (Analytical Chemistry Division) by energy dispersive x-ray analysis in the scanning electron microscope (EDX-SEM) and by x-ray diffraction (XRD). The EDX-SEM analysis detected only uranium; no other elements were identified. The EDX-SEM method is sensitive to elements with atomic number greater than 11 and has a detection limit of about 1%. The XRD analysis showed that the powder was a mixture of U_3O_8 and UO_2. The hulls were primarily $UO_{2.25}$ and contained some UO_2. No XRD lines for uranium metal were observed. The uranium oxide mixture was thoroughly blended to prepare working samples for the leach tests. After blending, analytical samples were taken from the top, middle, and bottom of the bottle containing the blended sample. These analyzed at 85.4, 84.5, and 84.6% U, respectively. The powder also contained some niobium. Surface area measurements on portions of the blended sample showed a relatively low value for a powder; three separate samples gave a surface area of 0.87 ± 0.10 m^2/g.

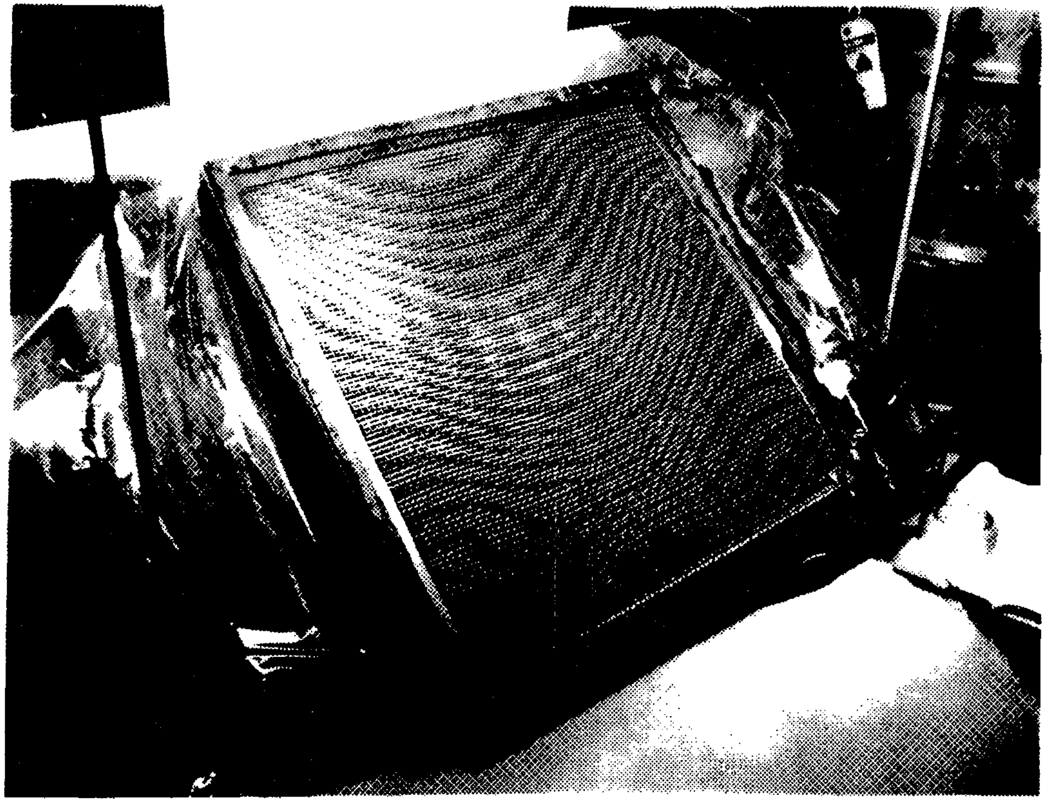

Fig. 6.17. Typical air filter.

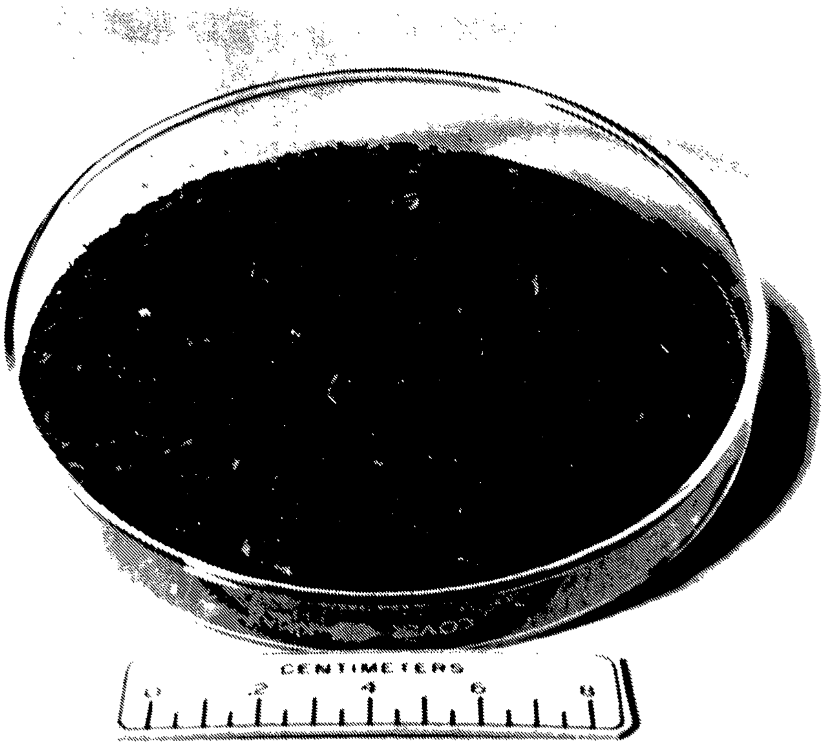

Fig. 6.18. Uranium oxide powder (as-received).

Table 6.17. Air filters

Filter[a] no.	Bag ID	Weight (kg)	Uranium (g)	Test no.
1	06-03-01	2.45	144	UFIL[b]
1	06-03-02[c]		131	
2	06-03-03[d]		409 ± 15	
3	06-03-04	2.27	231	3FIL
3	06-03-05	2.59	198	7FIL
4	06-03-06		132	
4	06-03-07		122	
5	06-03-08		370	
6	06-03-09	2.34	200	8FIL
6	06-03-10	2.36	218	4FIL
7	06-03-11	2.67	259	1FIL
7	06-03-12	1.91	198	5FIL

[a] Received from the Y-12 Plant on June 6, 1988.
[b] Four sequential leaches (3 $\underline{M}$ HNO_3, 1.5 $\underline{M}$ HNO_3, H_2O, H_2O) were made on this bag of filter media to remove all the uranium. The total leachate volume was 108 L.
[c] Bags not assigned a test number were not used.
[d] Mean ± 1 standard deviation for quadruple counts.

6.7.2 Appendix B - Methods for Preparation of Leach Solutions

Large volumes of synthetic groundwater and synthetic landfill leachate were needed. Stock solutions were prepared in cleaned, 30-gal polyethylene tanks that were equipped with polyethylene faucets.

Deionized water was used in the preparation of all leachants. The deionized water was prepared by passing building distilled water through a Milli-Q^{TM} Water System,[d] which consisted of one activated carbon cartridge, two ion exchange cartridges, one Organex-Q^{TM} cartridge, and one Milli-Pak^{TM} filter. Before use, the purity of the water was checked by measuring its conductivity.[e] Typically, the conductivity values were near or less than 0.2 umho.

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[d] Millipore Corporation.

[e] Yellow Springs Instrument Company Model 32 conductance meter equipped with a Radiometric American type PP1042 immersion conductivity cell.

6.7.2.1 Synthetic Groundwater

The synthetic groundwater composition selected was: 0.10 m$\underline{M}$ Na^+, 0.02 m$\underline{M}$ Cl^-, 0.08 m$\underline{M}$ HCO_3^-, and adjusted with HCl to pH 7.3. Thirty gallon-sized batches of synthetic groundwater were prepared by adding 0.763 g $NaHCO_3$ (ACS[f] grade) and 0.113 g NaCL (ACS grade) to 113.65 L of deionized water and mixed well by mechanical stirring. The pH was adjusted by adding 4 mL of 1.0 $\underline{N}$ HCL (NBS[g] certified) and 6 ml 0.1 $\underline{N}$ NaOH (NBS certified) and mixing well. Conductivity, pH, and temperature measurements were made for each batch and recorded in addition to the quantities of chemicals used. After standing overnight, the pH nominally was 7.15 ± 0.15 at 25 ± 1°C, and the conductivity was 11.5 ± 0.5 umhos.

6.7.2.2 Synthetic Landfill Leachate

The recipe for the preparation of synthetic landfill leachate is given in the Toxicity Characteristic Leaching Procedure as follows: "This fluid is made by adding 5.7 mL glacial acetic acid to 500 mL of the appropriate water, adding 64.3 mL of 1.0 $\underline{N}$ NaOH, and diluting to a volume of 1 L. When correctly prepared, the pH of this fluid will be 4.93 ± 0.05".

Thirty gallons of synthetic landfill leachate were prepared by adding 0.640 L (0.676 kg, 1.49 lb, or 0.169 gal) glacial acetic acid (ACS grade) to 50 L (110.23 lb or 13.21 gal) deionized water. These components were well stirred and then followed by the addition of 0.372 L (0.569 kg, 1.25 lb, or 0.098 gal) of 19.3 $\underline{M}$ NaOH (50.5 w/w % NBS certified NaOH) and 62.55 L (137.8 lb or 16.52 gal) of deionized water. The mixture was again well mixed. Subsequently pH, conductivity, and temperature measurements were made. The pH and conductivity values were 4.89 ± 0.03 and 3.95 ± 0.05 mmhos, respectively, at 25 ± 1°C.

6.7.3 Appendix C - Analytical Data for Well Water Samples and Soil Sample Leachates

Soil samples were acquired from locations in Bear Creek valley where soil for the lysimeter cap might be excavated, and these soil samples were leached to generate artificial shallow groundwaters for chemical analysis. Because groundwater composition is dependent upon the soil composition in communication with the water, several different soils were leached. Four samples of Conasauga colluvium and three samples of Conasauga saprolite were received from R. B. Clapp (ESD), and a 55-gal barrel of Knox residuum was received from L. S. Jones (Y-12 Plant). (Details of the location of these soil samples are given in footnotes to Table 6.18.) Samples of well water from wells GW-84 and GW-376 were also received from L. S. Jones. These soils

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[f] American Chemical Society.

[g] National Bureau of Standards.

Table 6.18. Artificial shallow groundwater and well water data

	Conasauga colluvium[a]		Conasauga saprolite[b]	Knox residuum[c]	Well GW-84[d]	Well GW-376[e]
	A	B				
Elements by ICP[f] (mg/L)						
Al	0.55 ± 0.37	0.82 ± 0.85	0.23 ± 0.04	<0.21	<0.21	<0.03
Ba	0.07 ± 0.08	0.07 ± 0.03	<0.02	0.02	0.15	0.32
Ca	0.89 ± 0.78	3.30 ± 0.36	<0.10	80.00	60.00	56.00
Fe	0.47 ± 0.44	0.48 ± 0.34	0.13 ± 0.05	0.03	0.04	<0.01
Mg	0.64 ± 0.29	1.78 ± 0.13	0.06 ± 0.02	13.00	4.80	13.00
Mn	0.08 ± 0.08	0.23 ± 0.09	0.01 ± 0.004	0.08	0.01	0.10
Na	5.23 ± 3.57	2.83 ± 0.63	2.77 ± 0.74	12.00	6.60	21.00
Si	10.33 ± 0.81	11.50 ± 1.00	24.00 ± 5.57	2.00	10.00	9.80
Elements by atomic adsorption (mg/L)						
K	1.07 ± 0.22	5.63 ± 0.35	1.10 ± 0.56	1.20	0.70	3.00
Anions by ion chromatography[g] (mg/L)						
Cl^-	1.45 ± 0.44	1.93 ± 0.31	1.20 ± 0.35	16.00	1.00	2.20
SO_4^{2-}	5.35 ± 0.47	18.00 ± 1.15	<5.00	57.00	6.50	14.00
Wet chemical methods[h] (mg/L)						
Alka.	2.81 ± 4.48	2.38 ± 2.56	0.92 ± 0.52	175.00	158.00	222.50
TIC	1.73 ± 1.45	1.58 ± 0.42	1.20 ± 0.26	0.30	35.90	50.00
TOC	1.30 ± 0.41	5.28 ± 0.33	0.83 ± 0.15	1.80	0.50	0.60
Other						
pH	6.5 ± 0.5	6.1 ± 0.3	7.3 ± 0.3	7.8	8.0	7.8
Cond.[i]	31.2 ± 7.8	16.9 ± 4.5	16.0 ± 5.7	506.0	321.0	438.0

[a] These data are the (mean ± 1 std. dev.) of four separate soil leach tests (two leach tests each on two different soil samples). These two soil samples were from the C-horizon at the Y-12 lysimeter site in Bear Creek Valley. Samples A were taken at a depth of 78 to 120 cm below the surface, and samples B were taken at 25 to 45 cm below the surface. These soils reportedly are not typical of the shaley soils in the Conasauga Group.

[b] These data are the (mean ± 1 std dev) of three separate soil leach tests (one leach test each on three different soil samples). These three soil samples were from the Packing Disposal Demonstration site in Bear Creek Valley. This soil reportedly [R. B. Clapp, (ESD)] is typical Conasauga Group soil.

[c] These data are from a single leach test of a single soil sample. This 55-gal barrel of soil was from the Y-12 sanitary landfill on Chestnut Ridge. The sample was from a depth of 20 ft below original grade at the north end of trench 3. The soil reportedly [R. B. Clapp (ESD)] is Knox residuum.

[d] This sample was water from well GW-84. The well is in the Maryville Formation of the Conasauga Group.

[e] This sample was water from well GW-376 (50 ft deep) which is located slightly upgrade of the Y-12 lysimeter site.

[f] Most other elements were below the detection limit.

[g] NO_3^- and PO_4^{3-} were <5 mg/L in all samples.

[h] Alkalinity is $CaCO_3$ in mg/L.

[i] Conductivity (umho) measured at 25°C and corrected for the cell constant (1.089/cm).

were prepared and leached as described below to generate the artificial shallow groundwater samples for chemical analysis.

The following procedure was used to prepare analytical samples of artificial groundwaters representative of shallow groundwater at various Bear Creek Valley or Chestnut Ridge locations, which may be considered for the disposal of Y-12 Plant low-level wastes:

1. The soil was air dried at room temperature to remove excess moisture. (Some samples were muddy or moist as received.) The operator wore rubber gloves during this and all subsequent steps to avoid possible contamination of the soil. The soil was spread in a thin layer on polyethylene sheeting in a large hood. (The hood had an appreciable air flow.) An infrared heat lamp in the hood was used to help accelerate the evaporation of water from the soil surface. (The temperature of the soil was not significantly increased by the heat lamp.) The soil was allowed to air dry for several days, or until dry and friable enough to permit mild disaggregation and screening.

2. The air-dried soil was placed in 4-mil polyethylene bags and disaggregated by mild contact with a leather-head mallet. The mallet also was wrapped in polyethylene. Only readily friable soil lumps were disaggregated. No attempt was made to crush rock fragments.

3. The soil was screened through a 6 mesh (Tyler equivalent; 3.36 mm openings) brass screen to remove and discard >6 mesh-size rock fragments, roots, etc.

4. After screening, all the screened portions (<6 mesh material) were combined and the soil was mixed for 5 min in a large Hobart mixer to yield a well blended soil sample.

5. Portions of the soil were leached with a minimum volume of demineralized water (Millipore MILLI-Q^{TM} water system). Two different leaching steps (6a and 6b below) were followed for each soil.

6a. 500 g of soil and 700 mL of demineralized water were placed in an EPA TCLP 2-L glass jar. The jar was capped and rotated for about 60 h.

6b. 500 g of soil and 700 mL of demineralized water were placed in a EPA TCLP 2-L glass jar. The jar was capped and rotated. The rotation was periodically stopped, a sample of the leachate removed, and the leachate conductivity measured (Yellow Springs Instrument model 32 conductance meter) and recorded. THe leachate was returned to the jar and rotation was continued. The conductivity was periodically measured in this manner (every 2 h during the first day, two or three times during the second day, and after filtration on the third day after approximately 60 h of leaching). A constant conductivity value was assumed to indicate solution saturation or steady-state leaching conditions.

7. After completion of the soil leach (step 6a or 6b), the mixture was poured into an EPA TCLP stainless steel Millipore pressure filtration apparatus and filtered through a 0.6- 0.8-um glass fiber filter (filter medium specified in the EPA TCLP proposed procedure). The first volume of filtrate often was cloudy, and this was returned to the apparatus and refiltered. The air pressure on the filter was slowly increased from about 20 to 50 psi. Filtration was terminated after about 250-300 mL of clear filtrate are obtained.

8. The pH, the conductivity, and the temperature were measured immediately after filtration and recorded.

9. Samples of the filtrate were submitted to Analytical Chemistry Division for the following analyses:

    a. elements by Inductively Coupled Plasma Spectrometry (ICP)
    b. anions by ion chromatography
    c. alkalinity by wet chemical titration
    d. inorganic and organic carbon with the International Carbon Analyzer

The chemical analysis of the artificial groundwaters and well waters are given in Table 6.18.

6.7.4 Appendix D - Laboratory Facility and Procedure for 30-Gal-Size Leach Tests

6.7.4.1 Description of Laboratory Facility

The Waste Characterization Facility (laboratory BG-74 in building 4501, ORNL) consists of an approximately 30- by 60-ft radiochemical laboratory with two large walk-in radiochemical hoods, one large double-sided radiochemical hood, and one smaller radiochemical hood. Equipment installed in the hoods and laboratory permit physical disaggregation and blending of bulk waste samples, allow waste leaching tests in both 2-L-and 30-gal-size apparatus, is equipped for recovery of the leachates and preparation of analytical and archive samples, and provides for preparation of both liquids and solids for disposal as radioactive solid or liquid waste.

A rotary-tine mill[h] for shredding paper-like or friable wastes and a 12-qt stainless steel food mixer[i] for blending soils or powdered wastes are installed in one of the walk-in hoods. The large hood is used to house the filtering apparatus (four 1.5-L Teflon^{TM}-lined filters[j]) for preparation of

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[h] Laboratory Mill Model 4, Thomas Scientific Company.

[i] Hobart Corporation, Model A120.

[j] Catalog No. YT30142HW, Millipore Corporation.

the analytical and archive leachate samples. The small radiochemical hood is used as a general-purpose laboratory hood. The facility also contains two refrigerators for storing samples at ~4°C. A calibrated electronic scale[k] with a capacity of 500 lb is used for large-scale weighing. Two small-scale calibrated balances[l] are used for weighing chemical reagents, etc.

Three stationary drum rotators[m] are used to agitate the 30-gal drums employed as the leaching apparatus. A drum handler[n] is available for moving both 30-gal- and 55-gal-sized drums. The drum handler has a manual pump to hydraulically raise and lower the drums, and a pull-chain crank which allows the drums to be handled horizontally and to be tilted for pouring purposes. A vacuum filtration apparatus is used to separate leachate from the solids after a leach step has been completed. This apparatus consists of a 122-cm-long, 1.27-cm-diam stainless steel tube, which is used to suction the leachate from a 91-cm-long, 5-cm-diam, 50 x 50 mesh (297-micron openings) stainless steel screen-walled tube with a stainless steel planchet welded to the bottom end. For use, the filtering assembly is slowly lowered into the drum to remove the leachate in a decanting manner. The filtered leachate is vacuumed through thick-walled Tygon tubing into a 5-gal Pyrex bottle that is backed up by a 5-gal-size Pyrex bottle safety trap to prevent sucking radioactive liquid into the building vacuum line. Both bottles are placed in 5-gal-size metal lard cans to provide an extra degree of safety in case of breakage.

Three 55-gal stainless steel drums are in one of the large radiochemical hoods. These drums are used as settling tanks for the liquid leachate wastes. Liquids that are sent to the radioactive waste tank farm must be free of solids. The filtered leachates are stored in the settling tanks for several weeks. Any oil rising to the surface from the leachate is daily removed by skimming with strips of blotter paper. Once the oily material (if present) is removed, the stored leachate is vacuum-filtered to one of two 90-gal stainless steel holding tanks which are designed to allow liquids to be steam-jetted to the building hot drain. This liquid waste discharge system is used because the facility is located in the basement of building 4501 and

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[k] Weightmeter Model DR-525, Electroscale Corporation.

[l] Sybron Model 36DK with a capacity of 3600 g made by the Digimetric Sybron Corporation, and an Ohaus Model 400D with a capacity of 400 g made by the Ohaus Scale Corporation.

[m] Morse Manufacturing Company, Inc. Model No. 1-5154-1, which rotated the drums at a rate of 39 rpm.

[n] Morse Manufacturing Company, Inc. Model No. 400ALO.

below the level of the main hot drain line from building 4501 to the WC-10 Tank Farm.

In the other walk-in hood, there is a drying oven (GCA Corp. Precision Model 27, capacity 0.14 m^3) for drying small volumes of laboratory-generated wastes after leaching. Drying is used to prepare wastes for disposal because solid wastes must contain no free liquid when sent to the SWSA-6 burial grounds. After oven and/or air-drying, solids from several 30-gal-scale leach tests are mixed with bentonite or clay (Wyoming bentonite or AGGUGEL-150 clay) in 55-gal-size disposal drums. Either of these adsorbents will remove any residual-free liquid. A nearby laboratory is used as a temporary storage area for the drums of solid waste generated before shipment to SWSA-6. While in storage, the drums are left open, but covered with cheese cloth, to allow as much water as possible to vaporize. This is fairly effective because the temperature in that room typically is 29 ± 2°C.

6.7.4.2 Procedure for 30-Gal-Size Leach Tests

Waste-stream samples for the leaching tests were prepackaged in plastic bags in 55-gal-size drums at the Y-12 Plant. Each package contained from 2.3 to 5.4 kg of waste. The packages were gamma counted to determine the amount of depleted uranium present. Counting was done in a large-scale analytical facility[o] at the Y-12 Plant used to assay truck loads of waste. The counter contains a pair of NaI(Tl) detectors. Each package was placed midway between the detectors (detectors are positioned about 4.6 m apart). A few of the bags were counted three separate times after the contents were physically rearranged and oriented differently in relation to the detectors. Replicate counts showed good agreement. The uranium content for each bag was determined by comparing the gamma count with a curve based on counting known depleted uranium standards. The standards were counted in a geometry similar to the waste packages. Only waste packages with ≥50 g uranium were used in the leach tests. For the packages that contained between 50 and 100 g uranium and were recounted as described above, the triplicate uranium values (gamma counts) had a standard deviation of ±8%; for packages that contained >200 g uranium, the triplicate standard deviation was ±3%. However, there were large differences in counts for packages containing as little as 15 g uranium.

The stainless steel drums (and drum lids) employed in the leaching tests were coated on the inside surfaces with Halar (a fluoropolymer resin, Ausimont, Inc.). The Halar coating was applied at the Rubber Shop at the Y-12 Plant after the stainless steel surfaces were cleaned and sandblasted at ORNL. Before being used in leach tests, the drums and lids were cleaned as follows: (1) they were brushed several times with solutions of Mr. Clean™ all-purpose cleaner, (2) hosed several times with building distilled water and then deionized water, (3) after hosing, the drums were partially filled with deionized water and shaken vigorously; this was repeated several times,

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[o] Personal communication from J. T. Foust to A. D. Kelmers, Y-12 Plant.

(4) rinsing was continued until there was little change in the conductivity of the deionized water after washing, and (5) finally, the drums were air-dried for several days and covered with clean plastic bags until used. The gasket (these gaskets were specially made by the "Green Door" Shop, ORNL) used in the drum-lid seal was made of 0.95 cm neoprene tubing joined at the ends with Zip Grip™ glue. The gasket was attached to the lid with Plybond™ glue in a way that allowed no contact with the leachate during a test.

At the start of a leaching test, the 55-gal shipping drum containing the waste packages selected for a given leach test was opened. The waste components were closely examined as to content and composition, and photographed. This examination was done in one of the walk-in radiochemical hoods, and the waste was placed into a weighed, cleaned, Halar-coated stainless steel 30-gal drum. Larger items such as sheets of paper or plastic, gloves, beverage cups, aluminum cans, etc. were cut into smaller pieces. Afterwards, the gross weight of the drum was measured to determine the weight of the waste. Once the waste weight was determined, an appropriate weight of leachant was added to the drum while on the electronic scale. The drum was then removed from the scale and sealed. About 50-lb torque was applied to the sealing bolt. Before being placed on the drum rotator, the drum was inverted with the drum handler and visually checked for leaks. (In all the leach tests conducted, only one minor leak occurred.) After leak-checking, the drum was placed on the drum rotator, the leaching started, and the date and time recorded.

Two types of leaching protocol were followed -- sequential and batch. In the sequential protocol, the leachate was removed and replaced with fresh leachant at selected times (once each day for 4 days and then after 3 days for the last contact). The volume of leachant was geometrically increased to yield the following series of liquid/solid (L/S) ratios: 2, 4, 8, 16, and 32 for the five replacement times. This sequence yielded a cumulative L/S ratio of 2, 6, 14, 30, and 62 for the sequential leach protocol. The batch leach protocol involved only a single contact under the selected test parameters of 2:1 or 20:1 L/S. The batch tests were sampled at 1, 2, 3, 4, and 7 days. For the four bulk wastes (production trash, combined waste, mixed metal chips, and air filters), the test matrix (batch contacts at 2:1 and 20:1 L/S and one sequential leach for both synthetic groundwater and synthetic landfill leachate) required 24 experiments (30-gal size) and generated 120 leachate samples for uranium analysis.

Batch tests were always started on Monday, and analytical and archive samples of leachate were taken each weekday (Tuesday through Friday) and on the following Monday. After each leach period, the drum was removed from the drum rotator, and the solids were allowed to settle for 1 to 2 h before sampling. The sampling time marked the end of a given leaching period and the start of the next leaching period. Samples of leachate were removed with a clean stainless steel ladle and poured into cleaned 1- or 2-L polyethylene bottles and then filtered. Filtration was through a 0.6- to 0.8-um glass microfiber filter (EPM2000, Watman, Ltd.), housed in a cleaned 1.5-L Teflon™-coated filter assembly (catalog no. YT30142HW, Millipore

Corporation) into a clean, weighed polyethylene bottle. Sometimes the leachate could be filtered without applying air pressure; at other times, up to 50-psi air pressure was required to force the filtrate through the filter. When needed, pressure was applied slowly in incremental steps of 10 psi. After filtering, the solids removed from the analytical and archive samples were put back into the leaching drum along with fresh leachant equal to the weight of leachate which was removed. The conductivity, pH, and temperature of the filtered leachate samples were measured; in a few tests, Eh measurements were also made. Leachate samples were stored in a refrigerator at ~4°C.

All of the steps described above for the batch tests were also employed in the sequential leach tests. However, after each leach period and the removal of the analytical and archive samples, the major portion of the leachate was removed by vacuum filtration as described in Sect. 6.7.4.1. The filtration apparatus that was used was different in that two layers of stainless steel screen were used to make the filter chamber. The outer and inner layers were made of 200 x 200 (74-micron openings) and 50 x 50 (297-micron openings) screens, respectively. The selected weight of fresh leachant was then added, and the sequential tests continued.

6.7.5 Appendix E - Laboratory Procedure for 2-L-Size Leach Tests

The procedure for the 2-L-size leaching tests was consistent with the EPA Toxicity Characteristic Leaching Procedure [Federal Register 1986]. Only the uranium oxide powder from the uranium chip oxidation facility (UCOF) was leached by this method. First, the as-received sample of uranium oxide powder was blended to assure homogeneity. This was done using a mixer (Hobart Corporation, Model N 50) with a stainless steel mixing bowl and agitator. Three portions of the blended sample were taken for analysis from different positions in the storage bottle demonstrate the degree of homogeneity. The results were: 854.93, 845.85, and 845.70 mg U/g sample. These analyses showed good blending and the assured preparation of replicate sample aliquots.

The leachants used were either synthetic landfill or synthetic groundwater (see Sect. 6.7.2). Three different leachant/solid ratios (L/S) were tested:

50/1 (2000 g leachant and 40 g solid),
20/1 (1700 g leachant and 85 g solid), and
2/1 (1600 g leachant and 800 g solid).

Wide-mouth (100-mm) 2-L borosilicate bottles with Teflon™-lined lids (Associated Design and Manufacturing Company Model 3740-WGB) were used as extraction vessels in these tests. The procedure for cleaning these bottles and lids was as follows: they were brushed with a solution of Mr. Clean™ all-purpose cleaner, rinsed several times with deionized water, rinsed with ~3 N HNO_3, and thoroughly rinsed again with deionized water. Afterward, they were filled with deionized water and shaken vigorously. If there was no significant change in the conductivity of the deionized water, the bottles were considered clean. Finally, they were air dried for several days before use.

A calibrated (by ORNL Balance Shop according to ORNL QA procedure) balance (Sybron Digimetric) was used for all weighing. Periodically, a standard weight was measured to confirm the accuracy of the balance. In each test, the order of measurement was: (1) borosilicate bottle and lid, (2) leachant, and (3) uranium oxide powder. Both the leachant and solid were preweighed before addition to the bottle. This served two purposes, as a check of the measured weights and to help minimize dusting of the powder.

After weighing, the bottles were tightly sealed and leak checked by inversion. Leaching was started and the time recorded. (Typically, room temperature was 25 ± 1°C.) A rotary device (Associated Design and Manufacturing Company, Model 3740-6-BRE) rotated the bottles end-over-end at a rate of 30 rpm. Two types of leaching protocol were followed: batch contact or sequential leachant additions. For either protocol, analytical samples were taken daily except on weekends. After a prede- termined leaching period (minimum of ~20 h), the bottle was removed from the rotary extractor, the time recorded, and the solids were allowed to settle for 2 h.

In the batch tests, ~50 mL of leachate was removed for analytical analyses by pipetting, and the sampling time was recorded. An equivalent amount of fresh leachant was added back to the extraction bottle to maintain the desired L/S ratio, and the gross weight was rechecked and recorded. The removed leachate was filtered through a thoroughly cleaned glass suction funnel through 0.6- to 0.8-um glass microfiber filters (Whatman Limited, No. EPM 2000). Only a trace of solid was present in these leachate samples as decanted, and filtration easily produced a clear sample for analysis. The end of the leaching period was considered to be the sampling time. This time period included both the rotary leaching and the 2-h settling times. The sampling time was also considered the start time for the next leaching period. The filtrate was divided into three equal samples: two for analyses and one archive sample. Conductivity, pH, and temperature measurements were made, and the samples were stored in a refrigerator at ~4°C. The samples were transported to Analytical Chemistry Division for analyses as soon as possible.

As in the batch tests, the leachates in the sequential leach tests were allowed to settle for ~2 h after the rotary leaching period. However, in these tests all of the clear liquid above the solids was decanted and filtered through the 0.6- to 0.8-um glass microfiber filter, for these samples housed in a thoroughly cleaned Teflon^{TM}-coated filter assembly (Millipore Corporation). Again, as in the batch test, very little of the solids were removed from the extraction bottle during the decanting step. While the leachate was filtering, the extraction bottle with lid was reweighed to determine the amount of leachate removed. As a double check, the weight of the filtrate was also weighed later. As quickly as possible, fresh leachant was added to the extraction bottle to replace the removed leachate to maintain the desired L/S ratio, and the next leaching period was started. Larger analytical samples were taken in these tests (~200 mL), and conductivity, pH, and temperature measurements were made. The samples were subsequently stored at ~4°C. The samples were transported to Analytical Chemistry Division for analyses as soon as possible.

6.7.6 Appendix F - Discussion of the Chemistry of Uranium Pertinent to Y-12 Plant Wastes Contaminated with Depleted Uranium

The discussion of the chemistry of uranium in this section is intended to aid in the interpretation and understanding of the uranium leaching data resulting from the laboratory leaching tests and to help guide the future field lysimeter experiments.

The discussion emphasizes the chemistry of the uranium(VI) and uranium(IV) solution species and the corresponding solid compounds (including fractional or mixed valence solids). The discussion emphasizes temperature, pH, and redox conditions relevant to Y-12 Plant waste disposal or treatment situations. The leachates (solutions which may contact disposed wastes and mobilize uranium) considered in the discussion are either natural or synthetic groundwaters (dilute Ca, Mg, Na, K, Cl, Si solutions at near-neutral pH), and a synthetic landfill leachate (0.1 M acetic acid-sodium acetate buffer solution at pH 4.9 as specified in the proposed EPA Toxicity Characteristic Leach Procedure[1]), which is typical or representative of the solution resulting from biodegradation of organic wastes in landfills. Groundwaters may be the leachate in mono-disposal situations for Y-12 Plant wastes, while the synthetic landfill leachate may simulate co-disposal situations for Y-12 Plant wastes involving biodegradable materials. The discussion in this section deals primarily with the generally oxidizing redox conditions and ambient temperatures which exist in solution in near-surface disposal situations and may be present in most treatment processes. Because the uranium-containing solids in the Y-12 Plant wastes may range from uranium metal to the higher oxides, solid phases from uranium(0) to uranium(VI) are addressed.

Several excellent extended critical reviews or evaluations of various aspects of uranium chemistry have been published in recent years, and this discussion has drawn heavily on five of these articles. (Copies of these publications can be obtained from the ORNL Waste Management Document Library, 4500N, MS-6235, 4-5197.) A thorough summary of the information on solution species for uranium(VI) and uranium(IV) for the system uranium-oxygen-water, including hydrolysis products and solubility values, is given in Baes and Mesmer [Baes and Mesmer 1976]. The solubility of uranium(VI) oxide at near neutral pH was still uncertain at the time of the Baes and Mesmer study, and a more recent publication by Krupka et al. [Krupka et al. 1985] contains the best experimental data for uranium(VI) oxide solubility as a function of pH. Langmuir [Langmuir 1978] has published an excellent review of the groundwater chemistry of uranium relevant to environmental mobility and ore formation. Lemire and Tremaine [Lemire and Tremain 1980] have published an exhaustive compilation of the relevant thermochemical data for uranium. An extensive review and reanalysis of the information for the system uranium-oxygen-water has been published by Smith et al. [Smith et al. 1982].

6.7.6.1 The System Uranium-Oxygen

The discussion in this section is principally drawn from the paper by Smith et al. [1982]. That publication is a critical review of the literature for this system and cites 269 references. Smith et al. states that despite the many investigations completed over decades, there are still U-O compositional ranges where the chemical behavior is not unequivocally understood, and many reported phases are as yet unverified. A summary of the U-O composition range, which is of interest to Y-12 waste disposal and treatment problems, is given in Figs. 2 and 4, and Table I of Smith et al.

It is important to recognize that the chemistry of the uranium-oxygen system is unusually complex, and this complexity, in turn, confounds the analysis and understanding of experimental data and/or the prediction of expected behavior. This complexity results from the many three-dimensional arrangements which can be produced when stacking uranium and oxygen atoms. Further, the crystal structures obtained are capable of maintaining electric neutrality over extended ranges of non-stoichiometric composition and, therefore, many uranium-oxygen compounds are stable over a wide span of composition from oxygen deficient to oxygen excess. As a result of these properties, the phases observed experimentally are dependent upon, not only the uranium-oxygen ratio, but also the temperature, oxygen fugacity, and total system pressure. It also depends on nucleation kinetics; it is possible to go from cubic $UO_{2\pm}$ to hexagonal UO_3 without passing through orthothrombic U_3O_8 structure in very fine UO_x powders oxidized at low temperature slowly.

$\underline{UO_3}$

The compound UO_3 contains uranium in the +6 valence. At least ten UO_3 phases and crystal structures have been reported. Two additional UO_{3-x} phases also have been described. Uranium(VI) is the most highly oxidized form of uranium normally observed under environmental conditions, and the solution species of uranium(VI) are the most mobile forms of uranium due to their appreciable solubility (see discussion below). Gamma-UO_3 (the form stable in air) exists from room temperature up to about 600°C; above that temperature it decomposes to U_3O_8. In the presence of water, however, anhydrous UO_3 is not stable, as discussed below. Because gamma-UO_3 can be formed from uranium metal or lower oxides by air oxidation only below 600°C, because low-temperature solid-phase oxidation reactions often are slow, and because UO_3 may be thermodynamically unstable in the presence of water, gamma-UO_3 probably is of limited importance in considering uranium behavior in environmental systems.

U_3O_8—($UO_{2.67}$)

The compound U_3O_8 can be considered as a mixed oxide $2(UO_3)\cdot UO_2$ or as the non-stoichiometric compound $UO_{2.67}$ having a formal uranium valence of +5.33. Many phases and crystal structures having compositions from $UO_{2.67+x}$ to $UO_{2.67}$ and $UO_{2.67-x}$ (where x = -0.06 to +0.25) have been reported (14 are cited in Smith et al. 1982). U_3O_8 phases are stable from room temperature to about 1100°C and are the usual compounds formed by high temperature oxidation or ignition of uranium metal or lower oxides in an excess of air· Although U_3O_8 phases may not be thermodynamically stable in the presence of water, as discussed below, experience shows that they may be only slowly converted to other uranium oxides. Understanding the chemistry of U_3O_8 phases is important to environmental applications involving Y-12 Plant wastes because these phases are commonly present in uranium metal or lower valence uranium oxide-containing wastes which have been heated or ignited. It is less clear if U_3O_8 phases would be readily formed by slow room temperature oxidation of uranium metal or lower oxide wastes.

U_4O_9—($UO_{2.25}$)

The compound U_4O_9 can be considered as the mixed oxide $UO_3\cdot 3UO_2$, or as the non-stoichiometric compound $UO_{2.25}$ having a formal uranium valence of +4.5. Three phases and crystal structures are cited in Smith et al. 1982. Some phases are stable from room temperature to about 1100°C. As with U_3O_8, these phases may not be thermodynamically stable in the presence of water. Because U_4O_9 phases cover a broad region of the U-O phase diagram, it would be expected that this compound would be a product of the oxidation or ignition of uranium metal or lower oxides when the air supply (oxygen fugacity) is restricted.

UO_2

UO_2 is one of the best characterized and most stable of the uranium oxides. It occurs widely in nature as the mineral uraninite and, of course, is the oxide composition chosen for LWR reactor fuel pellets. In UO_2, the uranium has a valence of +4. In addition to the stoichiometric phase UO_2, variable-composition oxygen deficient phases (UO_{2-x}) and oxygen excess phases (UO_{2+x}) are known. UO_2 has a single cubic crystal structure and is very stable (melting point of 2860°C). The compound UO_2 covers a broad region of the U-O phase diagram and would be expected to be formed by the oxidation or ignition or uranium metal under conditions such that the air supply is severely restricted and higher oxides such as U_3O_8 cannot form. UO_2 prepared at high temperature may approach theoretical density and may be very unreactive toward oxidants such as air or water--thus its application as a fuel form for LWR reactors. UO_2 is stable in the presence of water under reducing redox conditions. Knowledge of the chemistry of UO_2 is important in understanding the behavior of uranium-containing wastes under reducing or, at least, non-oxidizing environmental conditions.

UO

The oxide UO has been reported, but Smith et al. 1982 state that its existence is doubtful. It is not further discussed.

6.7.6.2 The System Uranium-Oxygen-Water

6.7.6.2.1 Solid phases

The discussion in this section also is drawn primarily from Smith et al. 1982. Only one hydrated uranium-oxygen compound and one anhydrous oxide are described as equilibrium solid phases in the system uranium-oxygen-water. Knowledge of the reactions involving these two solids is of importance to (1) understanding the reactions which may occur during waste disposal or treatment options, and (2) quantifying the mobility of uranium in groundwater or landfill leachate systems.

Schoepite—($UO_3 \cdot H_2O$)

The only hydrated uranium-oxygen compound containing uranium in the +6 valence is $UO_3 \cdot H_2O$. This compound may occur naturally as the mineral schoepite or may be prepared synthetically. Eight forms or crystal structures of schoepite have been reported. Under oxidizing redox conditions involving aqueous solutions, which do not contain species of other elements capable of forming complexes or other uranium(VI)-containing compounds (see discussion below), schoepite would be the equilibrium solid phase controlling the uranium(VI) solubility.

Uraninite—(UO_2 to UO_{2+x})

Uraninite, containing uranium in the +4 valence, is found widely in nature. The compound also has been identified as the mineral pitchblende when it is poorly crystallized. Hydrated forms have been reported but are not well documented [Smith et al. 1982]. Uraninite would be the equilibrium solid phase controlling the solubility of uranium(IV) under strongly reducing redox conditions. Because UO_2 solids may be very resistant to oxidation by air or water at ambient temperatures, UO_2 may also exist for long periods of time under oxidizing environmental conditions, although it would not be the equilibrium solid phase under such conditions.

6.7.6.2.2 Solution species

This discussion is based primarily on information in Baes and Mesmer [1976] and in Langmuir [1978]. In this section, only species (solute or dissolved solution forms of uranium) containing uranium, oxygen, and hydrogen are considered. The solution chemistry of uranium becomes considerably more complex when some other elements or ions are present in solution, and that situation is addressed in a following section.

Uranium(VI)

In the system uranium-oxygen-water, the species UO_2^{2+} is the simplest ion formed which contains uranium(VI). However, UO_2^{2+} may undergo both hydrolysis and condensation reactions to form other species. The species formed are primarily dependent on the total uranium concentration and the system pH. In the pH range of interest to environmental waste disposal concerns (pH of about 5 to 8), the following species (Fig. 9.3 and Table 9.5 of Baes and Mesmer 1976) form (left to right) at increasing uranium concentrations and/or higher pH:

$$UO_2^{2+} \quad UO_2(OH)^+ \quad (UO_2)_2(OH)_2^{2+} \quad (UO_2)_3(OH)_5^+$$

The condensed species are of importance in considering waste disposal or treatment situations. For example, at pH 6 or higher and at either high (0.1 M U) or low (10^{-5} M U) uranium concentrations, $(UO_2)_3(OH)_5^+$ is the dominant species [Baes and Mesmer 1976]. Langmuir [1978] also states that in pure water at pH 6 and at 10^{-6} M total uranium, the dominant species is $(UO_2)_3(OH)_5^+$, while at 10^{-8} M total uranium the species UO_2OH^+ becomes dominant. At 10^{-8} M total uranium, these is too little uranium present to favor condensation reactions at pH 6 and thus the species UO_2OH^+ predominates.

Uranium(IV)

The solubility of uranium(IV) species [assuming the redox condition of the system is reducing enough {low system Eh} to conserve uranium(IV) species without oxidation to uranium(VI) species] is much lower than for uranium(VI) species near neutral pH, and this lower solubility limits the consideration of relevant species (Fig. 9.3 of Baes and Mesmer 1976) to only the following (left to right with increasing pH) as important under environmental conditions:

$$U(OH)_3^+ \quad U(OH)_4 \quad U(OH)_5^-$$

At near neutral pH, the dominant solution species is the uncharged molecule $U(OH)_4$.

6.7.6.3 Solution Species Involving Additional Elements or Ions

Uranium(VI), and to a lesser extent uranium(IV), are capable of forming a wide range of complexes with certain anions in solution. The presence of such complexes may increase uranium solubility. Conversely, reaction of uranium with some elements or ions may result in the formation of new, lower solubility, equilibrium solid phases. It is beyond the scope of this paper to present an extensive discussion of these complexes and solids, however, several solution species are important in controlling the solubility or mobility of uranium in groundwater systems, and these are described briefly below. Much of this discussion is drawn from the review by Langmuir [1978]. Detailed calculation of the uranium speciation and solubility, and the equilibrium solid phases, as a function of groundwater composition and geochemical parameters such as pH and Eh, can be made using geochemical computer codes such as EQ3/EQ6 [Wolery 1983] or MINTEQ [Peterson et al. 1987].

6.7.6.3.1 With anions

The discussion of uranium(VI) complexes in the following sections are ranked according to the strength of the formation constants; e.g., phosphate complexes are most stable and fluoride complexes are the least stable of those discussed.

Uranium(VI)-Phosphate Complexes

Phosphate is frequently present at low concentrations in most groundwaters, primarily as the biphosphate anion HPO_4^{2-}. Langmuir [1978] reports the formation of the very stable uranyl biphosphate complex $UO_2(HPO_4)_2^{2-}$ at solution pHs of 5 or higher. The formation constant for $UO_2(HPO_4)_2^{2-}$ is greater than for any other uranium(VI) complex usually anticipated in natural groundwaters. Therefore, uranium(VI) in groundwaters would be expected to exist as this anionic complex in stoichiometric amounts equivalent to the phosphate content of the groundwater. The equilibrium solid phase containing phosphate, UO_2HPO_4 (see below), is important when considering the solubility or mobility of uranium(VI) in groundwater due to the greatly reduced solubility of uranium(VI).

Uranium(VI)-Carbonate Complexes

Carbonate anions, CO_3^{2-}, are frequently present in alkaline groundwaters at pHs of 8 or greater due to groundwater contact with limestone or dolomite formations. Stable carbonate complexes are formed with UO_2^{2+} when CO_3^{2-} ions are present. Complexes with the bicarbonate anion, HCO_3^- (which predominates at pHs below 8), either are much less stable or may not exist. According to Langmuir [1978], at pH 5 to 6, a total uranium concentration of 10^{-8} $\underline{M}$, and at the atmospheric partial pressure of CO_2, the neutral species UO_2CO_3 predominates both in solution and as the equilibrium solid phase. At pH 7, the predominant species becomes $UO_2(CO_3)_2^{2-}$ and at pH 8 or higher $UO_2(CO_3)_3^{4-}$ becomes controlling. These carbonate complexes have important implications for uranium mobilization considerations because they can substantially increase the effective solubility of uranium (see discussion below).

Uranium(VI)-Silicate Complexes

All groundwaters contain some amount of dissolved silicate species because all soils contain a variety of silicate minerals. A number of solution species of silicate may exist, and interchange between these often is slow and therefore that metastable silicate systems may be present.

Unfortunately, this complicated silicate chemistry considerably confounds consideration of the chemistry of uranium(VI) in groundwater due to the existence of stable uranyl-silicate complexes. Langmuir [1978] identifies the species $UO_2SiO(OH)_3^+$ as an important complex in groundwaters in the pH range of 5 to 7.

Uranium(VI)-Fluoride Complexes

Uranium(VI) also forms the complex UO_2F^+ under acidic conditions of pH <5 [Langmuir 1978]. This complex may be of less importance in considering the chemistry of Y-12 wastes in groundwaters unless the wastes also contain appreciable amounts of soluble fluoride compounds.

Combination of Uranium(VI)-Fluoride Complexes

When uranium(VI) is dissolved in typical groundwaters containing various concentrations of these complex-forming anions (most groundwaters contain at least some concentration of HPO_4^{2-}, CO_3^{2-}, $H_3SiO_4^-$, and F^-), the final concentration of the uranium-containing species is governed by the concentrations of all the constituents as well as the pH. If all the concentrations and the pH are known, geochemical computer codes can be used to calculate the equilibrium uranium speciation. Langmuir [1978] has calculated the dominant species for a typical groundwater as a function of pH (Fig. 11 of Langmuir 1978) at low uranium concentrations. Three species predominate in this situation: UO_2F^+ as pHs <5, $UO_2(HPO_4)_2^{2-}$ at pH 5 to 8, and $UO_2(CO_3)_3^{4-}$ at pHs >8. Other species are less important in understanding the chemistry of uranium in groundwater due to lower stability constants or pH ranges of instability.

At higher uranium concentrations, if the amount of the important complexing anions present in the groundwater (F^-, HPO_4^{2-}, and CO_3^{2-}) become consumed, any remaining uranium would then be present as the condensed hydrolysis species UO_2OH^+ at low concentrations or $(UO_2)_3(OH)_5^+$ at high concentrations.

In considering the chemistry of uranium in waste leachates, it is important to at least qualitatively understand which combination of these species may be present in the solution under consideration. Only then will it be possible to predict the behavior of uranium in the system under consideration.

6.7.6.3.2 With cations

No cation-cation species involving uranyl ions are expected to exist in groundwater solutions.

6.7.6.4 Uranium Oxide Dissolution Reactions

Dissolution of U_3O_8

The dissolution of U_3O_8 in the absence of an oxidant can be considered, for the purposes of discussion, to consist of a number of hypothetical sequential reactions. These are:

Hydrolysis and disproportionation to form schoepite and uraninite -

$$U_3O_{8(solid)} + 2H_2O = 2(UO_3 \cdot H_2O)_{(soild)} + UO_{2(solid)}$$

Dissolution of the schoepite -

$$UO_3 \cdot H_2O_{(solid)} + 2H_2O = UO_2^{2+} + 3H_2O$$

Hydrolysis of the uranyl ion, -

$$UO_2^{2+} + H_2O = UO_2OH^+ + H^+$$

Condensation to the trimeric species -

$$3UO_2OH^+ + 2H_2O = (UO_2)_3(OH)_5^+ + 2H^+$$

Thus, the overall reaction for the dissolution of U_3O_8 in the absence of an oxidant becomes:

$$3U_3O_{8(solid)} + 2H^+ + 4H_2O = 2(UO_2)_3(OH)_5^+ + 3UO_{2(solid)}$$

In the above equation, it was assumed that the total concentration of uranium was great enough so that the solubility of uranium(IV) species was insignificant and that the uraninite was not oxidized. If the dissolution system contains sufficient oxidant (represented here as O_2) to oxidize the UO_2 portion of the U_3O_8, then the overall reaction becomes:

$$2U_3O_{8(solid)} + 2H^+ + O_2 = 2(UO_2)_3(OH)_5^+$$

It is interesting to note for either the dissolution or oxidation-dissolution reactions that relatively small quantities of acid are consumed during the dissolution process. Therefore, the dissolution of relatively small amounts of uranium from U_3O_8-containing wastes may not be expected to cause a major shift of the groundwater pH to more alkaline values unless the groundwater is very poorly buffered.

Dissolution of UO_2

Consideration of the dissolution of appreciable amounts of uranium from UO_2-containing wastes assumes an oxidation reaction because the solubility of uranium(IV) species (see below) is very low. In the presence of an oxidant (represented here as O_2), the overall reaction is:

$$6UO_{2(solid)} + 3O_2 + 6H_2O = 2(UO_2)_3(OH)_5^+ + 2OH^-$$

While no acid is consumed in this reaction, hydroxide is formed during the oxidation step and the mixture may become more basic as a result of the oxidation-dissolution of UO_2.

6.7.6.5 Uranium Solubility Limits

The following brief qualitative discussion of uranium solubility may be useful in considering the results of laboratory or field experiments involving uranium leaching.

Uranium(VI)

Figure 1 of the paper of Krupka et al. [1985] contains the most recent data for the solubility of schoepite, $UO_3 \cdot H_2O$, in water as a function of pH. At pHs typical of landfill leachates or groundwaters (pH 5 to 7), the measured saturated solution concentration of uranium is about 10^{-3} to $10^{-3.5}$ M, or about 238 to 75 mg/L. This measured value is about 1 to 2 orders-of-magnitude higher than the concentrations calculated for these pHs by Krupka et al. [1985] using the available thermodynamic data. Krupka et al. [1985] state that the calculated value is in good agreement with their experimental results. In comparing experimental with calculated solubility values for systems as complex and poorly studied as uranium(VI) near neutral pH, agreement to within 1 to 2 orders-of-magnitude probably can be considered good.

Uranium(IV)

Figure 9.2 of Baes and Mesmer [1976] summarizes information on the solubility of UO_2 in water as a function of pH. At pH 5 to 7, the uranium solubility increases from about 10^{-12} to 10^{-11} M, or from about 2×10^{-7} to 2×10^{-6} mg/L. The principle solution species is neutral $U(OH)_4$. These are very low solubility values and serve to illustrate the relative insolubility and immobility of uranium in geologic systems under redox conditions reducing enough to form uranium(IV). A recent review by Kertes and Guillaumont [Kertes and Guillaumont 1985] of both computed and experimental data for the solubility of uranium(IV) oxide in water reported that solubility values ranged from 10^{-7} to 10^{-13} M, and the calculated solubility minimum ranged from pH 4 to 8. They concluded that the field is ripe for reinvestigation because, in addition to the uncertain solubility information, there is not even agreement as to the equilibrium solution species such as $U(OH)_{4(solution)}$, $U(OH)_n^{4-n}$, etc.

Carbonate-Containing Compounds of Uranium (VI)

Figure 1 of Sergeyeva et al. [Sergeyeva et al. 1972] shows the solubility of UO_2CO_3 as a function of pH at 25°C and 1 atmosphere of CO2. At pH 5, the uranium solubility is about $10^{-4.5}$ M, or about 7 mg/L. This value is less than the solubility of schoepite in water at this pH due to the high pCO_2. The solubility of UO_2CO_3 increases rapidly with increasing pH above pH 5 due to the formation of the soluble species $UO_2(CO_3)_2^{2-}$. At pHs of about 8 or greater, the solution species $UO_2(CO_3)_3^{4-}$ is formed, and the solubility increases still further. The uranium solubility value is, of course, a function of temperature and pCO_2 as well as pH. In general, carbonate complexation may not greatly increase the solubility of uranium, relative to pure water, until the solution pH reaches about 7 or greater.

Phosphate-Containing Compounds of Uranium (VI)

Estimating the solubility of uranium(VI) in the presence of phosphate is complicated by the large number of autunite solid phases which can form. (Uranium precipitates as autunite compounds, $M_2(UO_2)_2(PO_4)_2$, where M can be a number of monovalent cations such as H^+, Na^+, K^+, etc.) Langmuir [1978] has calculated the solubility of uranium for some typical groundwater concentrations of PO_4^{-3} as a function of pH (Figs. 21a and 21b of Langmuir 1978). For the pH range of 5 to 7, uranium solubilities of about 10^{-7} to 10^{-6} M, or about 0.02 to 0.2 mg/L, can be extrapolated from Langmuir's figures. These values are substantially lower than the values for schoepite and illustrate the reduced solubility or increased immobility of uranium in geologic systems containing appreciable levels of phosphate.

Other Relevant Uranium (VI) Compounds

Uranium(VI) can form soluble solution complexes and/or stable solid phases with many other elements, and the chemistry of the system under consideration rapidly becomes more complex as additional elements are involved. It is difficult to generalize about such complex systems. If the necessary thermochemical data are available, geochemical computer codes such as EQ3/EQ6 or MINTEQ can be used to calculate the equilibrium solids and the solution concentration of uranium. Unfortunately, the chemistry of uranium(VI) near neutral pH has not been extensively investigated, and the needed information is not always available to support the calculations.

6.7.8 Appendix G - Toxicity Test Results

The following communication was received from A. J. Stewart and L. A. Kszos, Environmental Sciences Division, on June 28, 1988, and is reproduced without change.

Appended are the results of toxicity tests of samples 5CHIPA and 7FSAEE, and of a reconstituted water (SGW). The toxicity of each of these samples was estimated using an EPA-approved 7-day chronic test procedure that relates toxicity to reductions in survival or fecundity of an aquatic microcrustacean

(Ceriodaphnia). Results of the tests show that the artificial ground water (sample SGW) used to prepare the two leachates (5CHIPA and 7FSAEE) probably did not contribute importantly to toxicity of the leachates. Sample 5CHIPA affected Ceriodaphnia at 0.3% of full-strength but did not affect their survival or reproduction at 0.1% of full-strength. Sample 7FSAEE was about three times more toxic than sample 5CHIPA: it affected Ceriodaphnia at 0.1% of full-strength but did not affect their survival or reproduction at 0.03% of full-strength.

1. Sample: Three water samples were delivered to the toxicity testing laboratory on April 14, 1988, by J. L. Collins. The three samples were labelled "SGW" (an artificial groundwater prepared from reagent-grade salts and distilled water), "5CHIPA," and "7FSAEE." For preparing test solutions, the samples were recoded to SGW, 5C, and 7F, respectively. The samples were stored in the refrigerator at about 7°C until being used to prepare test solutions. The solutions were also stored refrigerated, and portions were withdrawn and warmed to 25°C daily for use in the test. The SGW sample was tested at two concentrations (full strength and 50% of full-strength) during April 28-May 5. The 5C and 7F samples were tested during May 5-12. Each set of tests had a separate control.

2. Toxicity Test: Dilutions of the samples were prepared with 1:9 (v:v) degassed, diluted mineral water. The diluted mineral water was prepared from deionized, distilled water and Perrier water. All dilutions were tested with the microcrustacean, Ceriodaphnia dubia. The tests were conducted using EPA-approved procedures for estimating the chronic toxicity of waste and receiving waters [Horning and Weber 1985]. The neonates used to start the test were less than 6-h old. The animals were fed once per day (100 uL/beaker; a mixture of trout chow, yeast and cerophyll, amended with the unicellular green alga, Haematococcus lacustris).

3. *Ceriodaphnia* survival and fecundity test results:

   3.1 Date Test Started: May 5, 1988.
   Time Test Started: 10:23 a.m.

   3.2 Date Test Ended: May 12, 1988.
   Time Test Ended: 9:52 a.m.

   3.3 Daily Results from Ceriodaphnia Test: see Table 6.19.

   3.4 Summary of Test Results: see Table 6.20

Table 6.19. Daily results from <u>Ceriodaphnia</u> test

Dilution	Day	Replicate 1	2	3	4	5	6	7	8	9	10	No. Live Adults	No. Live Young
Control [SGW]	1	-	-	-	-	-	-	-	-	-	-	10	0
	2	-	-	-	-	-	-	-	-	-	-	10	0
	3	-	x	-	-	-	-	-	3	-	x	8	3
	4	0	x	4	0	2	0	x	0	2x	x	6	8
	5	0	x	11	8	8	9	x	5	x	x	6	41
	6	5	x	13	10	12	5	x	7	x	x	6	52
	7	0	x	0	0	0	8	x	0	x	x	6	8
	total	5	0	28	18	22	22	0	15	2	0	6	112
SGW 100%	1	-	-	-	-	-	-	-	-	-	-	10	0
	2	x	x	x	x	x	x	x	x	x	x	0	0
	3	x	x	x	x	x	x	x	x	x	x	0	0
	4	x	x	x	x	x	x	x	x	x	x	0	0
	5	x	x	x	x	x	x	x	x	x	x	0	0
	6	x	x	x	x	x	x	x	x	x	x	0	0
	7	x	x	x	x	x	x	x	x	x	x	0	0
	total	0	0	0	0	0	0	0	0	0	0	0	0
SGW 50%	1	-	-	-	-	-	-	-	-	-	-	10	0
	2	-	-	-	-	-	-	-	-	-	-	10	0
	3	-	-	-	2	-	-	-	-	2	-	10	4
	4	0	x	1	1	0	0	0	0	0	0	9	2
	5	9	x	0	7	0	4	0	7	7x	7	8	41
	6	6	x	x	0	0	0	5	0	x	8	7	19
	7	0	x	x	3	1	8	0	3	x	0	7	15
	total	15	0	1	13	1	12	5	10	9	15	7	81
Control [5C & 7F]	1	-	-	-	-	-	-	-	-	-	-	10	0
	2	-	-	-	-	-	-	-	-	-	-	10	0
	3	-	-	-	-	-	3	-	-	-	-	10	3
	4	4	2	x	x	1	0	4	0	4	1	8	16
	5	0	8	x	x	9	8	4	6	7	11	8	53
	6	0	0	x	x	12	0	0	0	0	0	8	12
	7	12	8	x	x	12	0	11	7	9	13	8	72
	total	16	18	0	0	22	23	19	13	20	25	8	156
7F 0.01%	1	-	-	-	-	-	-	-	-	-	-	10	0
	2	-	-	-	-	-	-	-	-	-	-	10	0
	3	-	-	-	-	-	-	-	-	-	-	10	0
	4	4	7	4	4	4	3	3	4	0	5	10	38
	5	11	0	10	6	5	6	6	6	7	0	10	57
	6	0	6	8	0	0	0	0	0	8	6	10	28
	7	12	0	0	9	10	7	11	9	0	12	10	70
	total	27	13	22	19	19	16	20	19	15	23	10	193

Table 6.19. (continued)

Dilution	Day	Replicate										No. Live Adults	No. Live Young
		1	2	3	4	5	6	7	8	9	10		
7F	1	-	-	-	-	-	-	-	-	-	-	10	0
0.03%	2	-	-	-	-	-	-	-	-	-	-	10	0
	3	-	-	-	-	-	-	-	-	-	-	10	0
	4	0	4	3	4	4	1	3	1	4	M	10	24
	5	6	8	7	7	7	5	7	8	8	M	10	63
	6	7	0	0	9	0	0	0	0	0	M	10	16
	7	8	10	11	0	12	9	12	11	10	M	10	83
	total	21	22	21	20	23	15	22	20	22	0	10	186
7F	1	-	-	-	-	-	-	-	-	-	-	10	0
0.1%	2	-	-	-	-	-	-	-	-	-	-	10	0
	3	-	-	-	-	-	-	-	-	-	-	10	0
	4	2	4	3	2	0	4	4	4	6	0	10	29
	5	8x	6	6x	6x	0	x	7x	8x	0	5	4	46
	6	x	x	x	x	4	x	x	x	9	8	3	21
	7	x	x	x	x	0	x	x	x	10	0	3	10
	total	10	10	9	8	4	4	11	12	25	13	3	106
7F	1	-	x	-	-	-	-	-	-	-	-	9	0
0.3%	2	-	x	-	-	-	-	-	-	-	-	9	0
	3	-	x	-	-	-	-	-	-	-	-	9	0
	4	x	x	2	1x	2	3	5	0	x	0	6	13
	5	x	x	0	x	0	0	x	0	x	5	5	5
	6	x	x	0	x	0	0	x	0	x	0	5	0
	7	x	x	0	x	0	0	x	0	x	0	5	0
	total	0	0	2	1	2	3	5	0	0	5	5	18
5C	1	-	-	-	-	-	-	-	-	-	-	10	0
0.03%	2	-	-	-	-	-	-	-	-	-	-	10	0
	3	-	-	-	-	-	-	-	-	-	-	10	0
	4	4	2	4	4	3	4	2	4	3	0	10	30
	5	8	9	7	6	10	9	8	7	8	x	9	72
	6	0	0	10	0	0	0	0	0	0	x	9	10
	7	9x	13	0	14	10	11	9	11	10	0	8	87
	total	21	24	21	24	23	24	19	22	21	0	8	199
5C	1	-	-	-	-	-	-	-	-	-	-	10	0
0.1%	2	-	-	-	-	-	-	-	-	-	-	10	0
	3	-	-	-	-	-	2	-	-	-	-	10	2
	4	4	5	4	4	4	0	2	4	2	4	10	33
	5	6	9	10	4	10	7	7	9	0	6	10	68
	6	0	0	0	0	0	8	0	10	7	0	10	25
	7	9	14	10	7	10	0	12	0	10	10	10	82
	total	19	28	24	15	24	17	21	23	19	20	10	210

Table 6.19. (continued)

Dilution	Day	Replicate 1	2	3	4	5	6	7	8	9	10	No. Live Adults	No. Live Young
5C 0.3%	1	-	-	-	-	-	-	-	-	-	-	10	0
	2	-	-	-	-	-	-	-	-	-	-	10	0
	3	-	-	-	-	-	-	-	-	-	-	10	0
	4	3	1	3	2	0	0	3	1	3x	4	9	20
	5	5	4	2	5	3	x	6	1x	x	6	7	32
	6	0	0	0	0	0	x	0	x	x	x	6	0
	7	7x	1x	x	4x	2	4x	0	x	x	x	2	18
	total	15	6	5	11	5	4	9	2	3	10	2	70
5C 1.0%	1	-	-	-	x	-	-	-	-	-	x	8	0
	2	x	x	x	x	x	-	-	-	-	x	4	0
	3	x	x	x	x	x	-	x	x	x	x	1	0
	4	x	x	x	x	x	x	x	x	x	x	0	0
	5	x	x	x	x	x	x	x	x	x	x	0	0
	6	x	x	x	x	x	x	x	x	x	x	0	0
	7	x	x	x	x	x	x	x	x	x	x	0	0
	total	0	0	0	0	0	0	0	0	0	0	0	0

\- = Live female too young to produce offspring,
x = Dead adult, no young produced before death,
N^x = Dead adult; N young produced before death,
M = Male.

Table 6.20. Summary of *Ceriodaphnia* survival and fecundity test results.

Effluent dilution	No. of replicate	No. of females surviving for 7 days	Mean number of offspring per female (± s.d.)
SGW Control	10	6	18.3 ± 7.9
SGW 100%	10	0*	--- ± ---*
SGW 50%	10	7	10.1 ± 5.3
5C,7F Control	10	8	19.5 ± 3.9
7F 0.01%	10	10	19.3 ± 4.1
7F 0.03%	10	9	20.7 ± 2.4
7F 0.10%	10	3*	14.0 ± 10.5*
7F 0.30%	10	5	2.4 ± 1.8*
5C 0.03%	10	8	22.3 ± 1.8
5C 0.10%	10	10	21.0 ± 3.8
5C 0.30%	10	2*	7.0 ± 2.8*
5C 1.0%	10	0*	--- ± ---*

3.5 Statistical Analyses for sample 7F:

Asterisks in Table 6.20 show concentrations significantly reducing survival and fecundity based on Fisher's Exact Test (for survival), followed by SAS-GLM (General Linear Model) procedure, and Dunnett's Test for reproduction. For the data above, the mean number of offspring per female is computed from females that survived for the entire test period. The least significant difference in fecundity at the 5% level ($LSD_{0.05}$) is 4.97 offspring per female, computed from the error mean square term obtained using the GLM analysis procedure (Table 6.21). The LSD represents a 25.5% reduction in fecundity relative to the control.

Table 6.21. GLM analysis of *Ceriodaphnia* fecundity, 7F sample.

Source	DF	Sum of Sq.	Mean Sq.	Calc F	$F_{(0.05)}$
Among	3	2193.644	731.215	27.11	2.88
Within	35	944.100	26.974		
Total	38	3137.744		Pr > F = 0.0001	

Table 6.22. GLM Analysis of *Ceriodaphnia* fecundity, 5C sample.

Source	DF	Sum of Sq.	Mean Sq.	Calc F	$F_{(0.05)}$
Among	2	162.867	81.433	1.68	3.35
Within	27	1311.300	48.567		
Total	29	1474.167		Pr > F = 0.2059	

3.5 Statistical Analyses for Sample 5C:

Asterisks in Table 6.19 show concentrations that significantly reduced survival and fecundity based on Fisher's Exact Test (for survival), followed by SAS-GLM (General Linear Model) procedure, and Dunnett's Test (for reproduction). For the data shown in Table 6.20, the mean number of offspring per female is computed from females that survived for the entire test period. The least significant difference in fecundity at the 5% level ($LSD_{0.05}$) is 6.2 offspring per female, computed from the error mean square term obtained using the GLM analysis procedure (Table 6.22). The LSD represents a 31.9% reduction in fecundity relative to the control.

3.7 A. Summary of Test Results for sample 7F:
No Observed Effect Concentration (NOEC): 0.03%
Lowest Observed Effect Concentration (LOEC): 0.10%
B. Summary of Test Results for sample 5C:
No Observed Effect Concentration (NOEC): 0.10%
Lowest Observed Effect Concentration (LOEC): 0.30%

3.7 Discussion

Short-term, sub-chronic toxicity tests, such as the *Ceriodaphnia* survival and reproduction test, are currently used to estimate the toxicity of effluents permitted under the National Pollutant Discharge Elimination System (NPDES). Test methods are standardized and fully described in W. B. Horning and C. I. Weber (eds.) Short-term methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms, EPA/600/4-85/014 (December 1985). In the NPDES permit reporting procedure, an effluents toxicity is commonly expressed in terms of its no-observed-effect concentration (NOEC). In the *Ceriodaphnia* test, the NOEC is the highest tested concentration at which the effluent has no statistically discernable adverse effect on survival or fecundity.

The NOECs for the synthetic groundwater, 5CHIPA leachate, and 7FSAEE leachate were 50%, 0.1%, and 0.03% of full-strength, respectively. The potential instream toxicity of the leachate may be estimated by comparing a samples NOEC to the anticipated concentration of the waste in the receiving stream (instream waste concentration or IWC). In general, for an effluent to be considered safe to discharge, the IWC must be equal to or less than the NOEC (IWC $\leq$ NOEC) [EPA 1985]. Therefore, if wastes such as 5CHIPA and 7FSAEE are discharged, the anticipated IWC should be <0.1% and <0.03%, respectively.

In some cases, an uncertainty factor (UF) may be used to adjust the toxicity data to account for unknown variations. When toxicity is measured using only one test species (i.e. *Ceriodaphnia*), other species may exhibit more sensitivity to the effluent. An uncertainty factor would adjust measured toxicity upward and downward to cover the sensitivity range of other, potentially more or less sensitive species (EPA 1985). In general, a factor of 10X is applied if only one species is tested, and a factor of 10X is applied if the effluent is highly variable. If a UF was applied to the 5CHIPA and 7FSAEE leachates, then the following relationship should hold true: IWC * 100 $\leq$ NOEC.

Water quality measurements (i.e. hardness, conductivity, alkalinity) are generally made for each water sample tested for toxicity. However, when an effluent is highly toxic (i.e. toxic at a low concentration), these water quality parameters may provide little information about the toxic agent per se. Chemical analyses of the leachate (such as ICP) would be necessary before hypothesizing what may be the cause of the toxicity.

QA/QC

All laboratory procedures are conducted according to EPA-approved procedures for estimating the chronic toxicity of waste and receiving waters [Horning and Weber 1985] and to established laboratory Standard Operating Procedures (SOPs). SOPs are available to all personnel in the laboratory and are currently part of the draft document, Quality Assurance Plan for the Toxicology Laboratory, Environmental Sciences Division, Oak Ridge National Laboratory.

6.7.9 Appendix H - Uranium Content of an Air Filter Sample Compared by Acid Leaching and Gamma Counting

During the conduct of this laboratory leaching task, a question was raised relative to the precision and accuracy of the gamma counting equipment used at the Y-12 Plant to analyze all of the waste samples used in the tests, with the exception of the uranium oxide powder. The Y-12 Plant gamma counter, colloquially called the "elephant gun," is used to monitor trucks of waste at the Y-12 Plant to determine if the truck load can be discharged to the sanitary landfill or if it must go to the low-level waste disposal site. Because ORNL has no facility capable of high sensitivity gamma counting of bulk waste samples, all of the head-sample analyses for the work described in this report were run on the "elephant gun" gamma counter at the Y-12 Plant.

While repetitive counts taken of a few samples showed good reproducibility (good counting precision), the question of accuracy remained open. Therefore, it was decided to leach several waste samples in strong nitric acid. (Initially, leaching all the solid residues from the synthetic landfill and synthetic groundwater tests was considered in order to get a uranium element balance for each test but was rejected because of the added effort that would be required and concern about the large volumes of nitric acid to be handled.) Strong nitric acid is a good oxidizer as well as an acid and presumably would dissolve the uranium contaminant in the wastes regardless of the uranium chemical form. The total uranium leached would then be compared with the uranium content calculated from the gamma counting data. Due to time constraints, only one air filter sample was acid leached for comparison.

Bag 06-03-01 from filter No. 1 (see Table 6.17 and Sect. 6.7.1.4), which was reported to contain 144 g of uranium was treated as follows. The filter media in the bag was sequentially leached in about 27 L each of 3 $\underline{M}$ HNO_3, 1.5 $\underline{M}$ HNO_3, H_2O, and H_2O for 1 day each (cumulative leach time of 4 days). The leachates were combined (total volume of 108 L) and thoroughly mixed. The leach residue was gamma counted and showed no significant activity; i.e., uranium leaching was essentially complete. Two separate samples were submitted to two different Analytical Chemistry Division laboratories at ORNL for uranium analysis. The uranium concentrations obtained by the two laboratories were 1.91 and 1.96 g U/L. The average concentration of 1.935 g/L times the volume of 108 L gave a calculated starting weight of 209 g uranium.

The agreement between the uranium value obtained by leaching (209 g) and that measured by gamma counting (144 g) was disappointingly poor. For this air filter sample, the "elephant gun" gamma counter gave a value which was only 69% of the actual uranium content. All of the data on fraction uranium leached given in this report is based on head-sample analyses obtained by gamma counting. Obviously, if the head-sample analysis is in error then all the calculated values are similarly biased.

Additional investigation and documentation of the "elephant gun" gamma counter accuracy seems highly desirable for a number of reasons. Unfortunately, time constraints did not allow us to pursue this issue further.

6.7.10 References for Sect. 6.7

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7. LEACHING STUDIES OF URANIUM-BEARING WASTE SOLIDS FROM MANUFACTURING OPERATIONS

J. M. McMahon, B. A. Tomkins, and W. H. Griest

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7. LEACHING STUDIES OF URANIUM-BEARING WASTE SOLIDS FROM MANUFACTURING OPERATIONS

7.1 INTRODUCTION

The management and disposal of uranium-bearing wastes is of vital concern of both government and private industry. Because of the long-lived nature of these wastes and their potential environmental impacts, the problems associated with their disposal warrant careful study. The federal agencies having a mandate to manage and dispose of these wastes are the Department of Energy (DOE), the Nuclear Regulatory Commission (NRC), and the Environmental Protection Agency (EPA). At present, the regulations governing the management and disposal of uranium-bearing wastes are complex and subject to conflicting interpretation. Clearly, much more must be known about the behavior of uranium-bearing wastes before a method of disposal is approved. This sanction must be supported by sound data, and must insure the protection of public health and safety both now and in the future.

The existing body of knowledge regarding the disposal of depleted uranium-bearing wastes (that is, uranium which is depleted in the fissile isotope U-235) is incomplete. The results of previous studies indicated a need for an experimental approach which could provide supplemental data for the evaluation of the leaching behavior. This approach would employ rapid, bench-scale leaching experiments which could supplement the results of larger-scale, longer-term studies. These data, in conjunction with other independently-performed studies, can be used to suggest a proper approach for disposing of uranium-bearing wastes.

A second objective of this study was to determine the leachability of seven of the eight toxic metals defined by the Resource Conservation and Recovery Act of 1976 (RCRA) from the depleted uranium-bearing wastes. These metals are silver, cadmium, lead, arsenic, barium, chromium, and selenium.

This study examined the potential environmental leaching behavior by groundwater on four uranium-bearing wastes obtained from the Y-12 Plant in which uranium was both machined and molded: (1) carbon, (2) blotter paper, (3) mixed metal chips, and (4) floor sweepings. These sample waste streams may be described as follows:

> <u>The carbon samples</u>, which were obtained from uranium castings, were black, hard chunks and grains, with sizes varying from a few millimeters to ca. 50 millimeters in diameter.
>
> <u>The blotter paper</u>, which was obtained from production areas, was white, fibrous material, a few millimeters thick, and shredded to lengths of approximately 150 millimeters. Dirt and other substances had obviously been absorbed.
>
> <u>The mixed metal chips</u>, which were obtained from production machining operations, were turnings of an unspecified shiny metal (with a few

other types of metals present). Lengths of the turnings varied, with approximately 200 millimeters being the maximum. The samples were submitted as tight spirals, suggesting that their primary source was a lathing operation.

The floor sweepings from production areas were a truly heterogeneous material. Cigarettes, candy wrappers, metal chips, dust, dirt, and paper were just a few of the components which could be readily identified.

The leaching method employed was a modified version of the U.S. EPA Toxicity Characteristic Leaching Procedure (TCLP). This approach was the method of choice for three reasons. First, it is designed to simulate the removal of metals and organics over extended periods of time using simulated ground water. Second, the TCLP yields a usable leachate in a short period of time (normally less than twenty-four hours). Third, the normal TCLP requires small masses of sample (100 grams) relative to other long-term studies. This latter restriction was modified to allow the leaching of samples as small as one to five grams.

7.2 METHODS AND MATERIALS

General Considerations

For the purpose of this study, a batch of samples consists of one can of each of the four aforementioned waste streams which was submitted for analysis at the same time. Four batches containing each of the four sample types (total of sixteen cans) were used in this work.

The TCLP (1) is designed to simulate the leaching of organics and metals from solid samples by groundwater. The leaching solution employed, which has been carefully selected to model the gross properties of groundwater, is a stable weakly-acidic sodium acetate/acetic acid buffer with pH 4.93. The method requires that the waste sample be tumbled for eighteen hours using a liquid-to-solid ratio of 20/1 in wide-mouth two-liter capacity jars.

A variety of liquid-to-solid ratios were employed in this study to evaluate a potential saturation limit for uranium in the groundwater. Ratios were chosen to bracket the normal 20/1 regulatory value. These were 100/1 and 50/1 (greater than the regulatory value) and 10/1 and 5/1 (smaller than the regulatory value). Duplicate leachings at each liquid/solid ratio, as well as a blank consisting of only the pH 4.93 buffer, were performed.

Two methods of agitation were employed in this work. The first, stirring in open beakers using magnetic stirrers, was discarded after the first batch (see below). The remaining batches were agitated using the TCLP-approved six-position tumbling apparatus, in which the leach solution and solid sample were rotated end-over-end in sealed vessels.

The final modification of the TCLP was a change in the volume of leach solution and mass of sample taken, although the liquid-to-solid ratios were maintained as described. In Batch 1, the volume of leach solution was held at 100 mL; the resulting masses of samples taken were 1, 2, 5, 10, and 20 g, respectively. In the remaining batches, the volume of leach solution was held at 500 mL; the resulting masses of sample were increased five-fold.

The four wastes selected for study were deemed to be representative waste streams by uranium-processing facility personnel at the Y-12 Plant, Oak Ridge, TN. Each batch (that is, one can of each type of waste) was received for study by this laboratory, and was subjected to leaching immediately. As soon as the prescribed leaching period was completed, the leachates were filtered, as described below.

Batch 1

The solids used in Batch 1 were shredded and mixed by hand to improve the homogeneity of the portions taken. The solids were stirred with 100 mL of leaching solution for eighteen hours (time specified by the TCLP) in a beaker using a magnetic stirrer. When the stirring time was completed, the liquids were filtered through No. 40 Whatman filter paper and collected in polyethylene bottles. These liquids were submitted for determination of uranium and, in one case, the RCRA metals (see below).

Batches 2-4

The solids used in the remaining batches were apportioned as received. Samples were tumbled for eighteen hours using a six-position tumbler and 2-L capacity wide-mouth jars, as described by the TCLP, using 500 mL of leaching solution. The filtration and further analyses were the same as for Batch 1 (see below).

Analytical Methods

The eleven liquids, an unleached portion of the original solid sample, and portions from the two leached solid remains of the 20:1 ratio duplicate portions (fourteen bottles per original sample) taken from each batch were then analyzed. The liquid from the two 20:1 portions were analyzed by ICP (inductively coupled plasma) emission spectroscopy for all RCRA (Resource Conservation and Recovery Act of 1976) metals except mercury. The remaining twelve analytical portions were tested for total uranium by fluorescence. The solids were included in this study so that the uranium mass balance for each sample could be determined.

7.3 RESULTS AND DISCUSSION

General Considerations

Although the normal TCLP requires a minimum of 100 g of solid waste sample per portion for leach testing, this requirement was waived for this study since one goal of these experiments was to operate on a minimum scale. Nevertheless, the most important elements of the TCLP, viz. the liquid/solid ratios, mixing time, and intimate contact between sample and leaching solution, were retained.

Initially, the analytical plan featured careful homogenization of the samples upon receipt and stirring small portions of solid in beakers. These features had to be modified immediately after experience in Batch 1 for several reasons. First, the purpose of the study was to simulate waste as it was put into the ground. Hence, homogenization was not considered absolutely essential. Second, some of the solid samples taken for Batch 1 were as small as 1 g. Since the wastes, particularly the floor sweepings and the carbon, were particularly heterogeneous, the use of very small samples led to major outliers in the analytical data. Finally, it was mechanically difficult to mix the samples and leaching solutions, particularly at the smaller liquid/solid ratios, using mechanical stirring in a beaker. This was particularly troublesome for blotter paper at liquid/solid ratio of 5/1 and the mixed metal chips at all liquid/solid ratios.

These problems were addressed in Batches 2 through 4 by maintaining the selected liquid/solid ratios, but increasing the volume of leach solution (and, therefore, the mass of sample taken). Furthermore, two six-position tumblers and 2 L wide-mouth jars replaced the beakers and magnetic stirrers as the mode of mixing.

The experimental design dictated that statistical regression analysis be performed on the data because the weights of the uranium-bearing samples were chosen in advance (i.e., the weights were not random), but the actual concentrations of uranium were not (i.e., the concentrations were random). This is in contrast to correlation analysis, in which both the sample weights and the concentrations must be randomly selected. The statistical model which was examined in all cases was a simple linear model where the intercept of the line was not necessarily zero, or

$$\text{U concentration} = b_0 + b_1\ (\text{sample weight}) + (\text{error})$$

As a further refinement, weighted statistical regression analysis was performed because there was a large difference in the calculated variances for the uranium concentration for some of the sample weights. The weighting factor employed is $1/s^2$, the inverse of the experimental variance for a given sample mass. When this particular weighting factor is used, the weighted least square estimates are the best linear unbiased estimates of the slope and intercept in the model given above. The standard error for both the slope and intercept are presented in Tables 7-1 through 7-16.

The coefficient of determination, which is calculated as part of the regression analysis and varies between zero and unity, represents the portion of the variation in the uranium concentration that is accounted for by the sample weight. A value of zero means that the chosen model explains none of the variation, while a value of unity means that the model explains all of it.

Table 7-1 shows the concentration of uranium in the leachate for each carbon sample pair, the average of these concentrations, and the leaching efficiency results as per the equation:

$$\text{Leaching Efficiency} = \frac{(\mu\text{g U/mL liq})\ (\text{vol lch sol'n mL})}{(\text{g samp.})\ (\mu\text{g U/g solid }\mu\text{nl})} \times (100\%)$$

where (μg U/mL liq) is the concentration of uranium in μg/mL in the leachate (a random variable); (vol lch sol'n mL) is the volume of leach solution (a fixed quantity); (g samp.) is the weight of sample taken (fixed quantities) and (μg U/g solid μnl) is the concentration of uranium in the solid (a constant value for each sample).

The coding B1-C3 in this table stands for Batch 1, Can 3, and is typical throughout this study.

Batch 1

For four data points for the carbon (those data points with the asterisks) the leaching efficiency exceeds 100%. These anomalies are probably caused by the determination of uranium in a single solid sample portion, rather than from multiple portions, taken from a nonhomogeneous material. Constraints of both time and cost prevented additional determinations of uranium in the solid samples to be performed. Further comments regarding the effects on the data of the single solid determinations are discussed in detail in the Mass Balance Ratio section.

When the data points and their means are graphed as uranium concentration vs. number of grams in the original sample (see Fig. 7-1), we observe good linearity with a coefficient of determination of 0.82, a value quite acceptable for such a small sample with non-homogeneous distribution. (The data points are shown as dark circles, and the average of the data points are shown as a hollow circle.) In this study, the abscissa (x-axis) of any graph employs grams of solid sample, rather than liquid-to-solid ratio. Recall, however, that the volume of liquid (100 mL) was held constant for all leachings in Batch 1.

When the data are graphed as the leaching efficiency vs. number of grams in the original sample (Fig. 7-2), the linearity decreases, especially with respect to the smaller sample portions. In the case of the carbon, results for the two-gram sample are sharply affected by the homogeneity in the original material.

Tables 7-2 through 7-4 and Figs. 7-3 through 7-8 show the results for the other three samples (blotter paper, mixed metal chips, and floor sweepings). The plots for the concentration of uranium vs. number of grams of blotter paper or mixed metal chips exhibit coefficients of determination exceeding 0.85, but that for the floor sweepings was less than 0.02. The latter value reflects the lack of any homogeneity in the original sample. At sample masses below 2 g, calculated leaching efficiencies exceeded 100%.

Sample inhomogeneity, which can produce an artificially low uranium concentration in the solid, was probably responsible for these suspect values.

Batch 2

Figures 7-9 and 7-10 and Table 5 describe the leaching of uranium from Batch 2 Carbon. [In this study, the abscissa (x-axis) of any graph employs grams of solid sample, rather than liquid-to-solid ratio. Recall, however, that the volume of liquid (500 mL) was held constant for all leachings in Batch 2]. The linearity in the graphs is evident, as indicated by the coefficient of determination = 0.81. These results are similar to Batch 1 Carbon results, in which the coefficient of determination was almost identical (0.82).

When certain points from the Batch 2 Carbon leaching are deleted, a larger value for the coefficient of determination results, with other values as "outliers". This behavior suggests both a rough baseline value for uranium distribution in this carbon sample and some "hot spots", where the uranium casting was in direct contact with the carbon mold. A non-uniform distribution of these "hot spots" among the portions taken for leaching would lead to non-linearity in uranium concentrations.

The very natures of the analyte and hard carbon sample matrix imply that uranium, if present, will remain on the surface and will never disperse uniformly in the bulk sample. Hence, for carbons, perhaps it is surface area, not simple mass, which should be the crucial parameter which governs uranium leaching behavior.

The results for Batch 2 Blotter Paper are given in Fig. 7-11 and Table 7-6. This graph suggests a strong linearity, as confirmed by the coefficient of determination = 0.89. The graph and coefficient of determination imply substantial homogeneity of uranium in the sample. Recall that the Batch 1 Blotter Paper also exhibited reasonable linearity and a coefficient of determination of 0.96.

Figures 7-13 and 7-14, and Table 7-7 summarize the data for Batch 2 Mixed Metal Chips. The plot suggests linearity (coefficient of determination exceeds 0.96), but the calculated slope is negative. These values imply an inverse relationship between uranium concentration and quantity of material leached. The absolute quantities of uranium detected, however, are consistently low (none above 0.17 μg U/mL solution), and the small negative value of the slope may not correspond to real behavior.

The data for Batch 2 Floor Sweepings are summarized in Figs. 7-15 and 7-16 and Table 7-8. Little linearity is apparent, as evidenced by the coefficient of determination of 0.38. This implies a lack of homogeneity in the uranium distribution in the sample. This is hardly surprising, since the sample itself is grossly non-homogeneous. Batch 1 Floor Sweepings also appeared non-homogeneous; its leaching data was badly scattered; and the resulting coefficient of determination suggested random, not related, leaching behavior.

Batch 3

The analytical results from Batch 3 Carbon are plotted in Figs. 7-17 and 7-18, and summarized in Table 7-9. [In this study, the abscissa (x-axis) of any graph employs <u>grams</u> of solid sample, rather than <u>liquid-to-solid ratio</u>. Recall, however, that the volume of liquid (500 mL) was held constant for all leachings in Batch 3. There was virtually no linear relationship between the sample weight and the uranium concentrations, as evidenced by a coefficient of determination equal to 0.06. The data again suggested the presence of localized uranium "hot spots", as described for Batch 2 Carbon. The fact that the highest average amount of uranium concentration (24.1 μg U/mL) was found in the liquid from the least amount of material leached (5 g) supports the concept of "hot spots" on the carbon surface.

Batch 3 Blotter Paper showed a homogeneity in uranium distribution, as depicted by Figs. 7-19 and 7-20 and summarized in Table 7-10. The coefficient of determination for this plot, 0.95, is consistent with the blotter paper results obtained from Batches 1 and 2.

The data for the Batch 3 Mixed Metal Chips (Figs. 7-21 and 7-22, Table 7-11) strongly resembled those for the same sample from Batch 2, in that the concentrations of uranium in the collected leaching solution were very low (slightly above blank levels, 0.12 μg U/mL) and the calculated slopes were very small. Figure 7-22 suggests the leaching efficiency is inversely proportional to the quantity of material leached, as described in Batch 2.

Table 7-12 and Figs. 7-23 and 7-24 show the results for Batch 3 Floor Sweepings. The modest coefficient of determination (0.73) was unexpected, given the inhomogeneous nature of the material. Although the unleached solid sample shows results in the mg U/g range, the leached material stays in the μg U/mL range.

Batch 4

Batch 4 Carbon (Fig. 7-25 and Table 7-13) exhibited generally low levels of uranium with a few "hot spots" which resulted in values of relatively high concentrations (notice those for 100 grams of material leached). [In this study, the abscissa (x-axis) of any graph employs <u>grams</u> of solid sample, rather than <u>liquid-to-solid ratio</u>. Recall, however, that the volume of liquid (500 mL) was held constant for all leachings in Batch 4]. The coefficient of determination, 0.94, remained reasonable for Batch 4 Carbon in spite of the "hot spots". The leaching efficiency (Fig. 7-26), though, appears erratic. Table 7-13 is the table corresponding to these figures.

Data for Batch 4 Blotter Paper sample is consistent with that for previous blotter paper batches. As seen in Table 7-14 and Fig. 7-27, low levels of uranium concentrations are observed (0.11 to 0.38 μg U/mL solution), and the coefficient of determination exceeded 0.99. The leaching efficiency depicted in Fig. 7-28 suggests an inverse relationship between leaching efficiency and amount of material leached. In general, it appears that the concentration of uranium remains low when leaching blotter paper, and the distribution of analyte through- out the sample is relatively uniform.

The data for the Batch 4 Mixed Metal Chips (Figs. 7-29 and 7-30, and Table 7-15) are comparable to those from Batches 2 and 3. The uranium concentrations in the leachate remained near background, between 0.027 and 0.53 μg U/mL solution. The coefficient of determination, 0.01, suggested that the leaching data is essentially random.

The Batch 4 Floor Sweepings results (Fig. 7-31 and Table 7-16) consistently showed very high levels of uranium (up to 382 μg U/mL solution) —the highest for any sample in any batch. This agrees with the concentration of uranium in the unleached solid (140 mg U/g solid)—more than three orders of magnitude greater than any of the other three samples in this batch. As with the previous two floor sweeping samples, the linearity is poor, as demonstrated by a coefficient of determination of 0.19. A glance at the leaching efficiency (Fig. 7-32), however, shows a general trend for diminished efficiency with an increased amount of material leached.

Mass Balance Ratio

The mass balance ratio is simply the total mass of analyte present in the leachate and solid after extraction divided by the mass of analyte originally present in the unleached solid (Table 7-17). This may be expressed as:

$$\text{Mass Balance Ratio} = \frac{(\text{U})\text{lch.liq.} \times (\text{vol.})\text{lch.liq.} + (\text{U})\text{lch.sol.} \times (\text{wt.})\text{lch.sol.}}{(\text{U})\text{unl.sol.} \times (\text{wt.})\text{unl.sol.}}$$

where <u>(U) lch liq</u> and <u>(vol) lch liq</u> are the concentration of uranium in, and volume of, the leach liquid, respectively; <u>(U) lch sol</u> and <u>(wt) lch sol</u> are the concentration of uranium in, and weight of, the leached solid, respectively; and <u>(U) unl sol</u> and <u>(wt) unl sol</u> are the concentration of uranium in, and the weight of, the unleached solid, respectively.

Mass balances significantly different from unity imply that the starting concentration of analyte in the solids is not uniformly distributed either on the surface or in the bulk of the sample.

Using analytical results for the 20/1 ratio for the leached portion of the calculation and the values obtained for the analysis of unleached portions of sample (Table 7-17), the experimental mass balance ratios were calculated and are reported in the Mass Balance Ratio Table, Table 7-18.

The results from Batch 1 show that the mass balance ratio calculation is closest to unity for the blotter paper sample (1.08), reasonably close to unity for carbon (3.48) and the floor sweepings (0.253), and significantly differently from unity for the mixed metal chips (0.065). The mass balance ratios from the last three batches proved to be rather erratic, and no strong trend can be observed.

These data must be viewed with a healthy degree of skepticism as to their true reliability. The calculations depend greatly upon the determination of uranium in a single portion of unleached solid sample, where the distribution of uranium is known to be nonuniform. The mass balance ratios do suggest in a general sense, however, the degree of homogeneity which may be expected for a given sample type.

Determination of RCRA Metals

For all sixteen waste samples, the concentrations of all RCRA metals (except Hg) were determined for the leachate resulting from the 20/1 liquid-to-solid experiment. These results are listed in Tables 7-19 through 7-22. In most cases, the concentrations of metals observed were an order of magnitude or more below the TCLP regulatory levels. There is no trouble in disposing of these wastes from the standpoint of these seven metals. The only questionable data points are those for selenium in Batch 2 Carbon: 1.0 ppm is the TCLP regulatory limit, and the measurement for this particular sample was reported as less than 1.3 ppm.

7.4 COMPARISONS

General Characteristics for Individual Sample Types

Carbon. Batches 1, 2, and 4 exhibited good agreement with the linear model with coefficients of determination exceeding 0.80. Batch 3 exhibited a coefficient of determination of 0.06, indicating essentially random behavior. In all batches except Batch 1, the graphs appeared to show not only a plot with respectable linear fit, but also some "outlier" values. The different methods of sampling, viz. pulverized vs "chunk", may help explain these observations.

Inspection of the Batch 2 graph showed very high concentrations for the smallest quantities of sample leached. When a model for surface uranium is proposed which allows both a uniform distribution and localized "hot spots," these anomalies can be explained. The relevance of surface area vs. bulk weight as the key parameter remains unresolved.

Blotter paper. Blotter paper consistently showed low levels of uranium concentration for each batch, high levels of homogeneity, and coefficients of determination which all exceeded 0.88. The inherently constant relationship between the surface area of the blotter paper and the bulk weight of the blotter paper may be a factor in this homogeneity.

Mixed metal chips. The concentration of uranium seen in the leached solution of mixed metal chips is uniformly low, often just above the value seen for the blank sample. The linearity in concentration of uranium vs. amount of sample leached in the last three batches was often inversely related. The result, however, for the first batch was quite different, with a coefficient of determination exceeding 0.86.

As mentioned previously, the manner of preparation was altered after Batch 1. This included a change from an open to a sealed container, which limited the amount of available oxygen. Indeed, when the seals were broken on these last three samples, a "popping" sound, similar to breaking a partial vacuum, was heard. This suggests that the uranium (and possibly other metals) were partially oxidized during the leaching. A greater extent of oxidation would be expected in the open-vessel leaching (Batch 1), but it is difficult to determine whether this had a major influence on the leaching results.

Floor sweepings. All four samples exhibited very high concentrations in the unleached solid; all are in the mg U/g sample or greater range (see Table 7-17). The leaching efficiencies, however, remained relatively low. The uranium distribution within a given floor sweepings sample is essentially random, as indicated by coefficients of determination which range between 0.02 and 0.73. This non-uniform uranium distribution is not surprising, though, when the non-homogeneous origin and composition of the sample type is considered. This feature also explains any sample-to-sample lack of homogeneity. The fact that consistently high concentrations of uranium were found in the unleached solids is therefore quite significant.

Intersample Comparisons

The floor sweepings shows the highest concentrations of uranium--in the mg U/g sample range, with an average of 176 mg U/g sample--for the four unleached solid sample types. The carbon sample was second, largely due to one sample with a large "hot spot" in the mg U/g sample range (25 mg/g). Mixed metal chips and blotter paper were third and fourth, respectively. The blotter paper typically exhibited an average 22.4 μg U/g sample.

The blotter paper had the greatest homogeneity in uranium distribution within a sample itself; and the floor sweepings showed the least. The data for the carbon samples showed a uniform distribution interrupted by local "hot spots". The presence of such "hot spots" suggests that perhaps it is surface area, not necessarily weight, which is the more crucial parameter. The very nature of the carbon suggests that the bulk of the sample will not enter into the leaching process at all. The mixed metal chips showed homogeneity for the first sample only, and introduced the effects of oxygen availability in open vs. sealed systems.

The mixed metal chips showed the lowest absolute concentrations of uranium in the leached solution, followed closely by the blotter paper samples. The carbon samples had the second highest levels of uranium concentrations, and the floor sweepings had the highest. The leaching efficiency calculations bear little meaning, as previously stated, since true representative sampling of the leached solid was difficult; only one unleached solid portion was analyzed, and too much emphasis on this result made the results for both leaching efficiency calculations and mass balance calculations questionable. A glance at the leaching efficiency graph for

Batch 2 Blotter Paper (Fig. 7-12) emphasizes this point; the leaching efficiencies range from 1090% to 3400% Similarities can be found in the mass balance calculations.

7.5 CONCLUSIONS

The study successfully examined the potential environmental leaching behavior of depleted uranium and seven of the eight RCRA metals in four waste streams. The results indicated the leachability of uranium-bearing wastes and the variability of each type of waste examined. The data indicate that the management of uranium wastes could benefit from the segregation and treatment of wastes based on waste type. The data, in conjunction with the results of the long-term, large-scale studies, should provide an objective basis for defining an acceptable method for the disposal of uranium-bearing wastes from the Y-12 Plant.

Models for uranium distributions in the waste samples were proposed, trends in relative concentrations could be seen. Further experimentation could be expected to identify the soluble fraction of uranium bearing wastes for each waste type and aid in evaluating the effectiveness of improved waste forms in reducing leachate generation.

With improvements in the identification of representative samples, the calculation of the leaching efficiency and mass balance could aid in determining waste forms that would contribute to the best management practices for the treatment and diagnosal of uranium-bearing wastes.

7.6 REFERENCE

United States Environmental Protection Agency, "Hazardous Waste Management System; Identification and Listing of Hazardous Waste; Notification Requirements; Reportable Quantity Adjustments; Proposed Rule", *Federal Register*, 51, Parts 261, 271, and 302, 21648 (June 13, 1986).

Table 7-1. Analytical results for carbon (B1-C3)

			(μg/mL)		Percentage	
Sample number	No. g sample	Liq/sol ratio	Conc. U	Aver	Leach effic.	Aver
1L	20	5	9.45		60.3	
2L	20	5	26.0	17.7	166	113
3L	10	10	3.28		41.9	
4L	10	10	5.38	4.33	68.7	55.3
5L	5	20	2.65		67.7	
6L	5	20	1.66	2.16	42.4	55.2
7L	2	50	3.25		208	
8L	2	50	0.78	2.02	49.8	129
9L	1	100	0.31		39.6	
10L	1	100	0.27	0.29	34.5	37.0
11L	0	--			--	

Unleached solid U conc. = 78.3 μg/g.

Linear regression values for conc. U vs. number g sample:
Slope (standard error) = 0.4796 (0.0784)
Intercept (standard error) = -0.1894 (0.0814)
Coefficient of determination = 0.8237

Table 7-2. Analytical results for blotter paper (B1-C4)

Sample number	No. g sample	Liq/sol ratio	(μg/mL) Conc. U	(μg/mL) Aver	Percentage Leach effic.	Percentage Aver
1L	20	5	1.19		10.	
2L	20	5	1.07	1.13	9.0	9.5
3L	10	10	0.58		9.7	
4L	10	10	0.60	0.59	10.1	9.9
5L	5	20	0.49		16.5	
6L	5	20	0.34	0.42	11.4	14.1
7L	2	50	0.22		18.5	
8L	2	50	0.071	0.15	5.96	12.6
9L	1	100	0.19		31.9	
10L	1	100	0.026	0.11	4.37	18.5
11L	0	--			--	

Unleached solid U conc. = 59.5 μg/g.

Linear regression values for conc. U vs. number g sample:
Slope (standard error) = -0.0062 (0.0028)
Intercept (standard error) = 1.2716 (0.1211)
Coefficient of determination = 0.3829

Table 7-3. Analytical results for mixed metal chips (B1-C2)

Sample number	No. g sample	Liq/sol ratio	(μg/mL) Conc. U	(μg/mL) Aver	Percentage Leach effic.	Percentage Aver
1L	20	5	1.11		4.55	
2L	20	5	1.27	1.19	5.20	4.88
3L	10	10	0.56		4.59	
4L	10	10	0.65	0.61	5.33	4.96
5L	5	20	0.11		1.80	
6L	5	20	0.061	0.086	1.00	1.41
7L	2	50	0.085		3.48	
8L	2	50	0.064	0.075	2.62	3.07
9L	1	100	0.030		2.46	
10L	1	100	0.029	0.030	2.38	2.42
11L	0	--	0.002		--	

Unleached solid U conc. = 122 μg/g.

Linear regression values for conc. U vs. number g sample:
Slope (standard error) = 0.0514 (0.0072)
Intercept (standard error) = -0.0219 (0.0073)
Coefficient of determination = 0.8652

Table 7-4. Analytical results for floor sweepings (B1-C1)

			(μg/mL)		Percentage	
Sample number	No. g sample	Liq/sol ratio	Conc. U	Aver	Leach effic.	Aver
1L	20	5	28.7		0.518	
2L	20	5	13.9	21.3	0.251	0.151
3L	10	10	3.37		0.122	
4L	10	10	5.00	4.19	0.181	0.151
5L	5	20	3.43		0.248	
6L	5	20	5.38	4.41	0.388	0.318
7L	2	50	34.9		6.30	
8L	2	50	7.33	21.1	1.32	3.81
9L	1	100	3.28		1.18	
10L	1	100	5.32	4.30	1.92	1.55
11L	0	--	0.007			--

Unleached solid U conc. = 27.7 mg/g.

Linear regression values for conc. U vs. number g sample:
Slope (standard error) = 0.0598 (0.1656)
Intercept (standard error) = 4.0300 (1.1970)
Coefficient of determination = 0.016

Table 7-5. Analytical results for carbon (B2-C8)

			(μg/mL)		Percentage	
Sample number	No. g sample	Liq/sol ratio	Conc. U	Aver	Leach effic.	Aver
1L	5	100	25.9		10.4	
2L	5	100	163.	94.5	65.2	37.8
3L	10	50	1.50		0.300	
4L	10	50	12.6	7.1	2.52	1.42
5L	25	20	3.22		0.322	
6L	25	20	4.02	3.62	0.402	0.362
7L	50	10	2.01		0.0804	
8L	50	10	5.79	3.90	0.232	0.156
9L	100	5	9.52		0.190	
10L	100	5	7.97	8.75	0.159	0.175
11L	0	--	0.018		--	

Unleached solid U conc. = 25 mg/g sample.

Linear regression values for conc. U vs. number g sample:
Slope (standard error) = 0.0672 (0.1160)
Intercept (standard error) = 1.9314 (0.5892)
Coefficient of determination = 0.8075

Table 7-6. Analytical results for blotter paper (B2-C6)

Sample number	No. g sample	Liq/sol ratio	(μg/mL) Conc. U	Aver	Percentage Leach effic.	Aver
1L	5	100	0.044		2000	
2L	5	100	0.075	0.06	3410	2730
3L	10	50	0.066		1500	
4L	10	50	0.11	0.09	2500	2000
5L	25	20	0.22		2000	
6L	25	20	0.15	0.19	1360	1730
7L	50	10	0.24		1090	
8L	50	10	0.29	0.27	1320	1230
9L	100	5	0.99		2250	
10L	100	5	0.60	0.80	1360	1820
11L	0	--	0.022		--	

Unleached solid U conc. = 0.22 μg/g.

Linear regression values for conc. U vs. number g sample:
Slope (standard error) = 0.0049 (0.0006)
Intercept (standard error) = 0.0371 (0.0147)
Coefficient of determination = 0.8893

Table 7-7. Analytical results for mixed metal chips (B2-C7)

Sample number	No. g sample	Liq/sol ratio	(μg/mL) Conc. U	(μg/mL) Aver	Percentage Leach effic.	Percentage Aver
1L	5	100	0.17		2.35	
2L	5	100	0.10	0.135	1.39	1.87
3L	10	50	0.13		0.900	
4L	10	50	0.14	0.135	0.970	0.935
5L	25	20	0.11		0.305	
6L	25	20	0.11	0.11	0.305	0.305
7L	50	10	0.064		0.089	
8L	50	10	0.069	0.067	0.096	0.092
9L	100	5	0.030		0.0208	
10L	100	5	0.025	0.028	0.0173	0.0190
11L	0	--	0.022		--	

Unleached solid U conc. = 722 μg/g.

Linear regression values for conc. U vs. number g sample:
Slope (standard error) = -0.0012 (0.0001)
Intercept (standard error) = 0.1388 (0.0024)
Coefficient of determination = 0.9680

Table 7-8. Analytical results for floor sweepings (B2-C5)

Sample number	No. g sample	Liq/sol ratio	(μg/mL) Conc. U	(μg/mL) Aver	Percentage Leach effic.	Percentage Aver
1L	100	5	2.8		3.90×10^{-3}	
2L	100	5	12.4	7.6	1.72×10^{-2}	1.06×10^{-2}
3L	50	10	0.9		2.51×10^{-3}	
4L	50	10	1.0	0.95	2.79×10^{-3}	2.65×10^{-3}
5L	25	20	1.3		7.24×10^{-3}	
6L	25	20	1.7	1.5	9.47×10^{-3}	8.36×10^{-3}
7L	10	50	0.84		1.17×10^{-2}	
8L	10	50	1.41	1.13	1.96×10^{-2}	1.57×10^{-2}
9L	5	100	1.1		3.06×10^{-2}	
10L	5	100	1.3	1.2	3.62×10^{-2}	3.34×10^{-2}
11L	0	--	0.01		--	--

Unleached solid U conc. = 359 mg/g.

Linear regression values for conc. U vs. number g sample:
Slope (standard error) = -0.0062 (0.0028)
Intercept (standard error) = 1.2716 (0.1211)
Coefficient of determination = 0.3829

Table 7-9. Analytical results for carbon (B3-C11)

			(μg/mL)		Percentage	
Sample number	No. g sample	Liq/sol ratio	Conc. U	Aver	Leach effic.	Aver
1L	5	100	2.28		17.5	
2L	5	100	46.	24.1	35.4	18.5
3L	10	50	4.70		1.81	
4L	10	50	3.09	3.90	1.19	1.50
5L	25	20	0.99		0.19	
6L	25	20	15.7	8.35	3.02	1.61
7L	50	10	8.50		0.654	
8L	50	10	1.23	4.87	0.095	0.375
9L	100	5	2.69		0.103	
10L	100	5	44.	23.3	1.69	0.896
11L	0	--	0.015		--	--

Unleached solid U conc. = 13 mg/g.

Linear regression values for conc. U vs. number g sample:
Slope (standard error) = 0.0551 (0.0784)
Intercept (standard error) = 3.3744 (1.1907)
Coefficient of determination = 0.0582

Table 7-10. Analytical results for blotter paper (B3-C17)

Sample number	No. g sample	Liq/sol ratio	(μg/mL) Conc. U (ppm)	Aver	Percentage Leach effic.	Aver
1L	5	100	0.068		32.9	
2L	5	100	0.13	0.099	62.8	47.9
3L	10	50	0.094		22.7	
4L	10	50	0.13	0.112	31.4	27.1
5L	25	20	0.13		12.6	
6L	25	20	0.13	0.13	12.6	12.6
7L	50	10	0.26		12.6	
8L	50	10	0.33	0.30	15.9	14.5
9L	100	5	0.38		9.18	
10L	100	5	0.35	0.37	8.45	8.94
11L	0	--	0.022			

Unleached solid U conc. = 20.7 μg/g.

Linear regression values for conc. U vs. number g sample:
Slope (standard error) = 0.0031 (0.0003)
Intercept (standard error) = 0.0519 (0.0064)
Coefficient of determination = 0.9497

Table 7-11. Analytical results for mixed metal chips (B3-C12)

Sample number	No. g sample	Liq/sol ratio	(μg/mL) Conc. U	Aver	Percentage Leach effic.	Aver
1L	5	100	0.025		66	
2L	5	100	0.017	0.021	44.9	55.4
3L	10	50	0.013		17.2	
4L	10	50	0.015	0.014	19.8	18.5
5L	25	20	0.011		5.8	
6L	25	20	0.074	0.048	39.1	25.3
7L	50	10	0.021		5.5	
8L	50	10	0.020	0.020	5.3	5.40
9L	100	5	0.018		2.4	
10L	100	5	0.021	0.020	2.8	2.60
11L	0	--	0.012		--	

Unleached solid U conc. = 3.79 μg/g.

Linear regression values for conc. U vs. number g sample:
Slope (standard error) = 0.0001 (0.0000)
Intercept (standard error) = 0.0157 (0.0017)
Coefficient of determination = 0.4037

Table 7-12. Analytical results for floor sweepings (B3-C18)

Sample number	No. g sample	Liq/sol ratio	(μg/mL) Conc. U (ppm)	(μg/mL) Aver	Percentage Leach effic.	Percentage Aver
1L	5	100	26.6		2.46	
2L	5	100	8.38	17.5	0.776	1.62
3L	10	50	76.8		3.56	
4L	10	50	92.8	84.8	4.30	3.93
5L	25	20	75.4		1.40	
6L	25	20	14.9	45.2	0.276	0.837
7L	50	10	87.2		0.807	
8L	50	10	53.6	70.4	0.496	0.652
9L	100	5	337.		1.56	
10L	100	5	300.	319.	1.39	1.48
11L	0	-	0.12			

Unleached solid U conc. = 108 mg/g.

Linear regression values for conc. U vs. number g sample:
Slope (standard error) = 2.4859 (0.5279)
Intercept (standard error) = 28.1648 (17.9260)
Coefficient of determination = 0.7349

Table 7-13. Analytical results for carbon (B4-C16)

Sample number	No. g sample	Liq/sol ratio	(μg/mL) Conc. U	Aver	Percentage Leach effic.	Aver
1L	5	100	0.16		27.7	
2L	5	100	0.11	0.135	19.0	23.4
3L	10	50	0.33		28.5	
4L	10	50	0.72	0.525	62.3	45.4
5L	25	20	0.81		28.	
6L	25	20	0.75	0.78	26.	27.
7L	50	10	0.96		16.6	
8L	50	10	1.56	1.26	27.	21.8
9L	100	5	4.70		40.7	
10L	100	5	13.1	8.9	113.	77.
11L	0	--	0.035		--	

Unleached solid U conc. = 57.8 μg/g.

Linear regression values for conc. U vs. number g sample:
Slope (standard error) = 0.0318 (0.0020)
Intercept (standard error) = -0.0193 (0.0342)
Coefficient of determination = 0.9678

Table 7-14. Analytical results for blotter paper (B4-C14)

Sample number	No. g sample	Liq/sol ratio	(μg/mL) Conc. U	Aver	Percentage Leach effic.	Aver
1L	5	100	0.22		293	
2L	5	100	0.12	0.17	160	226
3L	10	50	0.11		73	
4L	10	50	0.14	0.125	93	83
5L	25	20	0.19		51	
6L	25	20	0.19	0.19	51	51
7L	50	10	0.35		47	
8L	50	10	0.26	0.305	35	41
9L	100	5	0.38		25	
10L	100	5	0.37	0.375	25	25
11L	0	--	0.037		--	

Unleached solid U conc. = 2.42 μg/g.

Linear regression values for conc. U vs. number g sample:
Slope (standard error) = 0.0025 (0.0001)
Intercept (standard error) = 0.1280 (0.0019)
Coefficient of determination = 0.9934

Table 7-15. Analytical results for mixed metal chips (B4-C15)

			(μg/mL)		Percentage	
Sample number	No. g sample	Liq/sol ratio	Conc. U	Aver	Leach effic.	Aver
1L	5	100	0.53		2172.	
2L	5	100	0.030	0.28	123.	1150.
3L	10	50	0.027		55.3	
4L	10	50	0.20	0.114	410.	234.
5L	25	20	0.26		213.	
6L	25	20	0.034	0.15	27.9	123.
7L	50	10	0.037		15.2	
8L	50	10	0.13	0.084	53.3	34.4
9L	100	5	0.13		26.6	
10L	100	5	0.064	0.097	13.1	19.9
11L	0	--	1.70 x 10^{-5}		--	

Unleached solid U conc. = 2.44 μg/g.

Linear regression values for conc. U vs. number g sample:
Slope (standard error) = -0.0002 (0.0007)
Intercept (standard error) = 0.1154 (0.0524)
Coefficient of determination = 0.0148

Table 7-16. Analytical results for floor sweepings (B4-C13)

Sample number	No. g sample	Liq/sol ratio	(μg/mL) Conc. U	Aver	Percentage Leach effic.	Aver
1L	5	100	66.		4.71	
2L	5	100	254.	160	18.1	11.4
3L	10	50	228.		8.13	
4L	10	50	201.	215	7.17	7.65
5L	25	20	187.		2.67	
6L	25	20	95.	141	1.35	2.01
7L	50	10	129.		0.920	
8L	50	10	119.	124	0.848	0.884
9L	100	5	298.		1.06	
10L	100	5	382.	340	1.36	1.20
11L	0	--	0.15		--	

Unleached solid U conc. = 140 mg/g.

Linear regression values for conc. U vs. number g sample:
Slope (standard error) = -1.1550 (0.8384)
Intercept (standard error) = 190.1290 (40.0651)
Coefficient of determination = 0.1917

Table 7-17. Concentration of Uranium in Unleached Solid Samples (μg U/g sample)

	1	2	3	4	Mean	SD	RSD
Floor sweepings	2.77×10^4	3.59×10^5	108×10^3	140×10^5	1.59×10^5	1.42×10^4	89%
Metal chips	122	722	3.79	2.44	213	298	140%
Carbon	78.3	2.5×10^4	1.3×10^4	57.8	9.53×10^3	1.20×10^4	126%
Blotter paper	59.5	0.22	20.7	7.52	22.0	26.4	120%

Table 7-18. Mass Balance Ratios
Mass balance ratio*

	Batch one	Batch two	Batch three	Batch four
Carbon	3.48	0.00313	0.019	0.378
Blotter paper	1.08	21.5	0.228	0.84
Mixed metal chips	0.065	0.333	1.18	2.47
Floor sweepings	0.253	1.00	1.27	0.151

*Mass balance ratio =

$$\frac{[(U)\text{lch.lqd.} \times (\text{vol.})\text{lch.lqd}] + [(U)\text{lch.sol.} \times (\text{wt.})\text{lch.sol.}]}{(U)\text{unlch.sol.} \times (\text{wt})\text{unlch.sol.}}$$

Table 7-19. Concentration of RCRA Metals in Leachates of Carbon.

	Ag	As	Ba	Cd	Cr	Pb	Se
TCLP max.	5.0	5.0	100.0	1.0	5.0	5.0	1.0
1st batch - 5	<0.036	<0.36	0.088	<0.012	<0.036	<0.30	<0.36
- 6	<0.036	<0.36	0.081	<0.012	<0.036	<0.30	<0.36
2nd batch - 5	<0.13	<1.3	0.068	0.057	<0.13	<1.0	<1.3
- 6	<0.13	<1.3	0.078	0.090	<0.13	<1.0	<1.3
3rd batch - 5	<0.036	<0.36	0.035	<0.012	<0.26	<0.3	<0.36
- 6	<0.036	<0.36	0.035	<0.012	<0.27	<0.3	<0.36
4th batch - 5	<0.036	<0.036	0.042	<0.012	<0.036	<0.30	<0.36
- 6	<0.036	<0.036	0.044	<0.012	<0.036	<0.30	<0.36

Note: Results are from liquid/solid of 20:1; all values are in μg/mL.

Table 7-20. Conconcentration of RCRA Metals in Leachates of Blotter Paper

	Ag	As	Ba	Cd	Cr	Pb	Se
TCLP max.	5.0	5.0	100.0	1.0	5.0	5.0	1.0
1st batch - 5	<0.036	<0.036	0.044	<0.012	<0.036	<0.30	<0.36
- 6	<0.036	<0.036	0.051	0.016	<0.036	<0.30	<0.36
2nd batch - 5	<0.036	<0.036	0.045	0.021	<0.036	<0.30	<0.36
- 6	<0.036	<0.036	0.043	<0.012	<0.036	<0.30	<0.36
3rd batch - 5	<0.006	<0.06	0.05	0.0025	0.0061	0.057	<0.06
- 6	<0.006	<0.06	0.046	0.0027	0.0084	0.055	<0.06
4th batch - 5	<0.036	<0.036	0.12	0.015	<0.036	<0.30	<0.36
- 6	<0.036	<0.036	0.12	<0.012	<0.036	<0.30	<0.36

Note: Results are from liquid/solid of 20:1; all values are in μg/mL.

Table 7-21. Concentration of RCRA metals in Leachates of Mixed Metal Chips

	Ag	As	Ba	Cd	Cr	Pb	Se
TCLP max.	5.0	5.0	100.0	1.0	5.0	5.0	1.0
1st batch - 5	0.0106	<0.06	0.0604	<0.002	0.0110	<0.05	0.157
- 6	0.00984	<0.06	0.0607	<0.002	0.0117	<0.05	0.137
2nd batch - 5	<0.066	<0.66	0.097	<0.022	<0.066	<0.55	<0.66
- 6	<0.066	<0.66	0.084	<0.022	<0.066	<0.55	<0.66
3rd batch - 5	<0.036	<0.36	0.090	0.016	0.27	<0.30	<0.36
- 6	<0.036	<0.36	0.012	0.029	0.31	<0.30	<0.36
4th batch - 5	<0.036	<0.36	0.054	0.016	0.045	0.30	<0.36
- 6	<0.036	<0.36	0.055	0.020	0.047	0.30	<0.36

Note: Results are from liquid/solid of 20:1; all values are in μg/mL.

Table 7-22. Concentration of RCRA Metals in Leachates of Floor Sweepings

		Ag	As	Ba	Cd	Cr	Pb	Se
TCLP max.		5.0	5.0	100.0	1.0	5.0	5.0	1.0
1st batch	- 5	0.017	<0.06	0.21	0.066	0.02	<0.05	<0.06
	- 6	0.029	0.10	0.16	0.081	<0.006	<0.05	
2nd batch	- 5	<0.036	<0.36	0.16	0.052	0.036	0.03	<0.36
	- 6	<0.036	<0.36	0.17	0.13	0.036	0.03	<0.36
3rd batch	- 5	0.083	<0.06	0.24	0.043	0.083	<0.05	0.092
	- 6	0.021	<0.06	0.25	0.069	0.012	<0.05	<0.06
4th batch	- 5	0.22	<0.36	0.25	<0.012	0.18	<0.30	<0.36
	- 6	0.22	<0.36	0.25	0.039	0.37	<0.30	<0.36

Note: Results are from liquid/solid of 20:1; all values are in μg/mL.

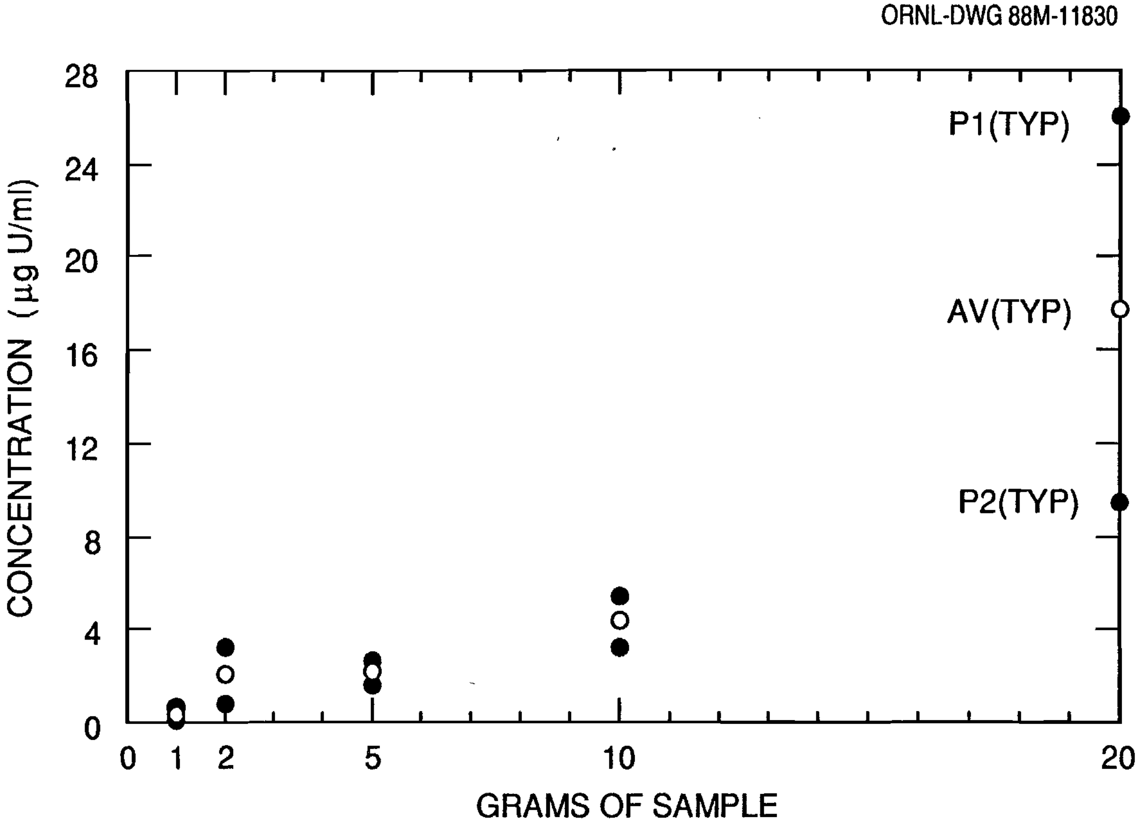

Figure 7-1. CARBON (B1 - C3)

ORNL-DWG 88M-11851

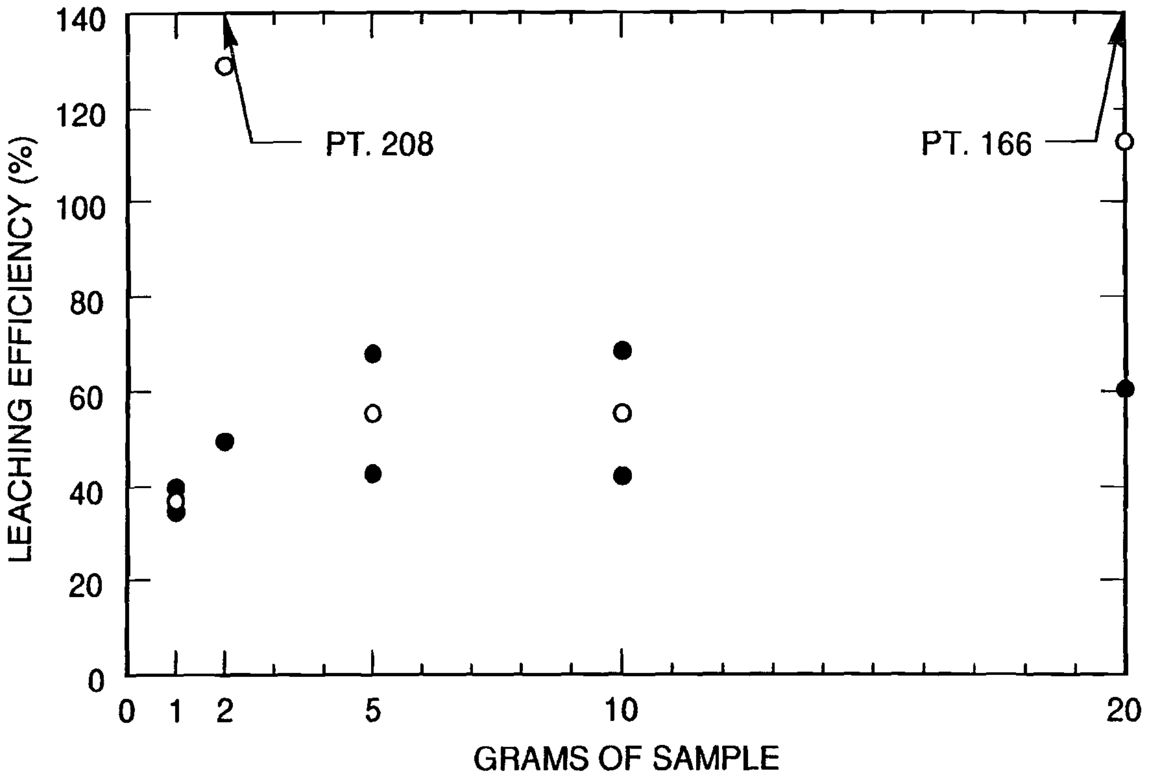

Figure 7-2. CARBON (B1 - C3)

ORNL-DWG 88M-11837

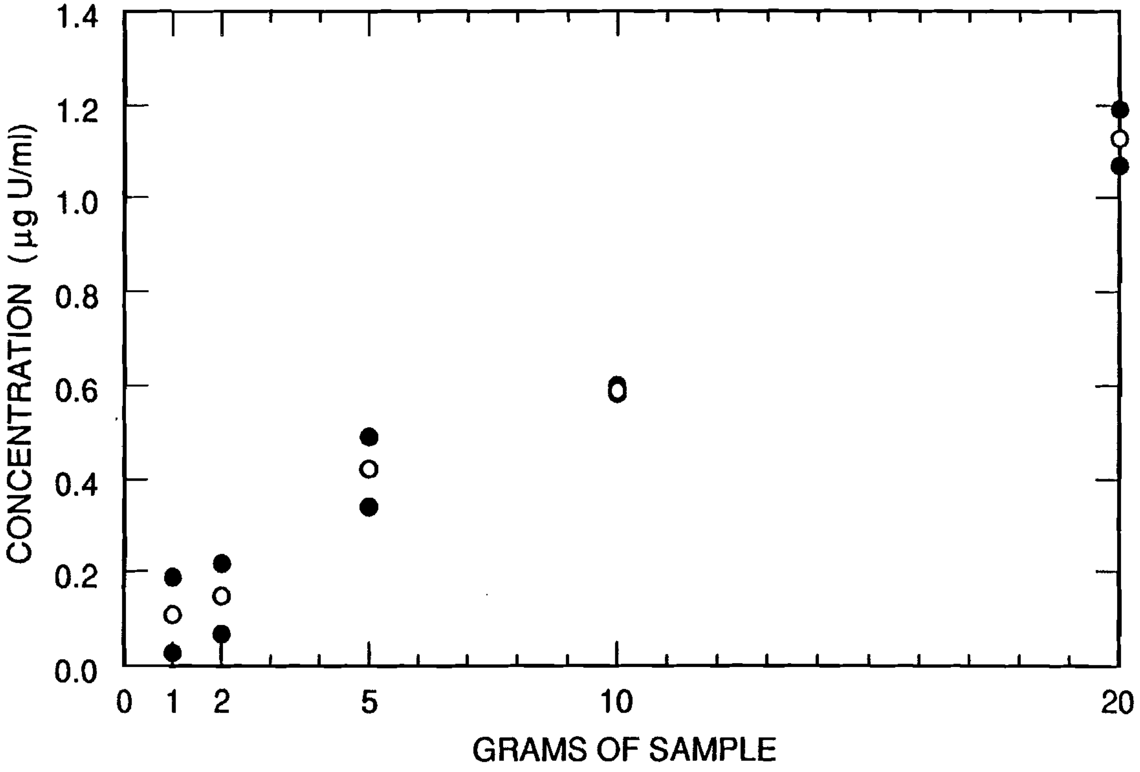

Figure 7-3. BLOTTER PAPER (B1 - C4)

ORNL-DWG 88M-11842

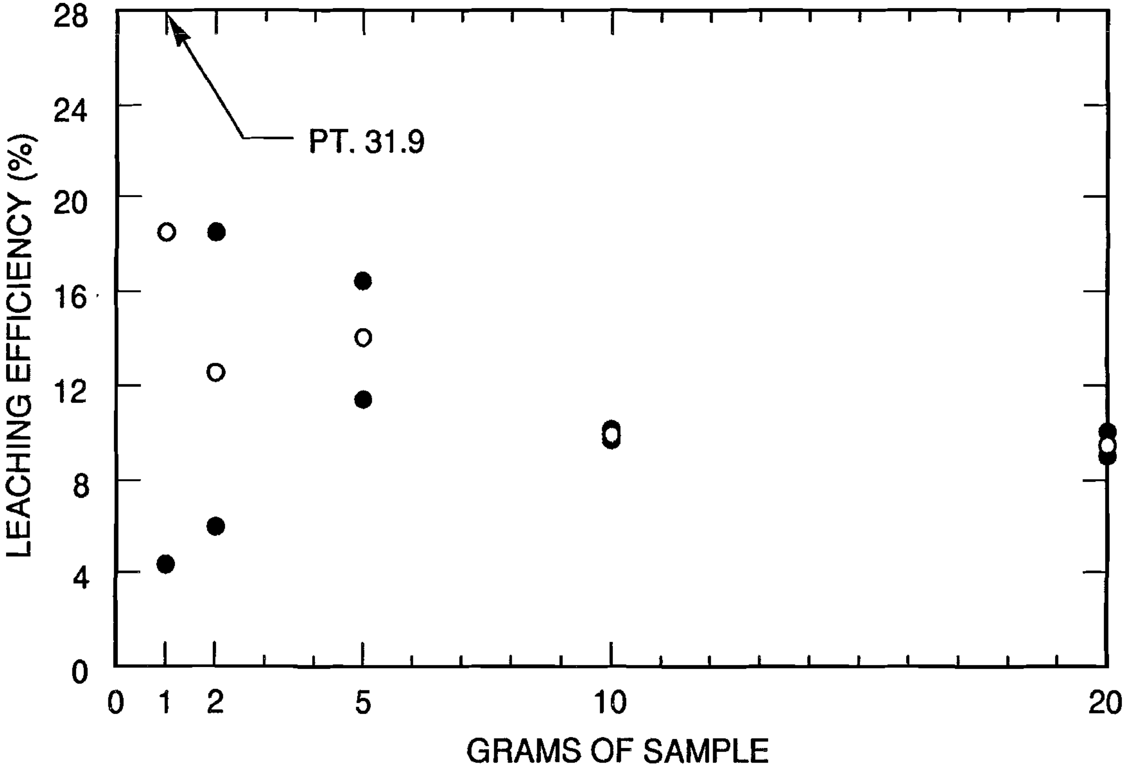

Figure 7-4. BLOTTER PAPER (B1 - C4)

ORNL-DWG 88M-11833

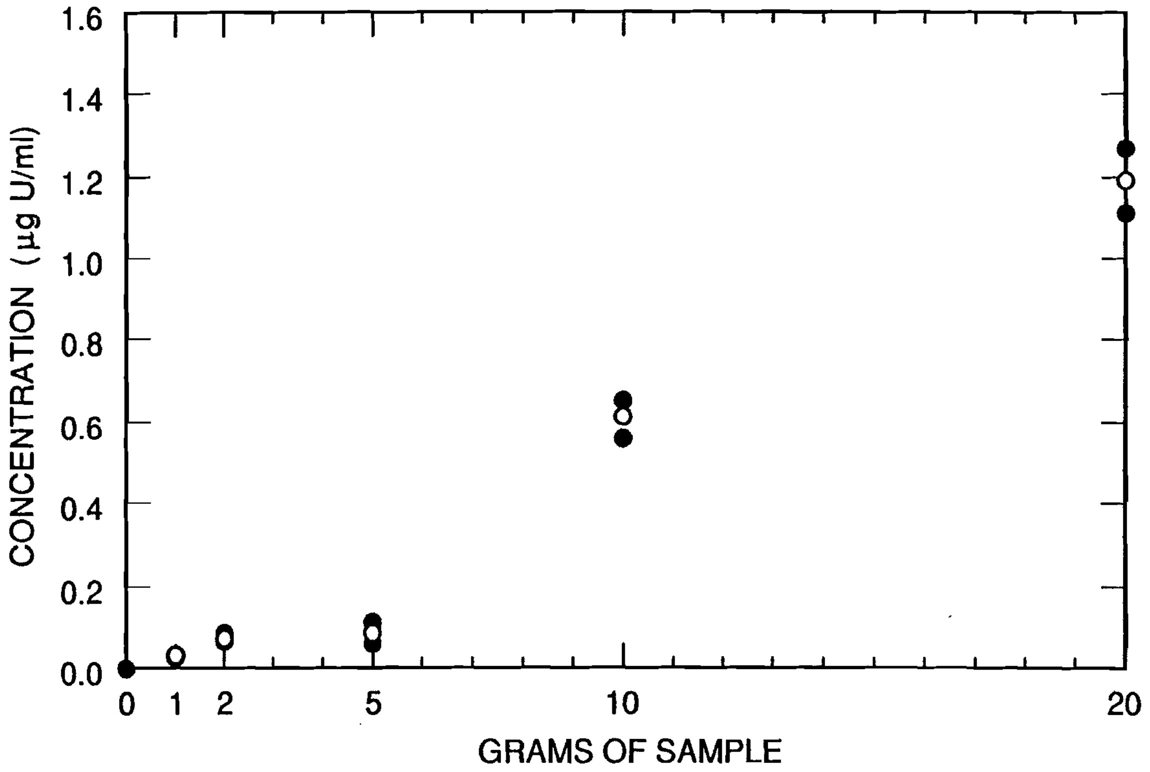

Figure 7-5. MIXED METAL CHIPS (B1 - C2)

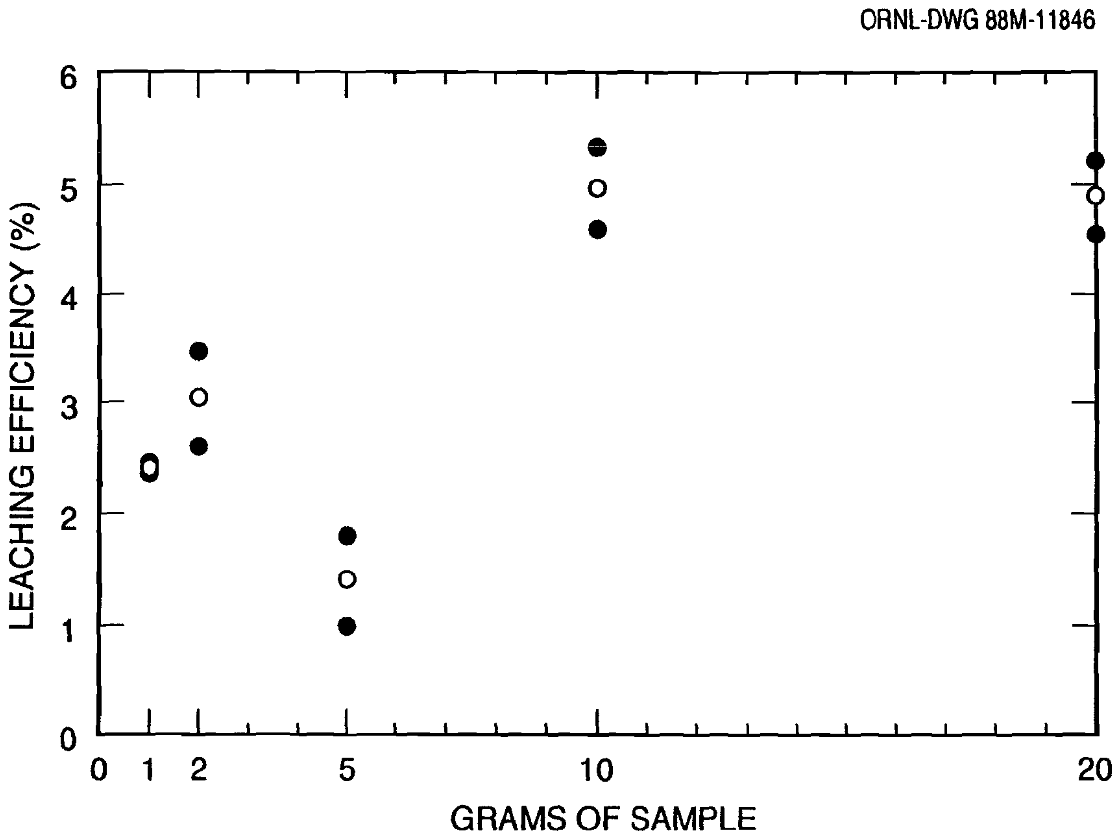

Figure 7-6. MIXED METAL CHIPS (B1 - C2)

ORNL-DWG 88M-11827

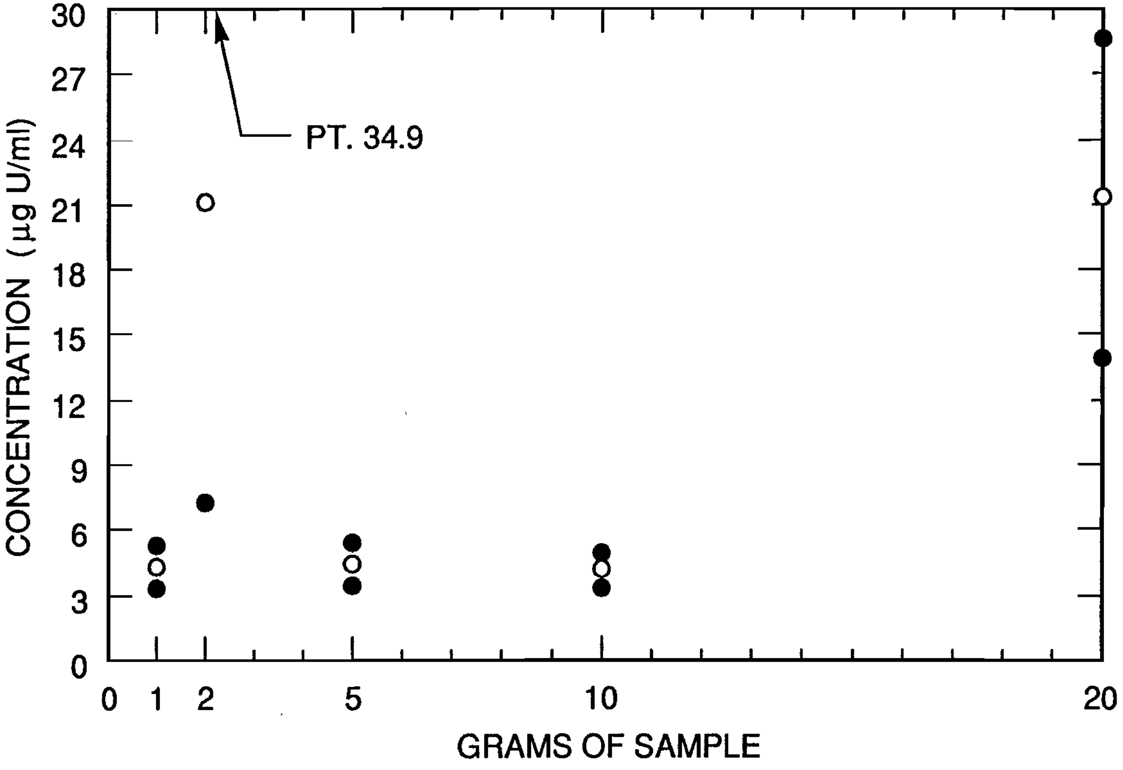

Figure 7-7. FLOOR SWEEPINGS (B1 - C1)

ORNL-DWG 88M-11847

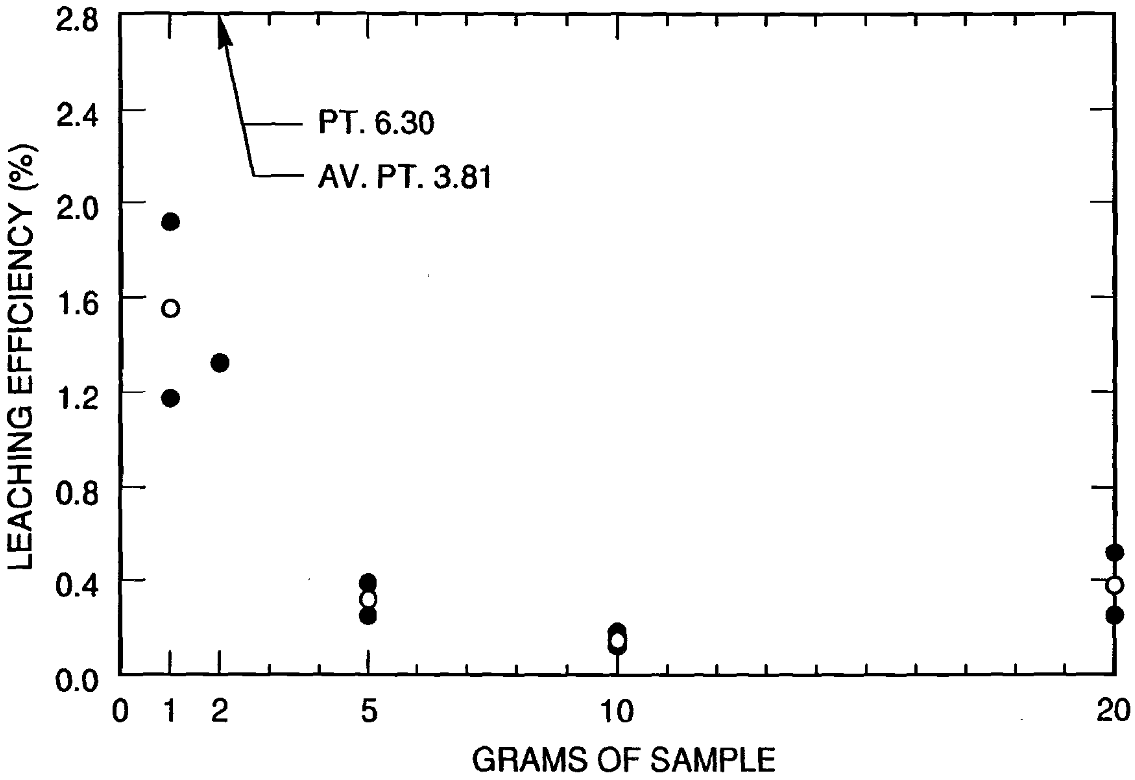

Figure 7-8. FLOOR SWEEPINGS (B1 - C1)

ORNL-DWG 88M-11831

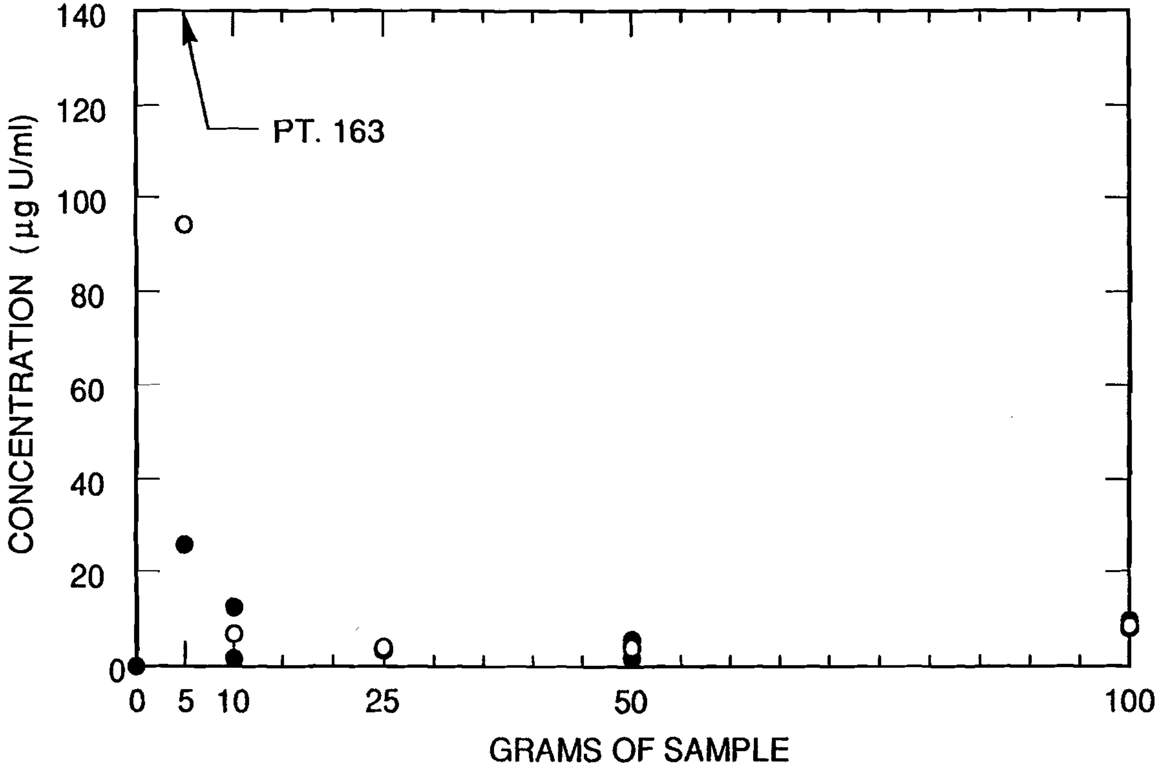

Figure 7-9. CARBON (B2 -C8)

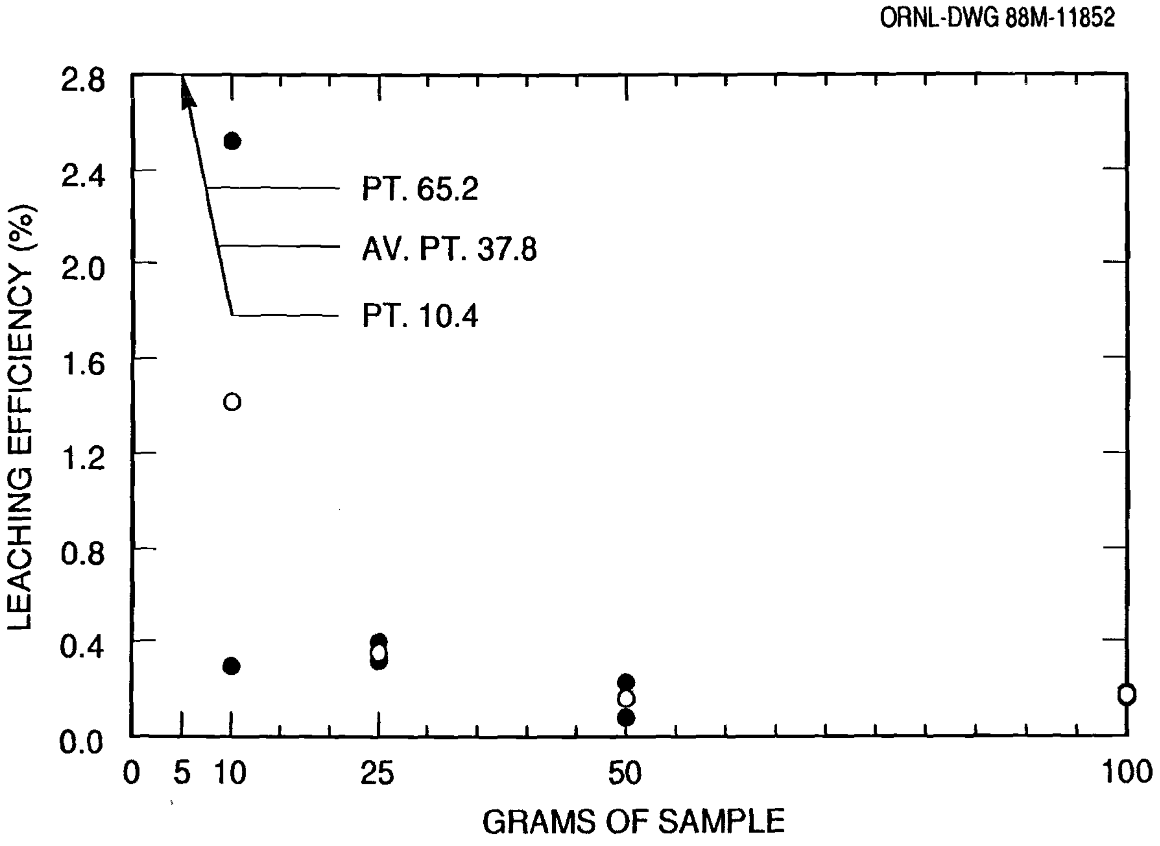

Figure 7-10. CARBON (B2 - C8)

ORNL-DWG 88M-11838

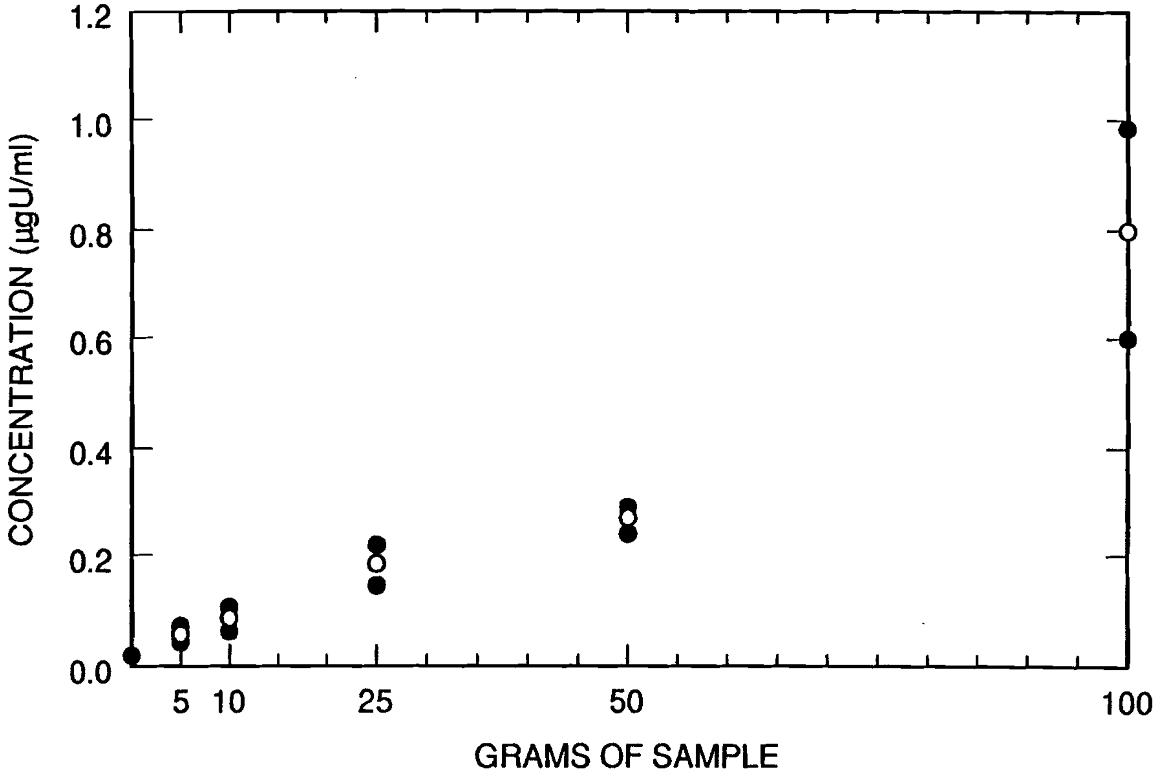

Figure 7-11. BLOTTER PAPER (B2-C6)

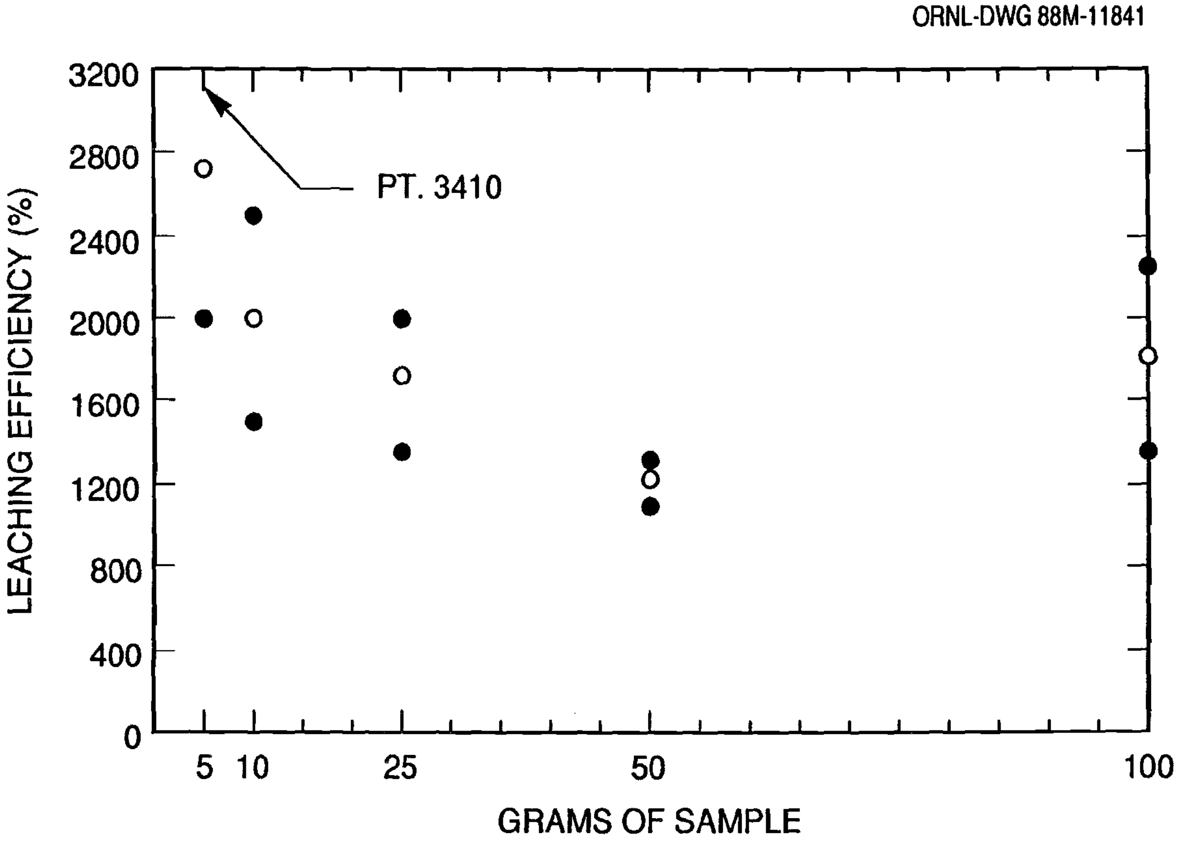

Figure 7-12. BLOTTER PAPER (B2-C6)

ORNL-DWG 88M-11834

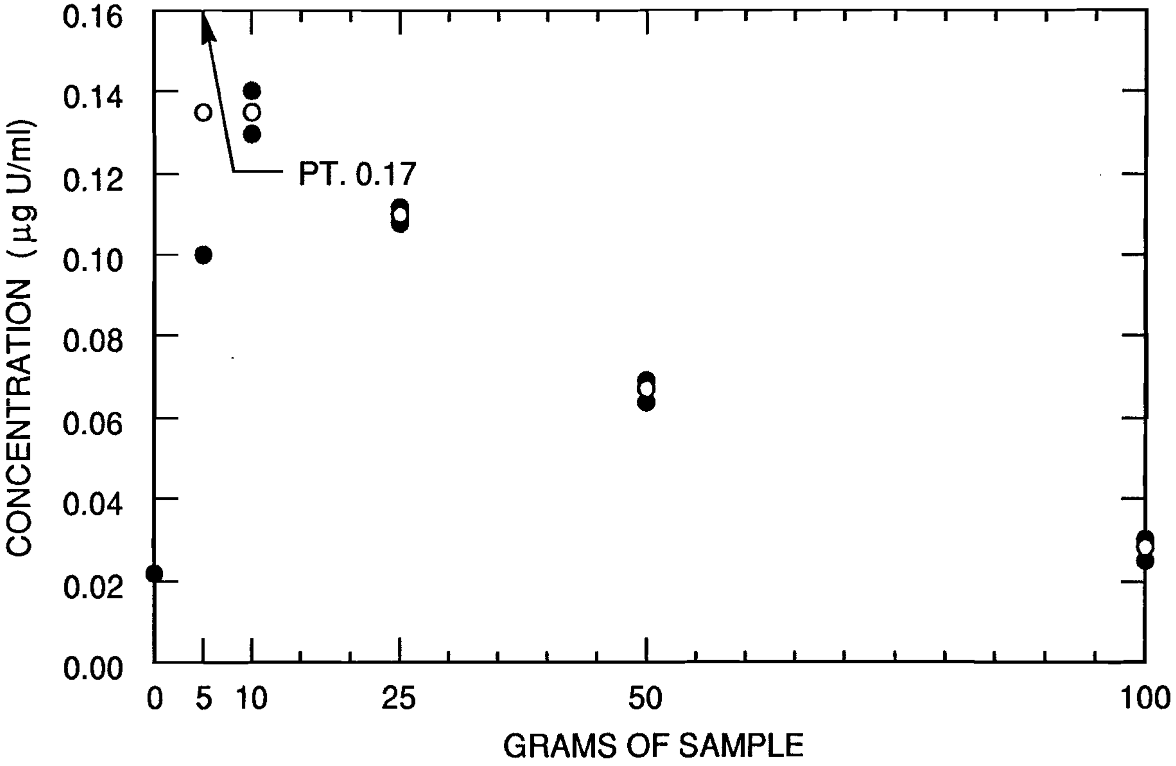

Figure 7-13. MIXED METAL CHIPS (B2 - C7)

ORNL-DWG 88M-11845

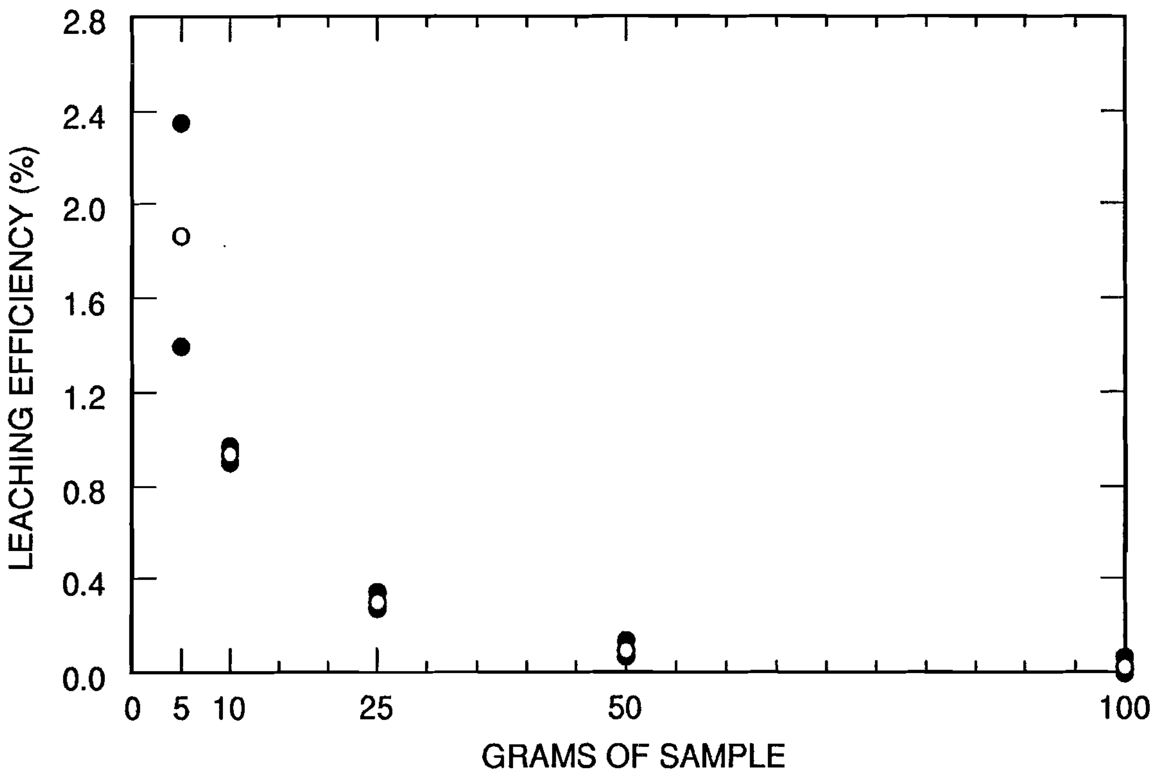

Figure 7-14. MIXED METAL CHIPS (B2 - C7)

ORNL-DWG 88M-11828

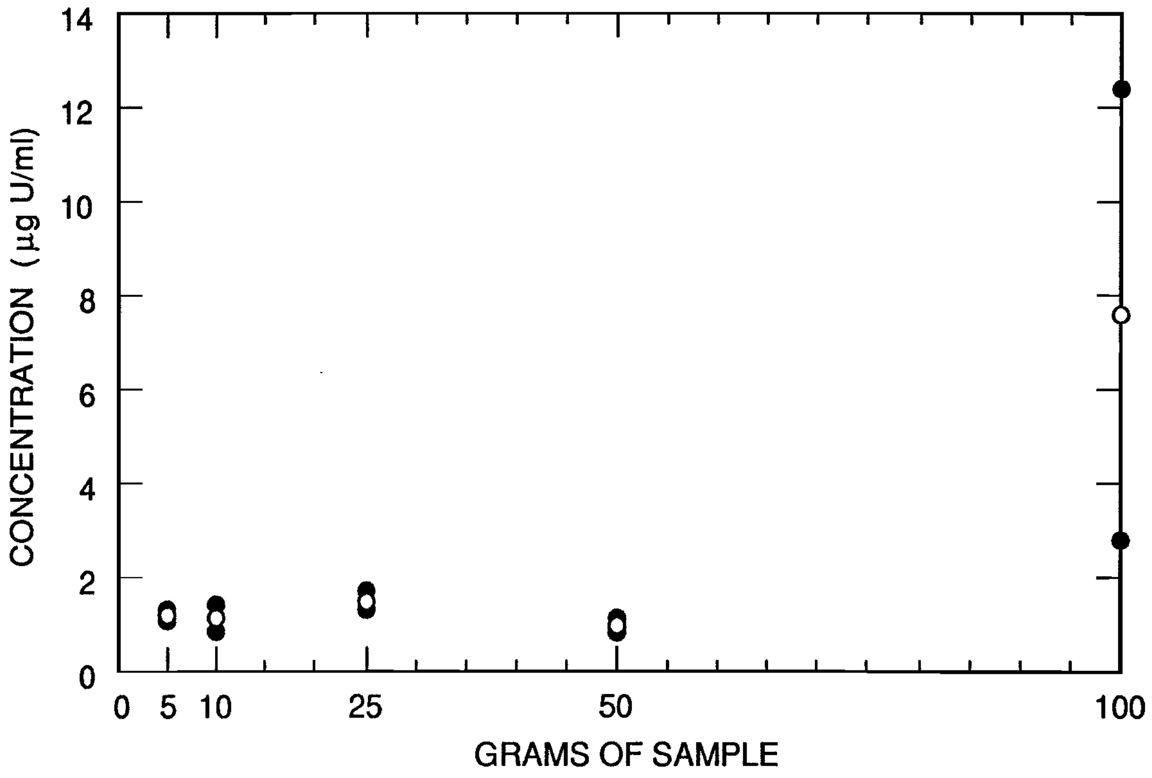

Figure 7-15. FLOOR SWEEPINGS (B2 - C5)

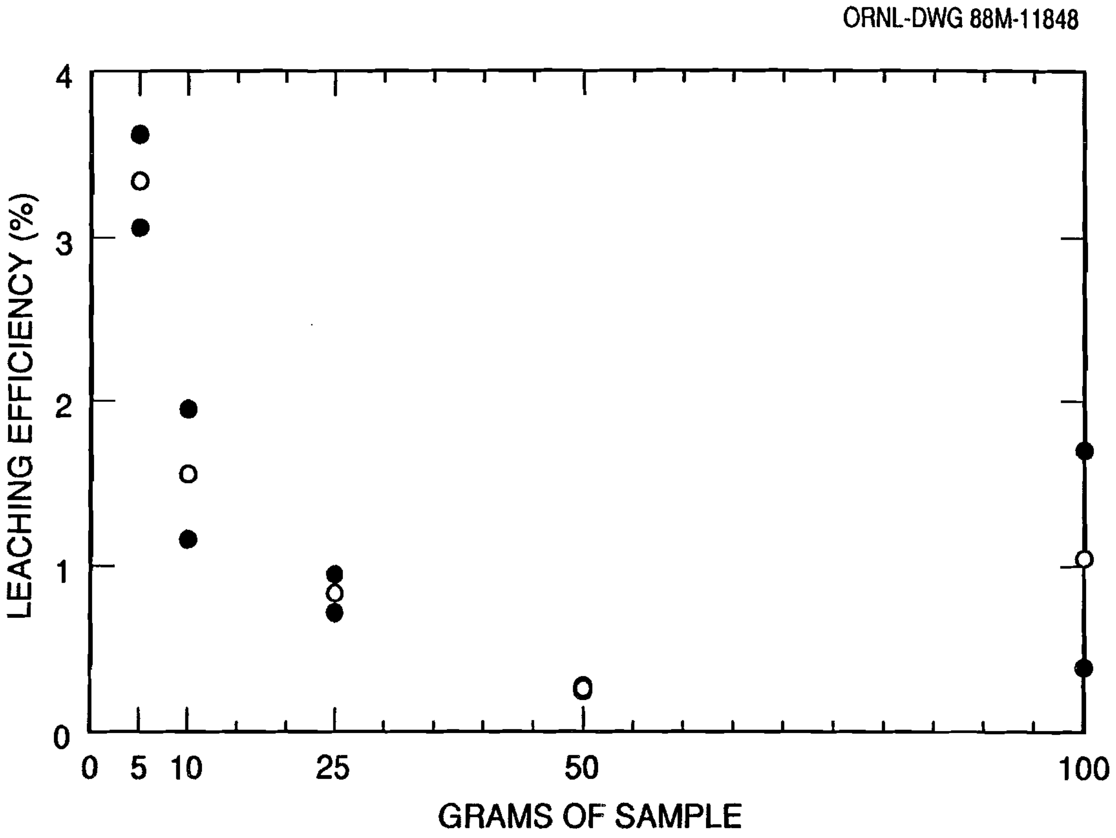

Figure 7-16. FLOOR SWEEPINGS (B2 - C5)

ORNL-DWG 88M-12119

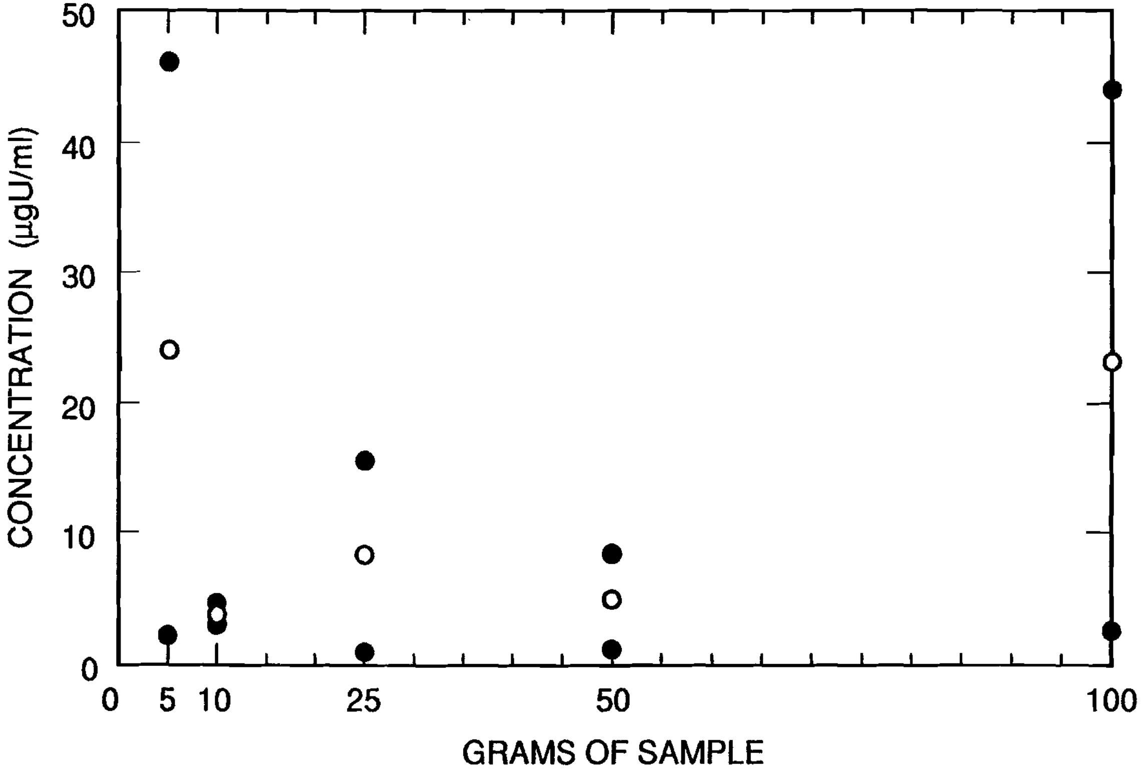

Figure 7-17. CARBON (B3-C11)

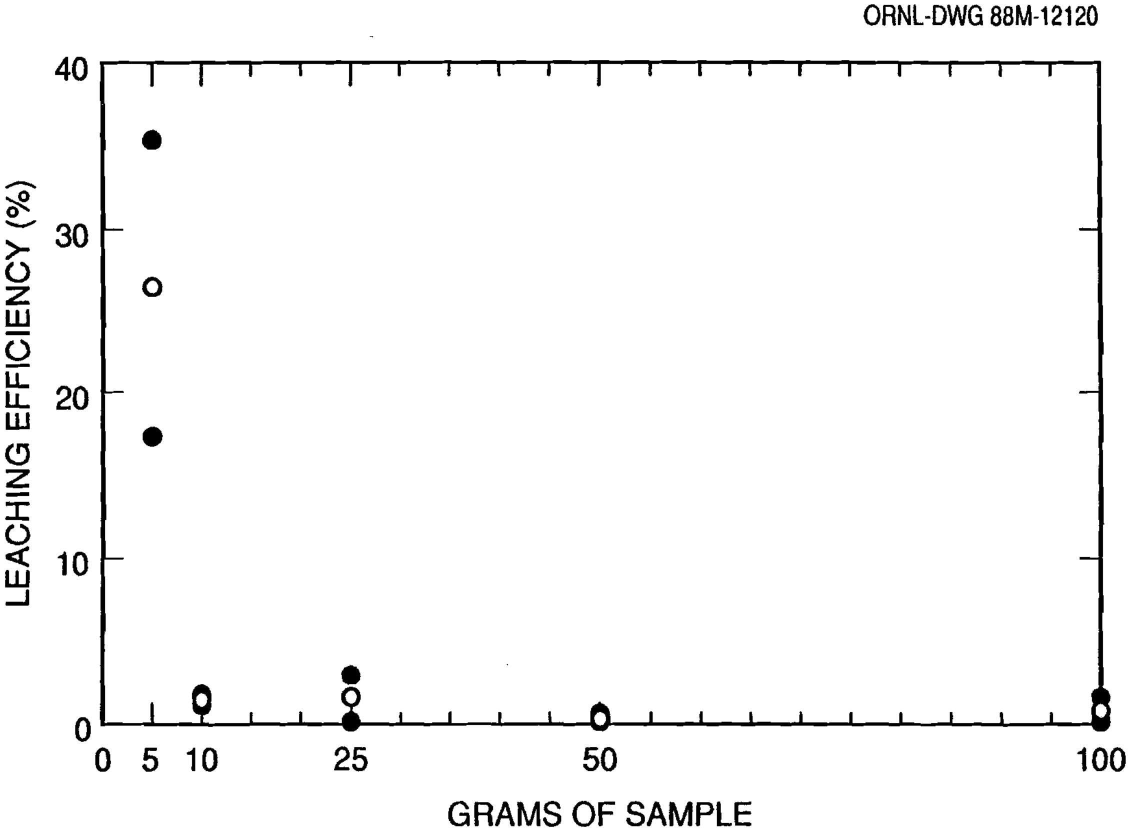

Figure 7-18. CARBON (B3-C11)

ORNL-DWG 88M-12121

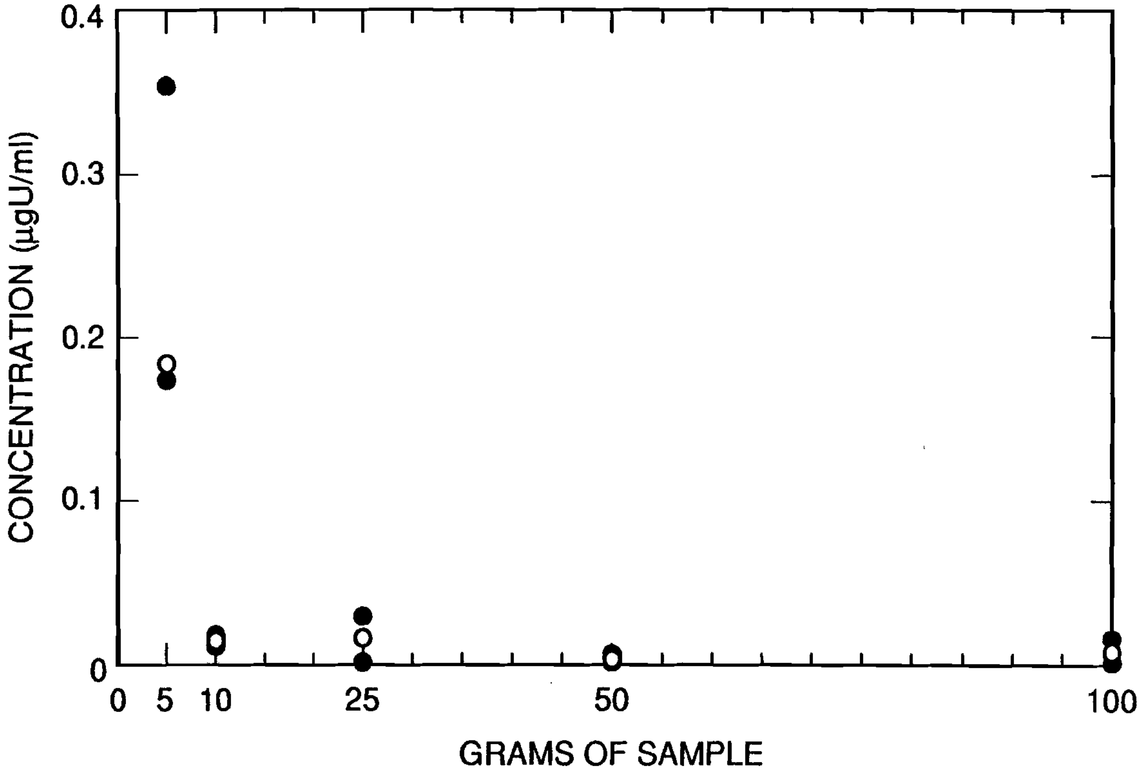

Figure 7-19. BLOTTER PAPER (B3-C17)

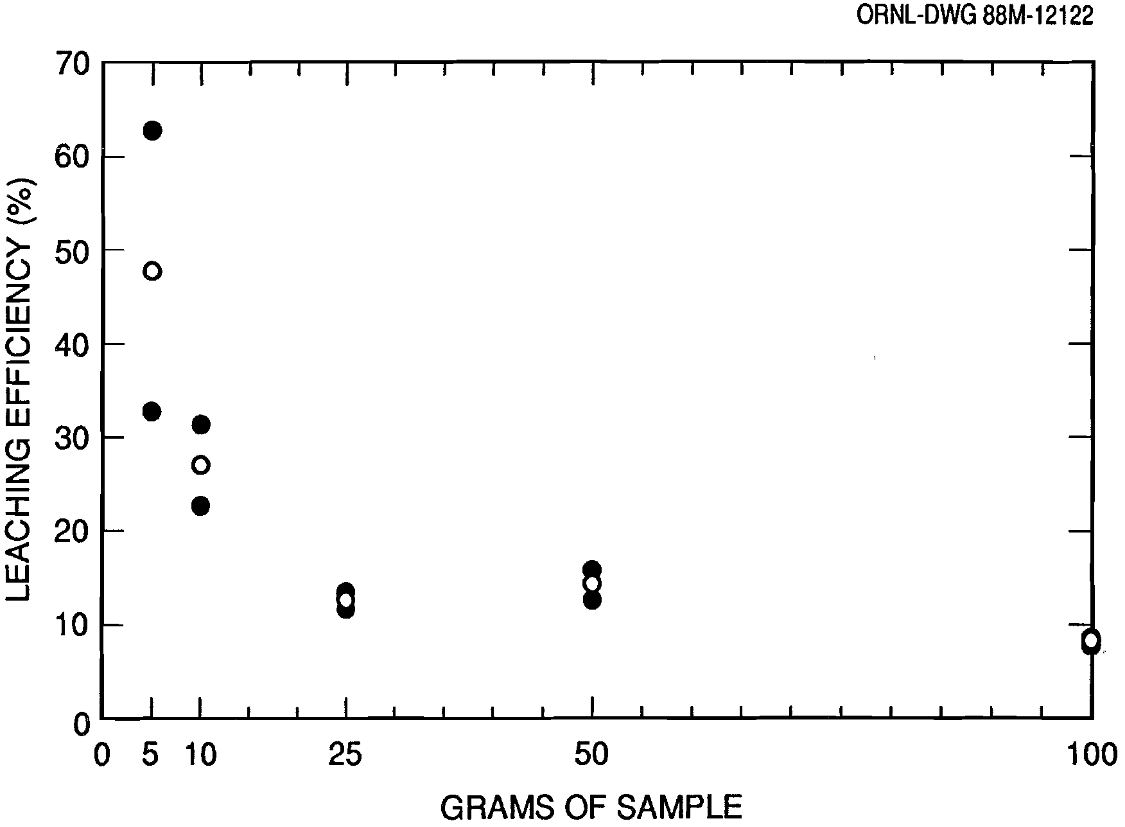

Figure 7-20. BLOTTER PAPER (B3-C17)

ORNL-DWG 88M-11835

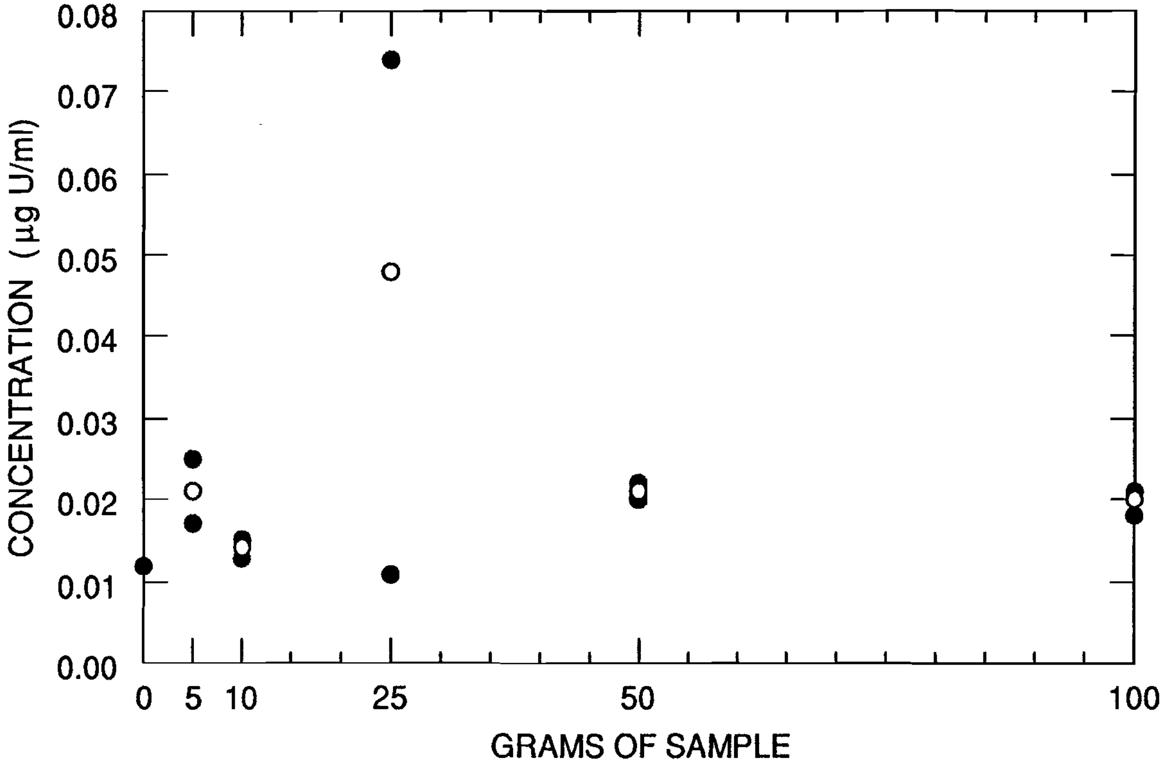

Figure 7-21. MIXED METAL CHIPS (B3 - C12)

ORNL-DWG 88M-11844

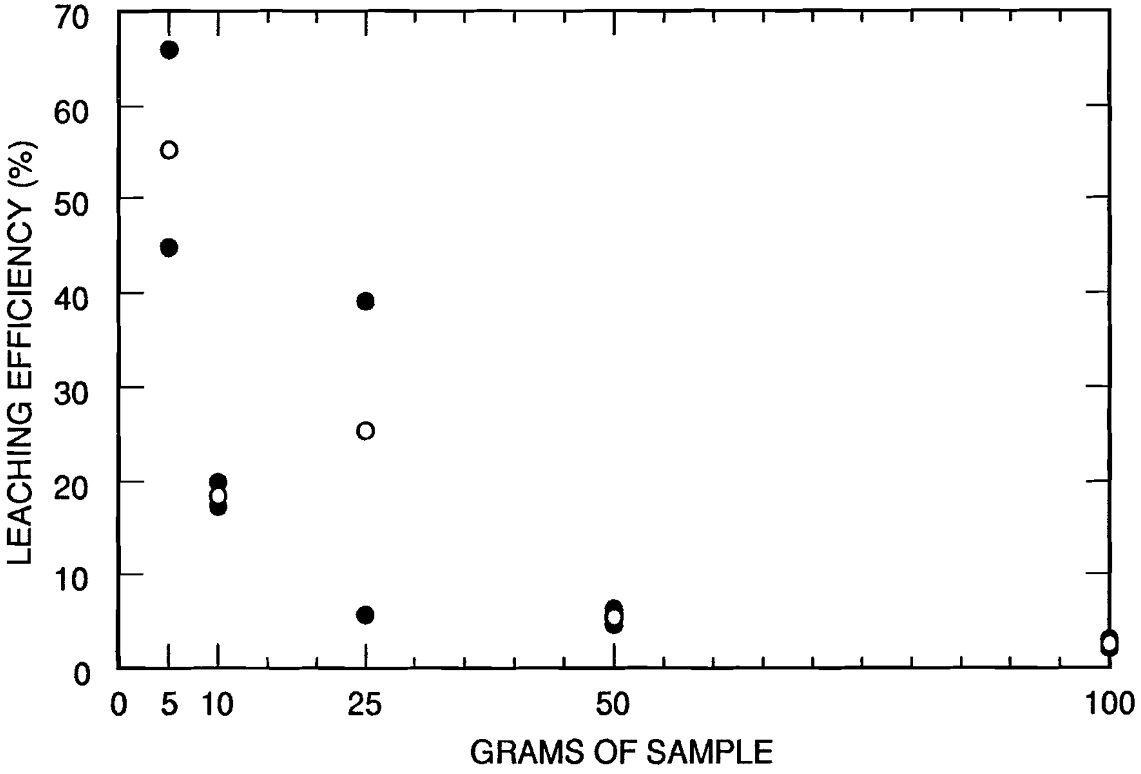

Figure 7-22. MIXED METAL CHIPS (B3 - C12)

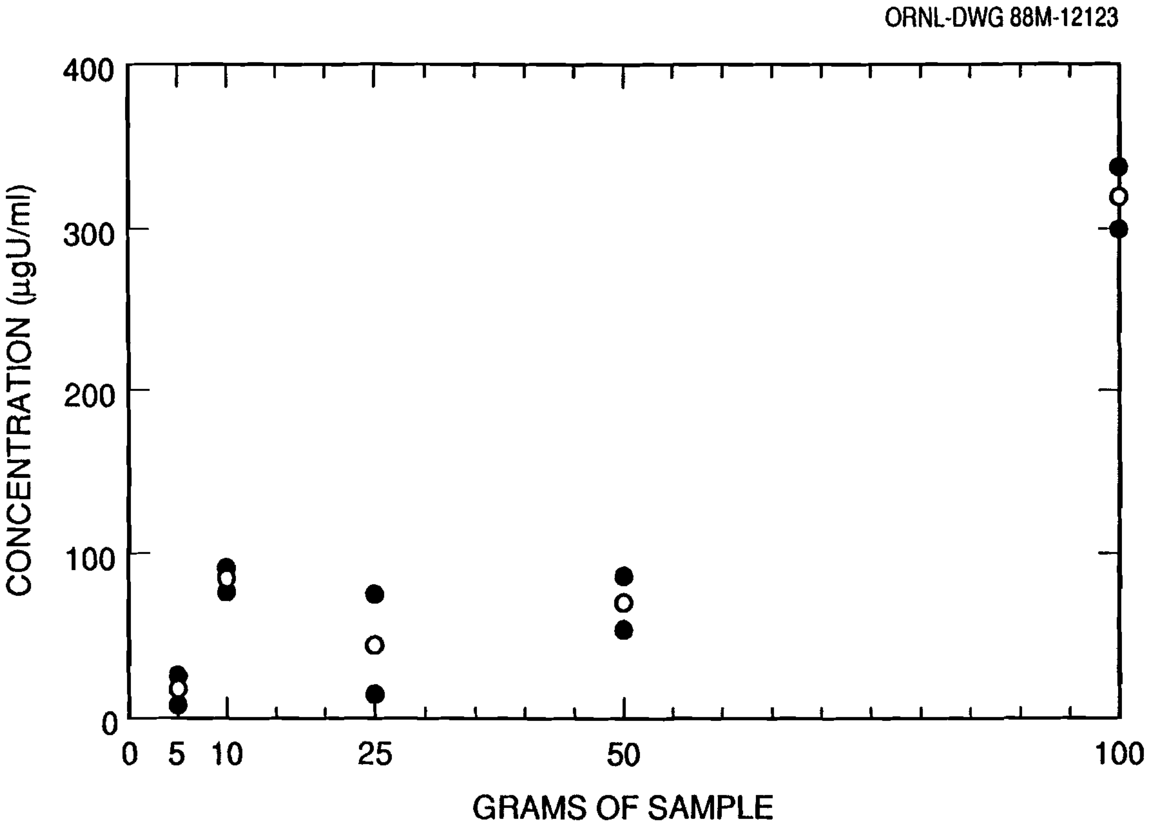

Figure 7-23. FLOOR SWEEPINGS (B3-C18)

ORNL-DWG 88M-12124

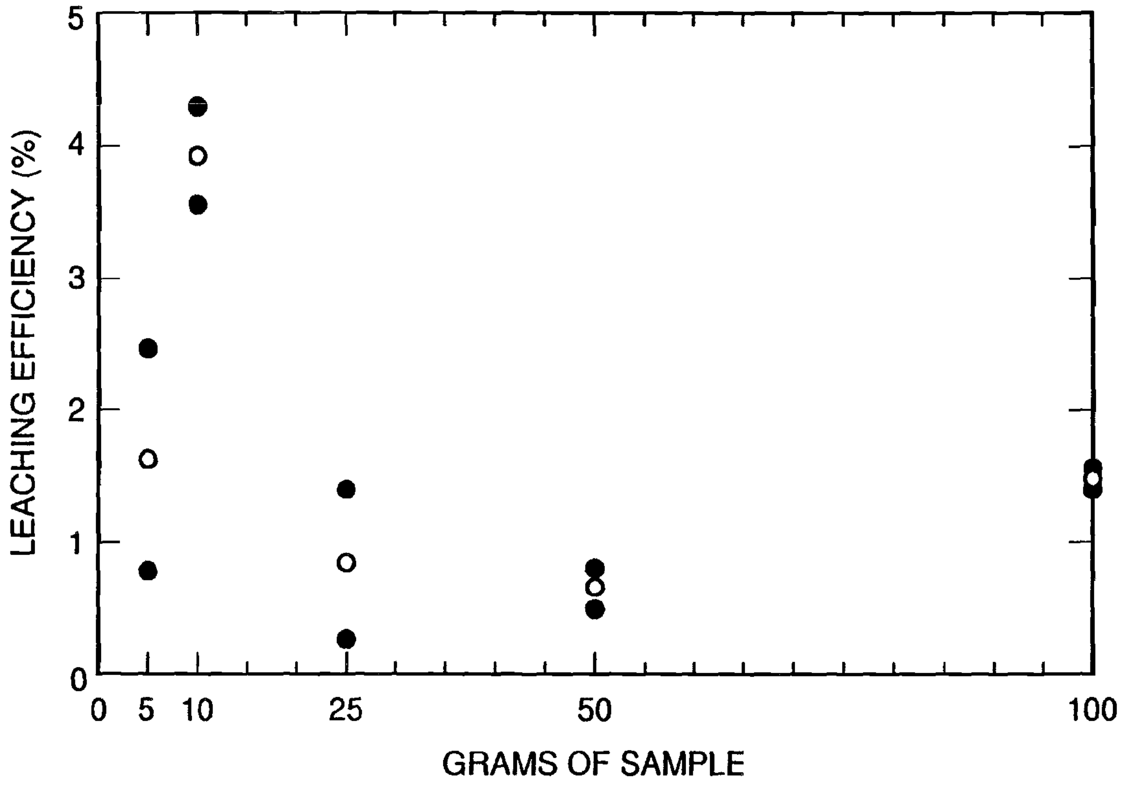

Figure 7-24. FLOOR SWEEPINGS (B3-C18)

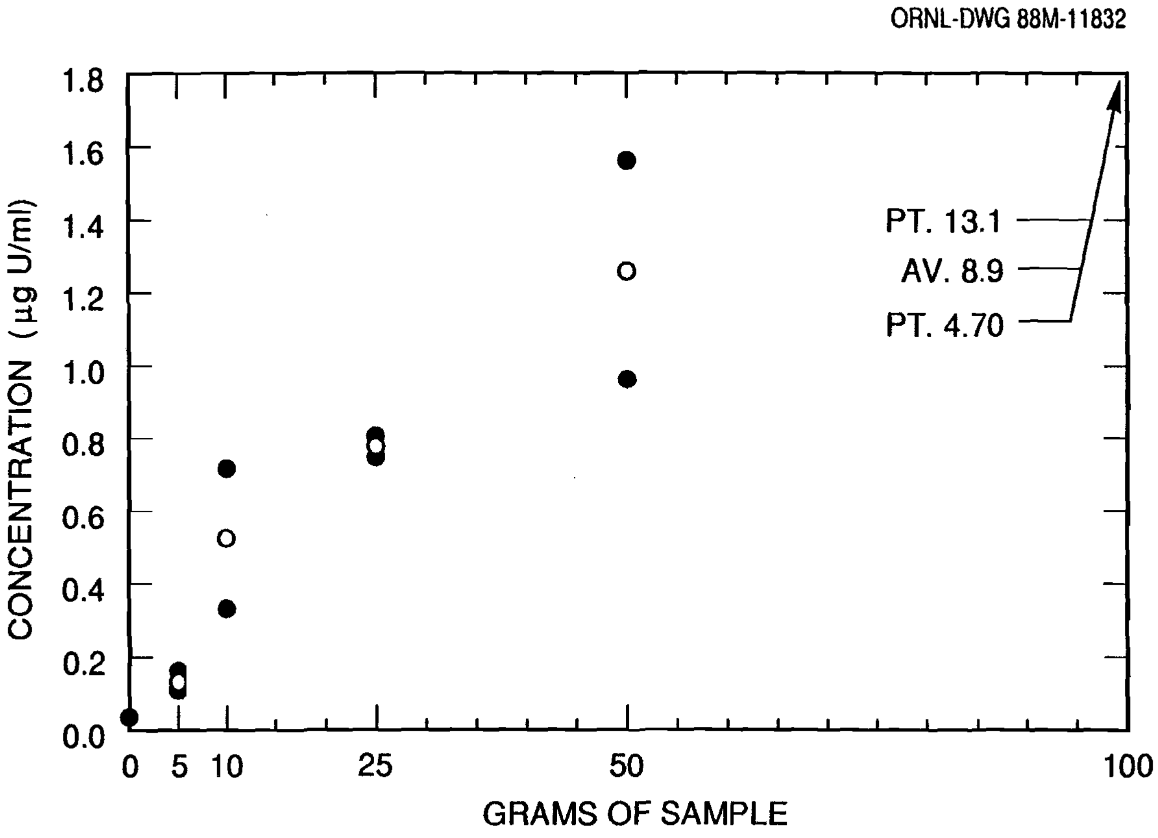

Figure 7-25. CARBON (B4 - C16)

ORNL-DWG 88M-11849

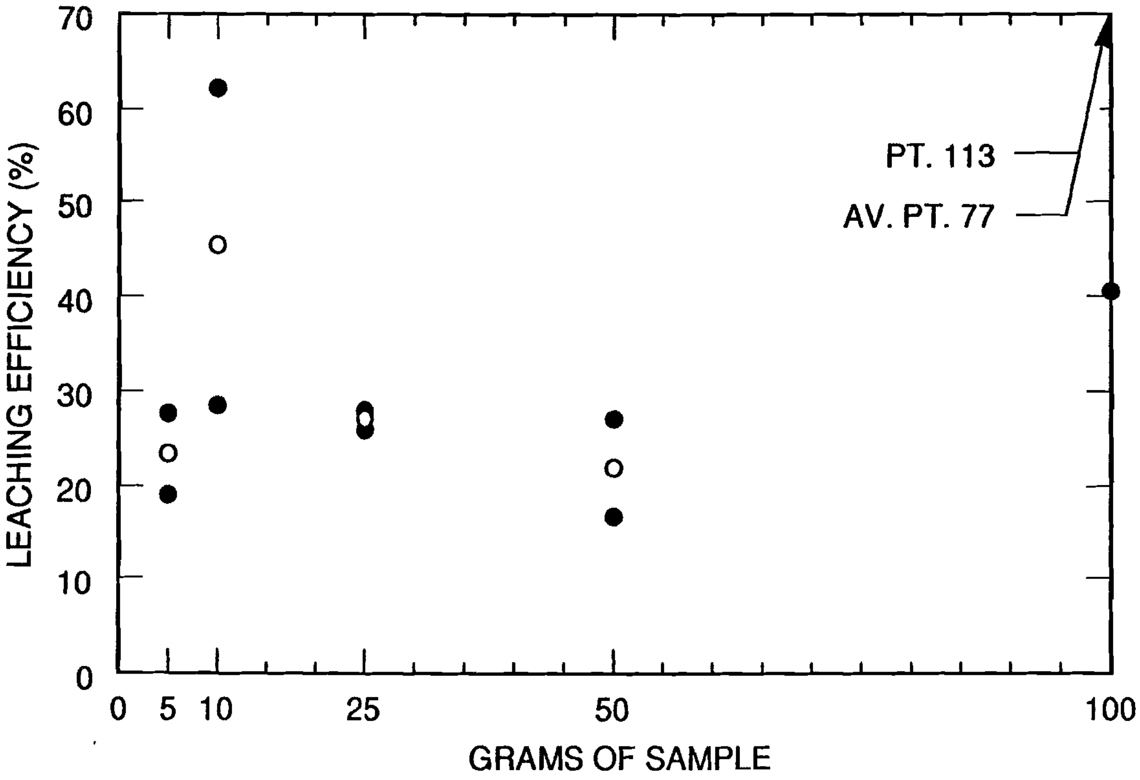

Figure 7-26. CARBON (B4 - C16)

ORNL-DWG 88M-11839

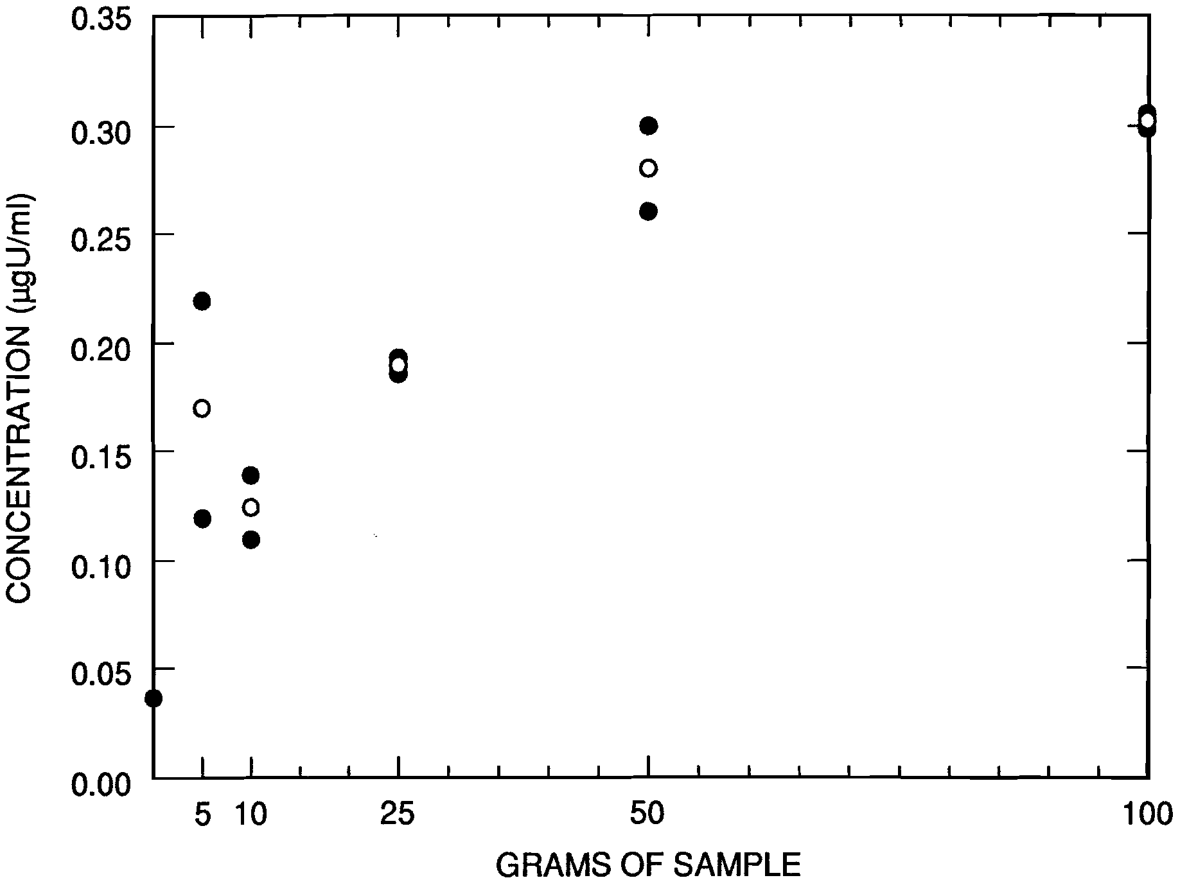

Figure 7-27. BLOTTER PAPER (B4-C14)

ORNL-DWG 88M-11840

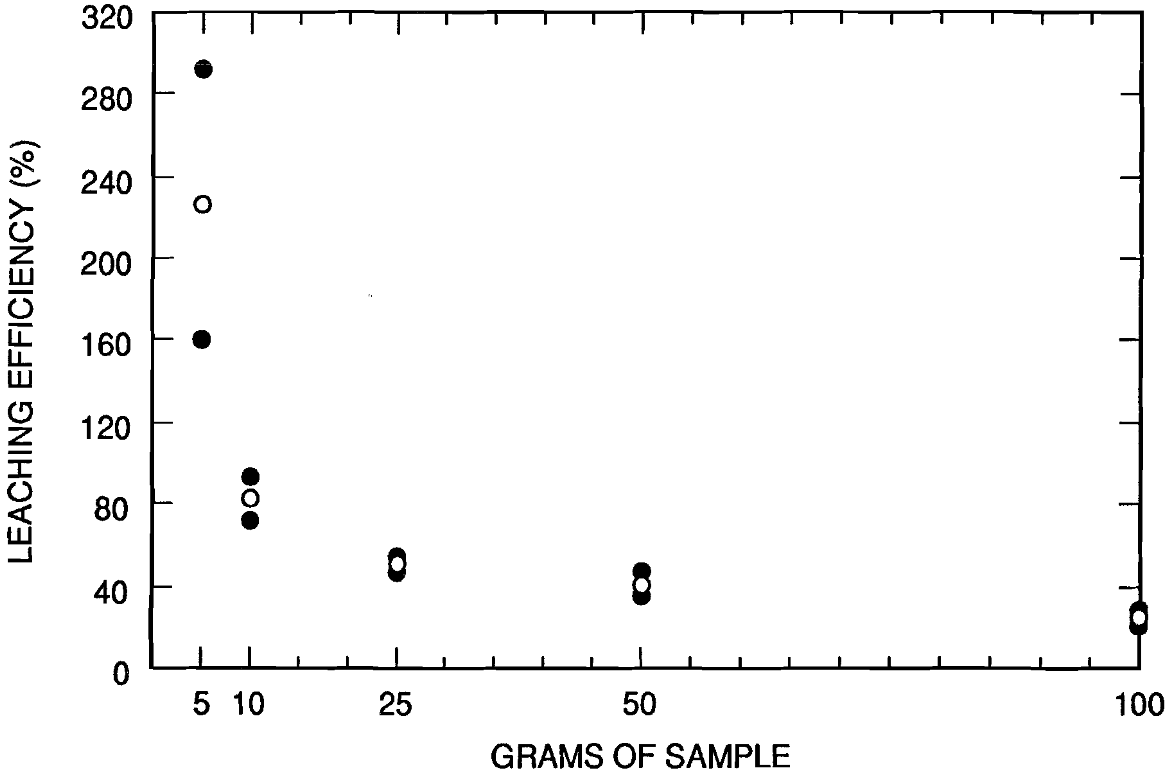

Figure 7-28. BLOTTER PAPER (B4-C14)

ORNL-DWG 88M-11836

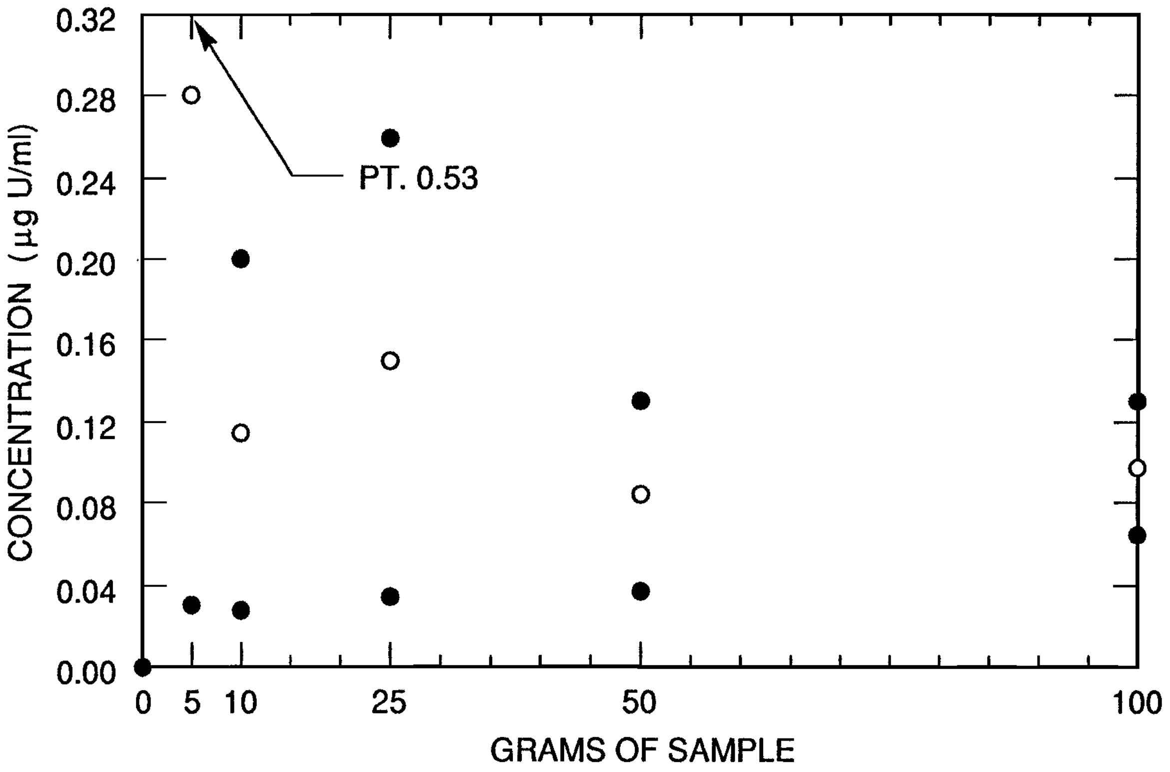

Figure 7-29. MIXED METAL CHIPS (B4 - C15)

ORNL-DWG 88M-11843

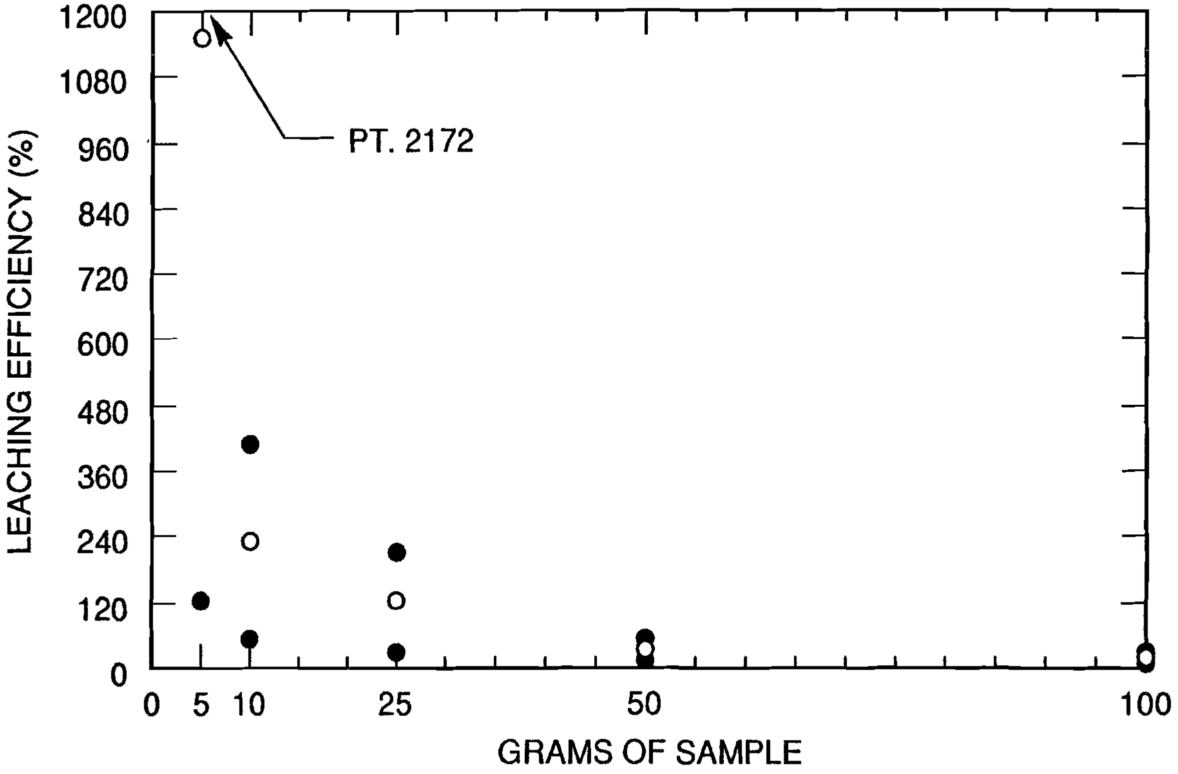

Figure 7-30. MIXED METAL CHIPS (B4 - C15)

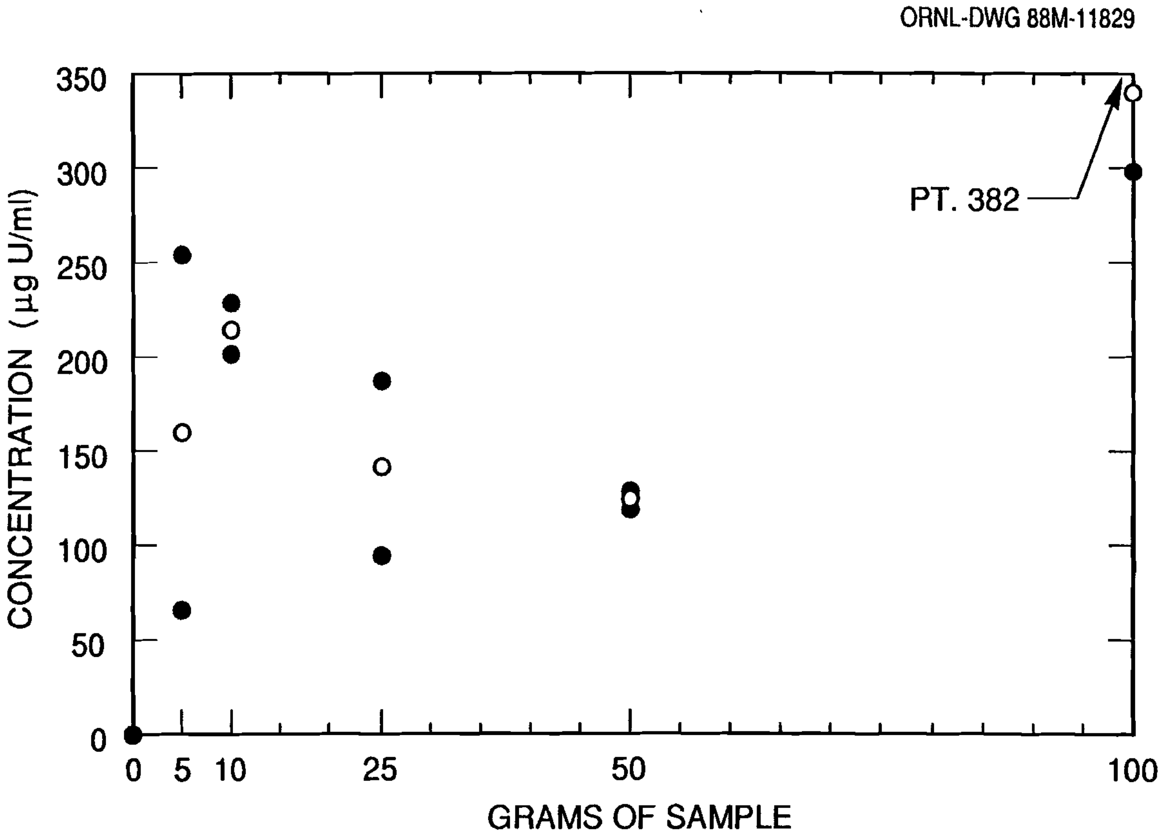

Figure 7-31. FLOOR SWEEPINGS (B4 - C13)

ORNL-DWG 88M-11850

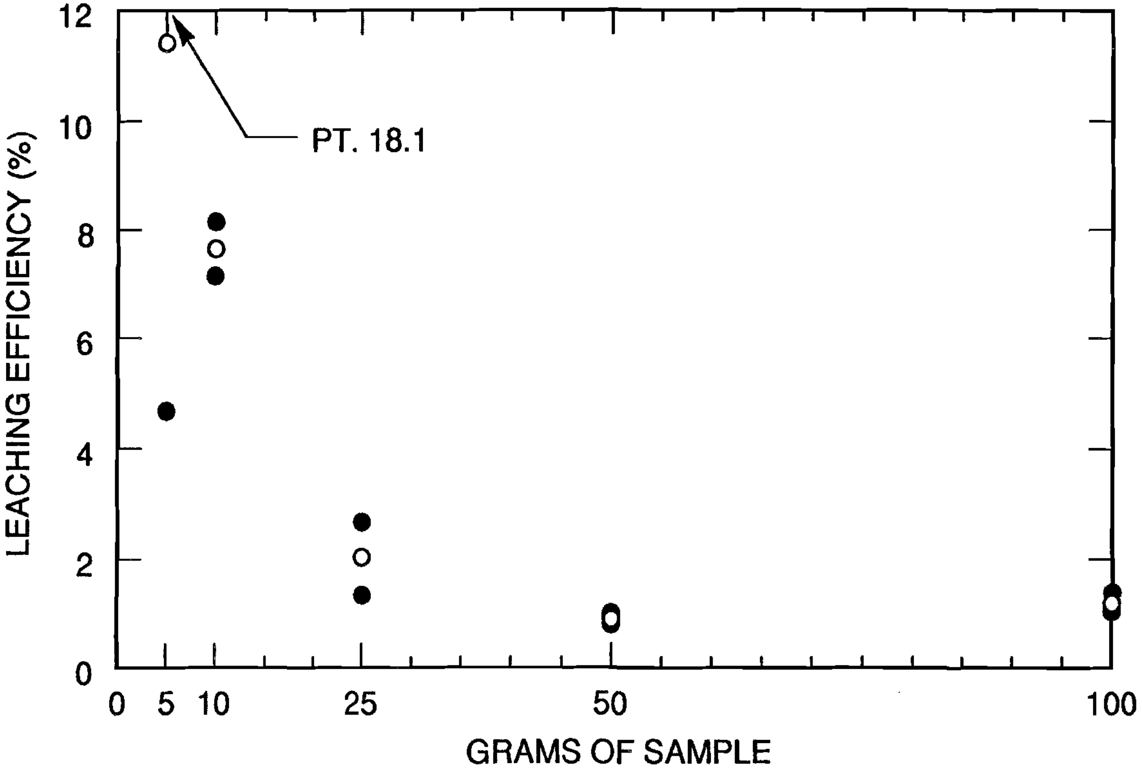

Figure 7-32. FLOOR SWEEPINGS (B4 - C13)

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20-21. OSTI, U.S. Department of Energy, P.O. Box 62, Oak Ridge, TN 37831

APPENDIX A

ADDENDUM TO SWSA 7 SOILS MAP

D. A. Lietzke

CONTENTS

LIST OF TABLES

INTRODUCTION

The soils of SWSA 7 were mapped in 1984. Since then, advances in soil-geology and soil-geomorphology relationships necessitated that the soil mapping be reevaluated and brought up to date to present levels of knowledge.

The following mapping unit descriptions replace those contained in ORNL/TM-9326 (Rothschild et al. 1984). The soils map that accompanies this supplement (Fig. 1) has an identification legend (Table 1) which identifies (1) the landform and parent materials, (2) the slope class, and (3) the erosion class.

Table 2 contains a conversion legend that is needed to relate the soils information contained in TM-9326 to the present soil map, mapping unit descriptions, and interpretations of this supplement.

The following mapping unit descriptions are a supplement to those contained in TM-9326. The soil identification numbers are the same as those used in the LLWDDD report (TM-10573) and the same as the Bear Creek soil survey report.

Soils from the Rutledge Formation

The No. 30 soils represent an interbedded silty limestone and calcareous siltstone member in the Rutledge Formation that forms hills. Most of the Rutledge Formation occurs in topographically low areas and is covered by alluvium and colluvium.

Rutledge Residuum

30D3, 30E3 Soils. The soils in these map units classify as Ruptic-Ultic Dystrochrepts; Clayey argillic and loamy-skeletal cambic, mixed, thermic. These soils occur on small hills and have an irregular distribution along the trace of the Rutledge Formation. The limestone beds have weathered to clay, and a clay enriched subsoil has formed near the surface. The siltstone part is less weathered and forms resistant areas between clayey strata. The siltstone forms the "ruptic" parts of the soil. Because these soils occur on sideslopes, they generate considerable overland runoff. Most areas were severely eroded from past farming and forestry activities. Erosion is still a hazard whenever the surface forest litter is disturbed. These soils have highly variable permeability. Limestone strata have weathered to permeable clays. The clayey strata have high cation exchange capacity, but they are also permeable and can transmit contaminants rapidly to the watertable. Siltstone and shale strata are relatively impermeable, even though they may be highly fractured. These soils are not suited for waste disposal because of their steep slopes and very high erosion hazard. Forest vegetation should be left on these soils for erosion prevention and to screen waste disposal operations. These soils have fair potential for pines due to shallow rooting depth, but are good for hardwoods because of the high natural fertility. The soils are a poor source for cover materials.

Table 1. Soil Identification Legend

Identification	Landform and Parent Material	
30	steep sideslopes	Rutledge saprolite
35	steep sideslopes	Rogersville saprolite
36	ridgetops and sideslopes	Rogersville saprolite
40	broad uplands (deep soils)	Maryville claystone and argillaceous limestone saprolite
41	uplands and sideslopes (deep soils)	Maryville siltstone & sandstone saprolite
42	uplands and sideslopes (moderately deep soils)	Maryville interbedded claystone, siltstone and argillaceous limestone saprolite
43	steep sideslopes (shallow soils)	Maryville interbedded siltstone and claystone saprolite
431	steep sidelopes (deep soils)	highly fragmented Maryville saprolite
46	toeslopes	colluvium over saprolite
47	footslopes	colluvium over saprolite
47/951	toeslopes	colluvium over alluvium over Maryville saprolite
51	uplands	Nolichucky saprolite
95	terraces	Holocene alluvium
952	terraces	Holocene and Pleistocene alluvium over Maryville saprolite
98	1st and 2nd bottoms	Modern alluvium
99	1st bottoms	Modern alluvium
101	low terraces	Modern alluvium over Holocene alluvium over Maryville saprolite

<u>Slope Classes</u>

A	0 to 2% slopes
B	2 to 5% slopes
C	5 to 12% slopes
D	12 to 25% slopes
E	25 to 45% slopes
F	> 45% slopes

<u>Erosion Classes</u>

0, 1, 2 (Not shown on soil map) range from slightly overwashed to moderately eroded.
3 severely eroded (shown on soil map)
4 very severely eroded with gullies

A typical map unit ID contains a numerical symbol that identifies the landform and parent materials, a letter that identifies the slope class, and an additional symbol that identifies, as stated, the erosion class. For example: the symbol 30D3 identifies a delineated area of soil on the soil map. The 30D3 symbol also serves to identify the particular mapping unit description of this delineated area in the section that follows.

Table 2. Conversion Legend

TM-9326	New legend	Parent materials
1	30	Rutledge
2	46 and 47	colluvium
4	41	Maryville
4S	431	Maryville
5	42 and 43	Maryville
6	98 and 99	alluvium
7	40	Maryville
8	95 and 98	alluvium
9	35 and 36	Rogersville
10	47	colluvium
10W	46	colluvium

Soils from the Rogersville Formation

The No. 35 and No. 36 soils form a weathering sequence on the Rogersville Formation, with the No. 35 soils having the least development, and thinnest genetic soil horizons.

Rogersville Residuum

35E, 35E3, 35F Soils. The soils in these map units classify as Typic Dystrochrepts; loamy-skeletal, mixed, thermic, shallow. These soils occur almost exclusively on steep north and northeast aspects below Maryville ridgetops. The saprolite beneath the soil solum ranges from brownish, grayish to pinkish siltstone and claystone and commonly contains glauconitic strata. These soils, because of the steep slopes and impermeable saprolite, generate overland flow which removes surface soil material almost as fast as rock weathers to form soil beneath. Thus, these soils are kept in a near steady state of youthfulness. Most areas of these soils have been logged, and some areas pastured; but little accelerated erosion from past activities has occurred. Present vegetation consists of hardwoods in areas with minimal past disturbance to a mixture of pines and hardwoods in severely eroded areas. These soils are not suited for waste disposal because of their steep slopes and very high erosion hazard. Forest vegetation of hardwoods should be left on these soils for erosion prevention and to screen waste disposal operations. They are also not suited as a source of cover materials due to the steep slopes and very high erosion potential after the forest floor has been disturbed.

36D3 Soils. The soils in these map units classify as Ruptic-Ultic Dystrochrepts; fine-loamy or clayey (argillic horizon) and loamy-skeletal (cambic horizon), mixed, thermic. These soils comprise the largest areal extent of the Rogersville Formation. They occur on summits and sideslope landforms. Severely eroded areas have lost most or all of their diagnostic features and have the morphology of Typic Dystrochrepts (No. 35 soils), or very shallow Udorthents (soils without genetic subsoil horizons), with the exception of clay plugged upper Cr horizons that are evidence that clay enriched subsoils once occurred. These soils, depending on past and present landuse have hardwood vegetation in undisturbed areas, a mixture of hardwoods, Virginia pine and cedars of old field succession, or planted pine trees. These soils, due to the shallow soil solum, do not have much water retaining capacity, so overland flow or near surface flow is common espscially on dip slopes. The rougher rock surface of obsequent slopes allows for longer water residence time and therefore more enters and moves down dip along planar surfaces or gradually downward through joints and fractures. These soils are on slopes too steep to be used for waste disposal, and should remain in hardwood forest.

Soils from the Maryville Limestone

The No. 40, No. 41, No. 42, No. 431 and No. 43 soils form a weathering sequence on the Maryville Formation. The No. 40 soils formed in saprolite from argillaceous limestone or in shale with limestone strata. They occupy gently sloping and stable landforms and are more highly weathered than the other Maryville soils in SWSA-7. They have a deeper solum that has stronger horizonation and a continuous clayey Bt subsoil horizon with a 2.5YR hue.

The No. 41 soils have similar morphology as the No. 40 soils except that they formed in lower clay content, mostly siltstone parent materials, and have loamy subsoil horizons. The No. 42 soils formed in interbedded siltstone and claystone parent materials which have undergone differential weathering. The No. 42 soils also occur on steeper slopes or on landforms with more convexity. These soils were periodically stripped of their upper soil horizons during the late Pleistocene so that in an open trench across strike, the Bt horizon is interupted by either a cambic Bw horizon or by C or Cr horizon saprolite materials. The No. 431 soils occur on very steep landforms, and are confined to easterly facing slopes. They have a cambic Bw horizon and have paralithic Cr horizon materials below a depth of 50 to 100 cm. The No. 43 soils also occur on the steepest and most convex landforms. They have no Bt horizon except in a few deep pockets, and with paralithic materials usually less than 50 cm to as little as 10 cm below the surface. The Maryville Formation contains more calcium carbonate than either the Pumpkin Valley, Rogersville, or Nolichucky Formations. As a result, hardwood tree growth appears to be better. There is higher density of hardwoods; notably white oak and tulip poplar with its understory of flowering dogwood and few, if any, blueberry shrubs or other shallow rooted acid tolerant ground cover. This vegetation community indicates that oak and poplar tree roots are in contact with deeper saprolite zones that still contain calcium carbonate, even though the soil solum, below the A horizon, and including the upper saprolite is extremely acid and leached. Enough calcium has been cycled to the surface to support and maintain ground cover that requires higher fertility.

Maryville Residuum

40D Soils. The soils in this map unit classify as Typic Hapludults; clayey, mixed, thermic. These soils formed in strongly weathered Maryville residuum. The soils have a Bt horizon with a 2.5YR hue and the underlying upper saprolite horizons are tightly plugged by clay. These soils occur on broad upland summits with little convexity and on gentle lower sideslopes in areas of steeper slopes. Most areas of these soils were not cultivated because of small extent or inaccessibility. Some areas that had been cultivated were severely or very severely eroded and now have morphological characteristics similar to the No. 42 soils except for the presence of 2.5YR clay plugging in the upper saprolite which was derived from a Bt horizon. The saprolite under these soils is more weathered and softer than that under the adjacent No. 42 and No. 43 soils. Clay, iron and manganese are being translocated downward in these soils. Some clay at depth is probably neo-formed from solution. Limestone strata in the deeper saprolite are filled in by manganese and either neo-formed or translocated clay as calcium carbonate is removed so that collapse does not occur. In fact, the addition of swelling clay tends to increase the original volume. It is not unusual to find good pedogenic structure and tree roots deep in the soil in these kinds of clayey saprolite zones. These soils, because of the greater solum thickness, tend to retain more water so that there is less overland runoff generated by most storm events. However, clay plugging in the upper saprolite reduces permeability so that water perches during prolonged storms and during the winter wet season. It is during these wet periods that the soil can become saturated, subsequently generating overland or near surface lateral flow of water. These soils have limited extent on the site. They have fair potential for either trenches, depending on depth to the watertable, and have fair to good potential for tumulus waste disposal depending on the slope gradient. These soils are fair for pines and fair to good for hardwoods. They are a fair to good source of cover materials, but with the high silt plus clay content, are difficult to compact.

41C3, 41D3, 41D4 Soils. Typic Hapludults; fine-loamy, mixed, thermic. These soils formed in calcareous siltstone and very fine grained sandstone facies of the Maryville limestone. Thus far in the mapping of the Roane County portion of the Oak Ridge Reservation (ORR), these soils only occur in SWSA-7 between the westernmost and easternmost drainageways that bound the site. They are similar to the No. 40 soils in morphology but lack clayey subsoil horizons. These soils occur on upland sideslopes and are mostly well drained. The Cr horizon occurs at depths of 50 to 100 cm, but is highly fractured and porous so that water does not perch except during periods of heavy rainfall. Cracks in the upper 5 to 10 cm of the Cr horizon are wide enough to admit clay sized particles. Below this depth only ions in solution can pass downward through the saprolite joint and fracture system into less weathered and oxidized saprolite beneath and finally into unweathered rock. Iron and manganese oxides and oxyhydroxides coat fracture and joint faces in the upper oxidized and leached saprolite zone. Three zones occur in this uppermost saprolite. The uppermost zone has a concentration of iron which coats fragment faces red or dark red. Below this is a mixed iron and manganese zone where iron coats upper surfaces of fragments and manganese coats lower surfaces. In the lower zone, manganese coats most fragment faces. Water flow zones in the upper saprolite can be readily identified by grayish streaks. The boundary between the uppermost oxidized and leached saprolite and the middle oxidized and partially leached saprolite seems to be the zone where the groundwater table fluctuates during the year. The middle saprolite zone may be several meters thick. The boundary between the oxidized and partially leached or unleached saprolite seems to coincide with the ground water level below which there is little fluctuation. Below the watertable, there are no visible coatings. The relationships between watertables, weathering properties and split spoon and both large and small diameter power auger refusal have yet to be worked out.

The upper 10 to 30 cm of these soils commonly shows effects from past agricultural activities. Because these soils occur on mostly gentle slopes, they were intensively cultivated in the past and became severely or very severely eroded. Most areas of soils with severe erosion, identified by the numeral "3" have lost at least half of their argillic horizon. The old plow layer usually has a clay loam texture. Between abandonment and either old-field succession or tree planting, additional erosion produced from few to many gullies from 0.5 to 1.5 m deep and wide. Map unit delineations with the "4" erosion symbol have many shallow to deep gullies. Some areas of severely and very severely eroded soils have lost so much of the soil solum that they have morphologic characteristics of the No. 42 or No. 43 soils except for the presence of a clayey Ap horizon.

Reforestation and surface stability has allowed soil horizons to reform in these areas. The neoformed A horizon has a thickness of 2 to about 10 cm and has been darkened by additions of organic matter. Soil texture in the A horizon has become less clayey due to removal of clay sized particles.

These soils seem to have a high content of soil fauna which appears to be responsible for the low bulk density and high porosity of the solum. Ants, termites and other soil arthropods tunnel extensively throughout the soil solum. Worms seem to be absent due to very high acidity and low organic matter content. Small areas of these soils are covered by a thin layer of colluvium, usually less than 50 cm thick. Other small areas have clayey subsoils, a reflection of the natural geologic variability in this section of the Maryville Formation.

These soils have the best potential for use as waste disposal sites. They are quite deeply weathered. The saprolite in which waste will be emplaced has weathered enough in the upper 3 to 4 meters that cation exchange should be moderately high. Iron and manganese compounds and clay plasma which coats most fragments in this upper saprolite zone controls most geochemical activity. These soils have about the same potential and problems as the No. 40 and No. 42 soils have in SWSA-6 for retention of radioactive nuclides. Unless trenches are properly designed to keep out lateral subsurface water flow, water ponding will produce low re-dox potentials and result in the migration of iron and manganese. Tumuli concrete pads should be located only on firm undisturbed paralithic saprolite after all of the soil solum has been removed to prevent differential settlement.

42B3, 42C, 42C3, 42D, 42D4, 42E Soils. The soils in these map units classify as Ruptic-Ultic Dystrochrepts; clayey (Bt argillic horizon) and loamy-skeletal (Bw cambic horizon), mixed, thermic. These soils occur on narrow summits and upper and middle sideslopes with considerable convexity, and are the most extensive soils underlain by the Maryville Formation. They formed in less weathered but highly interbedded siltstone and claystone with thin strata of argillaceous limestone and very fine grained sandstone saprolite of the Maryville Formation. These strata have undergone differential weathering which increases soil variability, especially permeability in the upper saprolite. These soils have an intermittant clayey Bt horizon which has 2.5YR-5YR hue. Siltstone and claystone fragments in the solum and upper saprolite have a 10YR-2.5Y hue. Depth to paralithic (Cr horizon) materials is highly variable ranging from less than 10 cm to more than 100 cm over very short distances. Areas of these soils that were not cultivated support good stands of northern hardwoods, including white oak and its understory of flowering dogwood, and some white pine. This is surprising given the relatively shallow solum depth and high acidity of the soil solum and upper saprolite. However deep rooted trees have cycled nutrients to the surface where they are tightly recycled by the forest vegetation. Where these soils have been cultivated in the past without or with minimal additions of lime and fertilizer, erosion has stripped off this higher pH and nutrient rich surface A horizon, greatly impoverishing the soil. These eroded soils do not support the kinds of trees, nor at the same density, that uneroded soils do. Very severely eroded areas of these soils are mostly in short term pine rotation with continuing erosion problems. Continued pine rotation will deplete near surface plant nutrients to the extent that weedy ground cover will not adequately supply vegetative cover to the soil, thus increasing the rate of soil erosion. In addition, short term pine rotation does not allow for deep penetration of roots to tap calcium supplies, and large pine tap roots cannot easily penetrate paralithic saprolite. Severely eroded soils and smaller areas of very severely eroded soils have lost most of the genetic horizons of the solum now have morphologic properties similar to the No.43 soils, with the exception of reddish clay flows in the saprolite which came from a Bt horizon that was once present.

The soils in these mapping units have about the same potential and the same problems as their counterparts have in SWSA-6. Design and placement of trenches is important in minimizing the flow and trapping of surface and subsurface water into them, resulting in ponding of wastes. Trench depth will vary depending on elevation and depth to the watertable. Tumuli pads should be placed on firm saprolite after the soil solum and clay plugged uppermost saprolite have been removed in order to minimize differential settlement and cracking. These soils are fair for pines due to the limited rooting depth for tap rooted trees, but are good for hardwoods. They are a poor source of cover materials, but if the soil has been stockpiled and the fragments allowed to weather, they have a fair potential. High silt plus clay content soils are difficult to compact, are they are also highly erodible.

43D4, 43E3 Soils. The soils in these map units classify as Typic Dystrochrepts; loamy-skeletal; mixed, thermic, shallow. These soils occur on steep sideslopes of drainageways that are cutting headwardly through the Maryville Formation, or they are on highly convex shoulders and sideslopes of spur ridges with lower slope gradient. Most areas of these soils are located on northwest, west, and and southerly aspects. These soils have a thin solum, usually less than 50 cm thick above paralithic materials. The saprolite directly beneath the solum usually has a 2.5Y to 5Y hue, or if more weathered, has a 2.5Y- 10YR hue. Because of the shallow solum, these soils cannot retain much rainfall, resulting in the generation of considerable overland or near surface lateral flow during many storm events. Overland flow has removed soil particles from the surface almost as fast as soil is formed by the weathering of rock beneath. Consequently, these soils are kept in a near steady state of youthfulness. In addition, most areas of these soils in SWSA-7 were disturbed in the past by clearing and pasturing resulting in very severe erosion. Vegetation on these soils consists of low quality oaks and pines. Poison Ivy also grows very well on most areas of these soils due to the more open canopy and higher nutrient status.

These soils should not be used for waste disposal due to their extremely high erosion hazard. The saprolite below the soil solum is also less weathered and has a lower cation retention capacity than under the No. 40, No. 41 and No. 42 soils. These soils should remain in hardwoods or be managed for long rotation hardwood forest.

431E, 431F Soils. The soils in these map units classify as Typic Dystrochrepts; loamy-skeletal, mixed, thermic. The soils in these map units formed in highly fractured calcareous siltstone facies of the Maryville Formation. They are on steep and very steep easterly facing sideslopes, and have slope gradients ranging from 25% to about 85%. Most slope shapes are doubly convex but straight inclined segments occur between the break in the summit shoulder and the lower begining of the footslope. On disturbed slopes where there has been past erosion, vegetation is mostly second growth of red maple, Virginia pine, white pine, sourwood, scattered white oak, and black gum. On some slopes with less past disturbance, white oak is the dominant tree species, indicating that long lived tree roots can extend through highly weathered and very acid saprolite into less weathered saprolite or rock that contains calcium carbonate. Calcium and other base cations are cycled to the surface by these long-lived deep rooted trees.

The soils in these map units are similar to the No. 43 soils except that the depth to the Cr horizon ranges from about 50 cm to about 200 cm. The mid range is between 70 and 100 cm. The Cr horizon is not clay plugged nor does it perch much water. Above the Cr horizon shale fragments are silt or occasionally clay coated. Below the Cr, most paralithic fragmented shale material is not coated with silt or clay particles but with either iron oxide (red) or manganese (black) plasma. The oxidized and leached saprolite zone is thicker beneath these soils than under the No. 43 soils.

Included in mapping were some small doubly convex upland summits that were less than 100 feet wide and the shoulder slope between the summit and sideslope. These included No. 43 soils have been subjected to more intense geologic and man-accelerated erosion, where the present depth to the Cr horizon is less than 50 cm, and paralithic materials are less weathered and harder. Also included are narrow footslopes where layers of colluvium have accumulated unless a stream has been undercutting the slope.

Nearly all areas of Map Unit No. 431 are on obsequent slopes where the shale dips steeply into the slope.

These soils should not be used for waste disposal. Slopes are too steep and the erosion hazard is extremely high. They should be left in hardwood forest and managed for long term hardwood saw timber because of the slope steepness and erosion hazard.

Soils from The Nolichucky Shale

The Nolichucky Formation can be readily identified by the oxidized brownish or pinkish brown color of the claystone and siltstone saprolite. Geomorphic processes of erosion and denudation do not result in the formation of high hills and steep slopes when compared to the adjacent Maryville Formation on the SWSA-7 or SWSA-6 sites. In addition, lower saprolite and bedrock porosity would have produced more overland runoff resulting in more uniform removal of the upper soil horizons.

A combination of landform configuration and saprolite color were the primary distinguishing characteristics used to locate the boundary zone between the Maryville and Nolichucky Formations. Clay enriched subsoil horizons in Nolichucky soils have yellowish brown or strong brown hues in contrast to the yellowish red to red hues of Maryville subsoils. The lower Nolichucky is interbedded with the upper Maryville. This transitional area can be identified by interbedded olive brown (Maryville) and strong brown (Nolichucky)strata. Due to the low angle dip in SWSA-7, the intergrade area between the Nolichucky and Maryville Formations is quite wide, and constitutes the "panhandle" of SWSA-7. This transitional area appeared to have a higher limestone influence and was placed into Maryville No. 42 soils rather than Nolichucky No. 51 soils.

Nolichucky Residuum

51D Soils. The soils in these map units classify as Ruptic-Ultic Dystrochrepts; 10YR and 7.5YR clayey (Bt argillic horizon) and loamy-skeletal (Bw cambic horizon), mixed, thermic. These soils occupy summits, upper, middle and lower sidelopes. Because of favorable topography, they were intensively cultivated in the past. Most areas, even on gentle slopes, were severely eroded. Because of the past erosion many borings of these soils have the morphologic characteristics of Typic Dystrochrepts, but the underlying saprolite contains abundant clay flows which had been translocated from a Bt horizon. Present vegetation consists of pine plantations or of poor scrubby hardwoods. Because of the lower calcium carbonate content in the Nolichucky Formation, deep rooted trees do not contact much calcium thus the present hardwood vegetation is tolerant of low nutrient and extremely acid conditions in the upper several meters of soil. White oak or tulip poplar with its flowering dogwood understory and acid intolerant ground cover is a rare occurrance on these soils. These soils generate high amounts of overland or near surface lateral water flow during most storm events. Due to the relatively impermeable nature of the saprolite, the upper soil layers become saturated readily, and because of the high silt and clay content, they tend to move down slope quite readily.

These soils have limited extent in SWSA-7, although depending on final placement of transition zone soils, could have larger extent. Because of their low elevation in the landscape and nearness to the water table thay have very poor potential for trench waste disposal. They have fair to good potential for the tumulus type of waste disposal with above ground storage of waste. Tumulus concrete pads should be placed on undisturbed firm saprolite after all the soil solum and any clay plugged upper saprolite has been removed and stockpiled. The stockpiled soil can be used for covering materials. These soils have poor to fair potential for pines and fair to good potential for hardwoods. The potential varies according to the amount of limestone strata at any one place in the formation.

Rogersville-Maryville-Nolichucky Colluvial Soils

The soils that formed in colluvial materials that washed and rolled downslope from the Rogersville, Maryville and Nolichucky Formations have similar morphologic characteristics so that they were grouped together in mapping the SWSA-7 site. A major criterion for the recognition of colluvial soils is the presence of more than 50 cm of colluvium that usually overlays an older truncated soil that commonly formed in residuum. The second criterion is the landform position and slope shape. Most colluvium occurs in footslope and toeslope landscapes with slope shapes that are doubly concave. The only exception is the occurrence of old colluvium which is not often related to present concave landforms.

46C, 46C3, 46D Soils. The soils in these map units classify as Aquic Hapludults; fine-loamy, mixed, thermic. These soils occur mostly in heads of major drainageways, where smaller first order drainageways coalesce. There is very little surface water flow across these soils. Most water flow is below the surface, either along horizon boundaries, or lithologic discontinuities, and at the top of the Cr horizon. Because of the longer residence time of water in these soils, it also tends to move downward into the saprolite beneath these soils. Most slope shapes are doubly concave and have gradients of about 2 to about 25%. Lower slope gradients occur in the bottoms of drainageways, and where these soils merge and interfinger with modern alluvial soils (No. 98 and No. 99). Areas of steeper slopes occur where these soil merge with steep residual soils of mid and lower sideslopes. Vegetation is mostly second or third growth since many of these soils were logged several times or were in agricultural production if individual areas were extensive enough.

Parent materials in these soils is often of three kinds: the buried underlying residuum, the truncated and buried remains of an older colluvial soil (No. 49) and a younger uppermost colluvium that has a higher coarse fragment content and must be more than 50 cm thick. Because of past agricultural activities on the uplands, lower areas of these soils are commonly covered with a layer of local alluvium or colluvium, especially where areas of these soils occur below gullied upland soils.

The soils in these map units have good potential for cover and trench liner material that can be doped with chemicals for retention of cations and anions. The soils can also be easily compacted and made relatively impermeable. These soils also have good properties for final cover materials. These soils are not suited for trenches because of sidewall instability, lateral water movement and closeness to the watertable in these low landscapes. They are not very well suited for tumulus concrete pads because of the potential for differential settlement causing cracking. These soils tend to fill with water during winter and spring. Water perches at one or more depths after heavy rains. The dominant flow of water in these soils is lateral. These soils have good potential for both pines and hardwoods.

47B, 47C, 47C2, 47D Soils. The soils in these map units classify as Typic Hapludults; fine-loamy, mixed, thermic. These soils are on footslopes, toeslopes, and fan terraces. They usually have one or more lithologic discontinuities, but there is little evidence of perched water at lithologic contacts unless the truncated remains of a clayey argillic horizon in the buried paleosol are present. Erosion during the Pleistocene evidently stripped off most of the overlying soil before deposition of this aged colluvium began. Below the lithologic or time discontinuity there is either an older colluvium or the truncated remains of a residual soil. These soils are most common on the Maryville Formation, but they also occur on the Rogersville and Nolichucky Formations. Most areas of these soils occur in first order drainageways and sideslopes of these drainageways. Many areas have been partially covered by recent colluvium and local slope wash alluvium produced by cultivation of adjacent landforms. Included in mapping are small and scattered areas of a younger colluvium, but only about 50 cm thick. Many areas of these soils were cultivated in the past, but have reverted to forest. Because these soils have favorable physical properties including relatively low clay content and high porosity, they have not been severely eroded in the past. These soils have the capacity to retain most rainfall, much of this goes downward or laterally and contributes to stream base flow. The soils in these map units have good potential for cover and liner material that can be easily compacted and made relatively impermeable. These soils also have good properties for final cover materials. These soils are not suited for trenches because of sidewall instability, lateral water movement and closeness to the watertable in these low landscapes. They are poorly suited for tumulus concrete pads because of the potential for differential settlement causing cracking. These soils tend to fill with water during winter and spring. Water perches at one or more depths after heavy rains. The dominant flow of water in these soils is lateral. These soils have good physical properties for both liner and cover materials, and can be made relatively impermeable when properly compacted. They also have good chemical properties for cation retention. In addition, they have favorable properties for establishing vegetative cover.

47/951B Soils. The soils in this map unit classify as Typic Hapludults; fine-loamy, mixed, thermic. These soils formed in No. 47 colluvium over No. 951 Pleistocene alluvium which covers Nolichucky saprolite residuum. These soils occur adjacent to and slightly above the No. 951 soils in footslope and toeslope landforms, where Pleistocene alluvium was buried by colluvium. Not all possible areas have been identified due to location problems in dense pine thickets and of small narrow areas around larger areas of Nolichucky soils. Larger areas that were identified are located on the soil map primarily for geomorphology studies.

Old Alluvium

What is "old" and what is "young" alluvium is relative. The guidelines used to distinguish between the two is the degree of soil genesis based on observable morphology, location in the landscape and relationship to present streams, floodplains and the Late-Holocene terrace system.

Old alluvium ranges in absolute age from mid-Holocene back through the Pleistocene, although in SWSA-7, the oldest alluvium is probably no older than mid-Pleistocene. Old alluvial soils have definite soil horizonation, and most important, a clay enriched subsoil or argillic horizon which requires a minimum of about 3000 years to form. Some old alluvial soils have a fragipan horizon commonly above or in the top of a truncated older soil.

Young alluvial soils have minimal expression of soil horizons, and are commonly stratified close to or at the surface, or if an older soil is within 100 cm of the surface it has been buried beneath more than 50 cm of alluvium that retains its fine stratifications, evidence of recent deposition in flowing water.

95B Soils. The soils in this map unit classify as Typic Hapludults; fine-loamy, mixed, thermic. These soils occur on low terraces of tributary drainageways mostly in areas downstream of Rome and Conesauga soils. They have a high content of very fine sand and silt throughout the profile and have a yellowish brown Bt horizon with a loam or light clay loam texture. There are generally very few or no coarse fragments. These soils are similar in morphology to the upper part of the older alluvium No. 952 soils, but they occur in defined drainageway terrace landforms, where they are connected to the No. 47 soils and their landforms. The No. 95 soils otherwise have similar morphology but do not have segregated iron-manganese and are much younger than the No. 952 soils. They are probably are late Holocene or neo-glacial in age, or about 2800 to 4000 years.

952B Soils. The soils in this map unit classify as Typic and Aquic Fragiudults; fine-silty, mixed or siliceous, thermic. These soils occupy toeslope and terrace positions in the intergrade zone between the Nolichucky and Maryville Formations in SWSA-7. They formed in a thin layer of loess and the underlying alluvium that has a high silt and very fine sand content. These soils have a fragipan that occurs at a depth of 80 to 125 cm below the soil surface. Below the fragipan is a buried residual soil with a clayey argillic horizon that perches water. The presence of large nodules of manganese and iron above and in the fragipan is a distinguishing feature of these soils. The No. 95 soils which occur on lower terraces lack both the fragipan and the iron-manganese concenrations and nodules. These soils are of minor extent but are significant for geomorphic studies in that a buried paleosol is preserved beneath younger surficial sediments. These soils are not suited for trench waste disposal due to the high watertable. They have poor potential for tumulus waste disposal unless the alluvium, which overlies saprolite, has been removed. The alluvial part of these soils is very poor for cover material because of the high silt content. Cover material from these soils also has a very high erosion potential. If these soils were used as a source for cover, a final cover containing less clay and silt would be needed to lower the erosion potential. The best on-site combination source of cover materials consists of the No. 952 soils for the initial cover, and additional final cover from either the No. 46 or No. 47 soils.

Young Alluvium

98B Soils. The soils in this map unit classify as Typic and Aquic Udifluvents; coarse or fine-silty; mixed, thermic. These soils formed in Modern and late Holocene alluvium and have a high silt content. Very young modern alluvium can be identified by the presence of fine stratifications close to or at the surface. Late Holocene-aged alluvium has minimal subsoil horizonation. There has been minimal soil genesis in these soils, with the exception of the "A" horizon in which organc matter is accumulating. These soils typically have irregular distributions of organic matter because of frequent burial of leaves and other organic materials. Most areas of these soils are in narrow drainageways in areas of Rogersville, Maryville and Nolichucky soils. Areas of first order drainageways too small to show on the soil map are identified by drainageway symbols. These well drained and moderately well drained soils are undifferentiated with respect to degree of wetness. Better drained areas usually have a more entrenched channel, or there is less seepage water passing through the soil. The largest areas of these soils in SWSA-7 occur on the floodplain and low terraces of Whiteoak Creek. Nearly all areas of these soils have a Holocene-aged buried soil between a depth of 50 cm and 100 cm. Narrow areas of these soils probably were never cultivated and have hardwood tree vegetation, but larger adjacent areas were cultivated and reverted back to forest vegetation via old-field succession.

These soils have an important role in the filtration and purification of surface water. Most water flow in these soils is within the biologically active zone of the soil. Areas of these soils and their vegetative cover should not be disturbed or covered during trench or tumuli waste disposal operations.

99A Soils. The soils in these map units classify as Typic and Aeric Fluvaquents; fine or coarse-silty, mixed, thermic. These somewhat poorly to poorly drained soils occur in nearly level drainageways within areas of Rogersville, Maryville, and Nolichucky soils that contribute high silt-content sediments to drainageways. Most areas of these soils have a buried Holocene soil between a depth of 50 and 100 cm. Many areas of these soils contain springs or seepage zones, or occur below such areas and the soil is kept constantly wet and anoxic by water moving over and through the soil. Present vegetation is hardwoods with a ground cover of water tolerant plants.

These soils and their vegetative cover have an important role in surface and near surface water filtration and purification. They should not be disturbed by land clearing activities nor should they be filled.

101A Soils. The soils in this map unit classify as Aeric Ochraqualfs; fine-silty, mixed, thermic. These soils formed in alluvium of the same age as the Old Alluvium No. 952 soils, but have a surficial capping of loess and younger modern alluvium that is less than 50 cm thick. The residuum beneath these soils is the intergrade zone between the Maryville and Nolichucky Formations. These somewhat poorly drained soils occupy a nearly level abandoned paleo-floodplain in SWSA-7, and are adjacent to the slightly higher laying No. 952 soils. Present day vegetation is a dense stand of hardwoods and abundant poison ivy ground cover.

These soils should not be disturbed or filled during waste disposal operations because they have an important function in water filtration and purification. They have the highest organic matter content and are able to retain certain anions. A reducing environment is present most of the time in these soils. They tend to have low levels of iron and manganese compounds unless seepage water is carrying these materials in from upland and footslope soils.

APPENDIX B

SWSA 7 WELL CONSTRUCTION LOGS

R. H. Ketelle

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SWSA 7 EXT.

CONSTRUCTION DETAILS

These construction details were prepared from the data provided by Highland Drilling.

The bedrock depth was assumed to be hole bottom for the shallow wells.

The bedrock depth for deep wells was assumed to be thirty feet above the hole bottom.

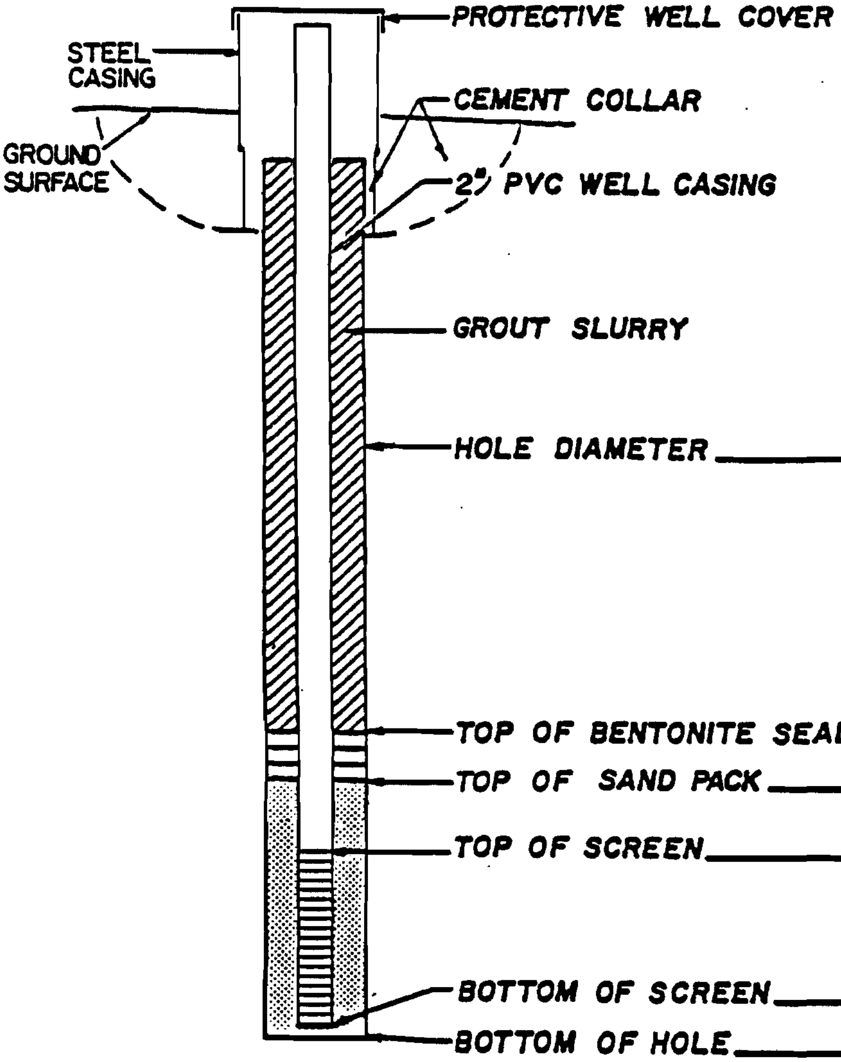
The screen bottom depth was derived by adding the screen amount in feet to the given top of screen depth.

PIEZOMETER CONSTRUCTION ABOVE BED ROCK

WELL NO. 1113 DATE INSTALLED: July 1987

MAP NO. SWSA-7 EXT.

LOCATION NORTH: ______ EAST: ______



HOLE DIAMETER 6 1/8"

TOP OF BENTONITE SEAL 5'

TOP OF SAND PACK 7'

TOP OF SCREEN 8'

BOTTOM OF SCREEN 18'

BOTTOM OF HOLE 18'

BEDROCK LEVEL 18'

NOTE: ALL DEPTHS ARE RELATIVE TO TOP OF GROUND.

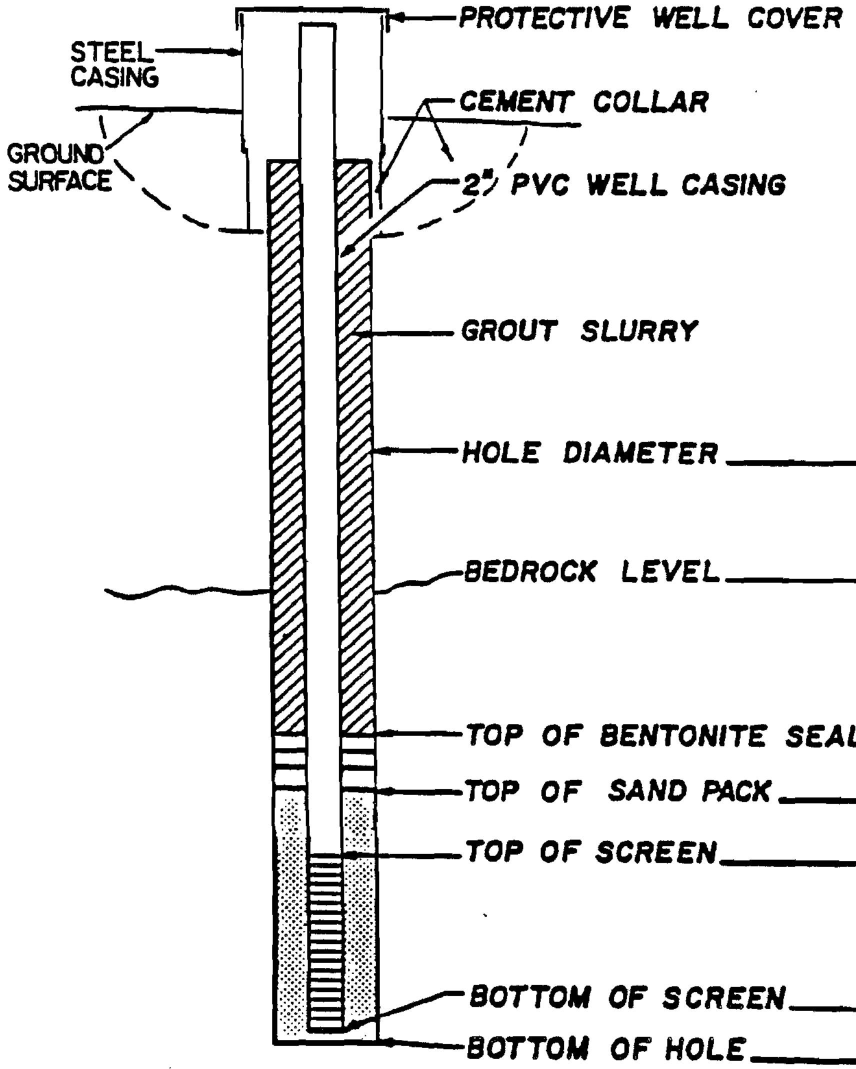
DRAWING NOT TO SCALE.

PIEZOMETER CONSTRUCTION IN ROCK

WELL NO. 1114 DATE INSTALLED: July 1987

MAP NO. SWSA-7 EXT.

LOCATION NORTH: EAST:



HOLE DIAMETER 6 1/8"

BEDROCK LEVEL 15'

TOP OF BENTONITE SEAL 25'

TOP OF SAND PACK 28'

TOP OF SCREEN 30'

BOTTOM OF SCREEN 40'

BOTTOM OF HOLE 45'

NOTE: ALL DEPTHS ARE RELATIVE TO TOP OF GROUND.

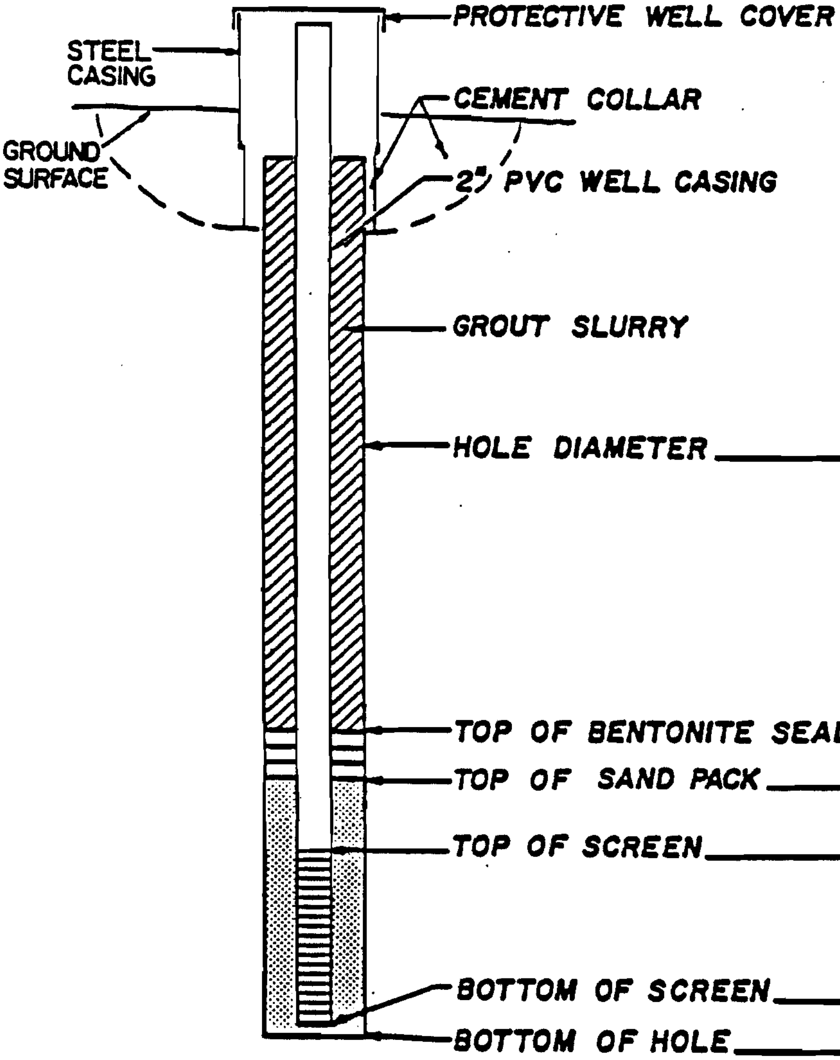
DRAWING NOT TO SCALE.

PIEZOMETER CONSTRUCTION ABOVE BED ROCK

WELL NO. 1115 DATE INSTALLED: July 1987

MAP NO. SWSA-7 EXT.

LOCATION NORTH: EAST:



HOLE DIAMETER 6 1/8"

TOP OF BENTONITE SEAL 2'

TOP OF SAND PACK 4'

TOP OF SCREEN 5'

BOTTOM OF SCREEN 10'

BOTTOM OF HOLE 10'

BEDROCK LEVEL 10'

NOTE: ALL DEPTHS ARE RELATIVE TO TOP OF GROUND.

DRAWING NOT TO SCALE.

PIEZOMETER CONSTRUCTION IN ROCK

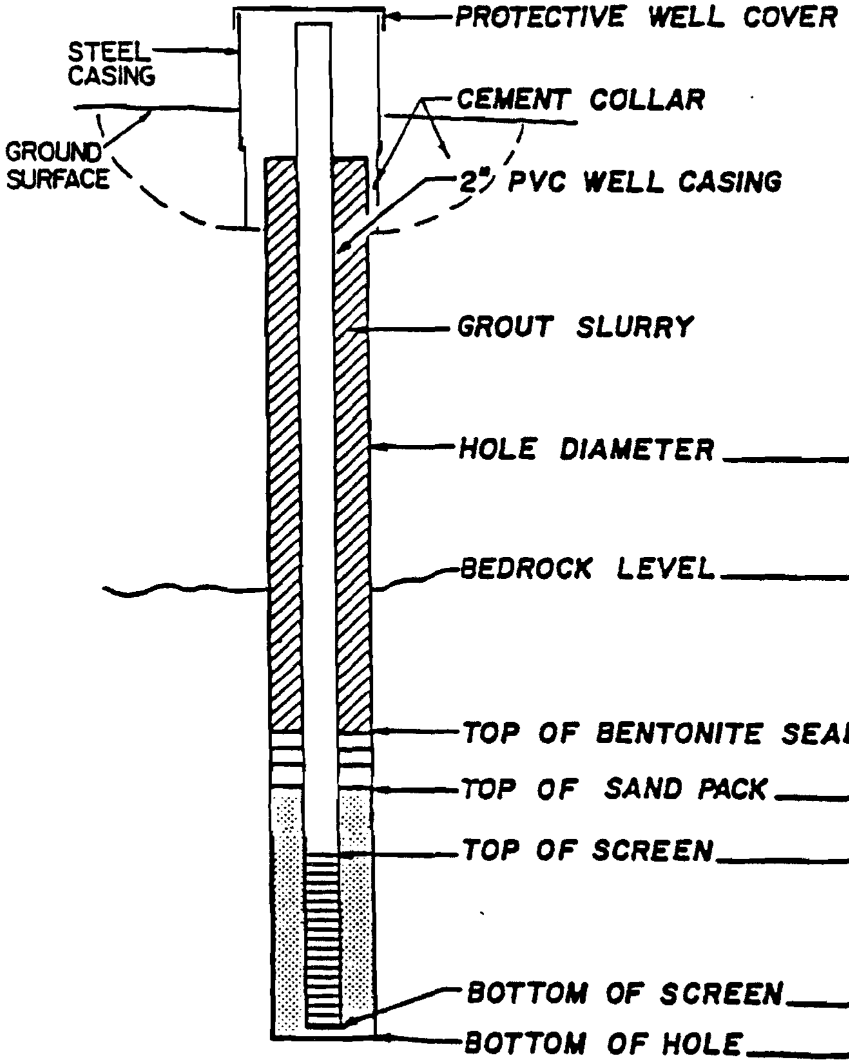
WELL NO. 1117

DATE INSTALLED: July 1987

MAP NO. SWSA-7 EXT

LOCATION NORTH:

EAST:



HOLE DIAMETER 6 1/8"

BEDROCK LEVEL 10'

TOP OF BENTONITE SEAL 21'

TOP OF SAND PACK 24'

TOP OF SCREEN 25'

BOTTOM OF SCREEN 35'

BOTTOM OF HOLE 40'

NOTE: ALL DEPTHS ARE RELATIVE TO TOP OF GROUND.

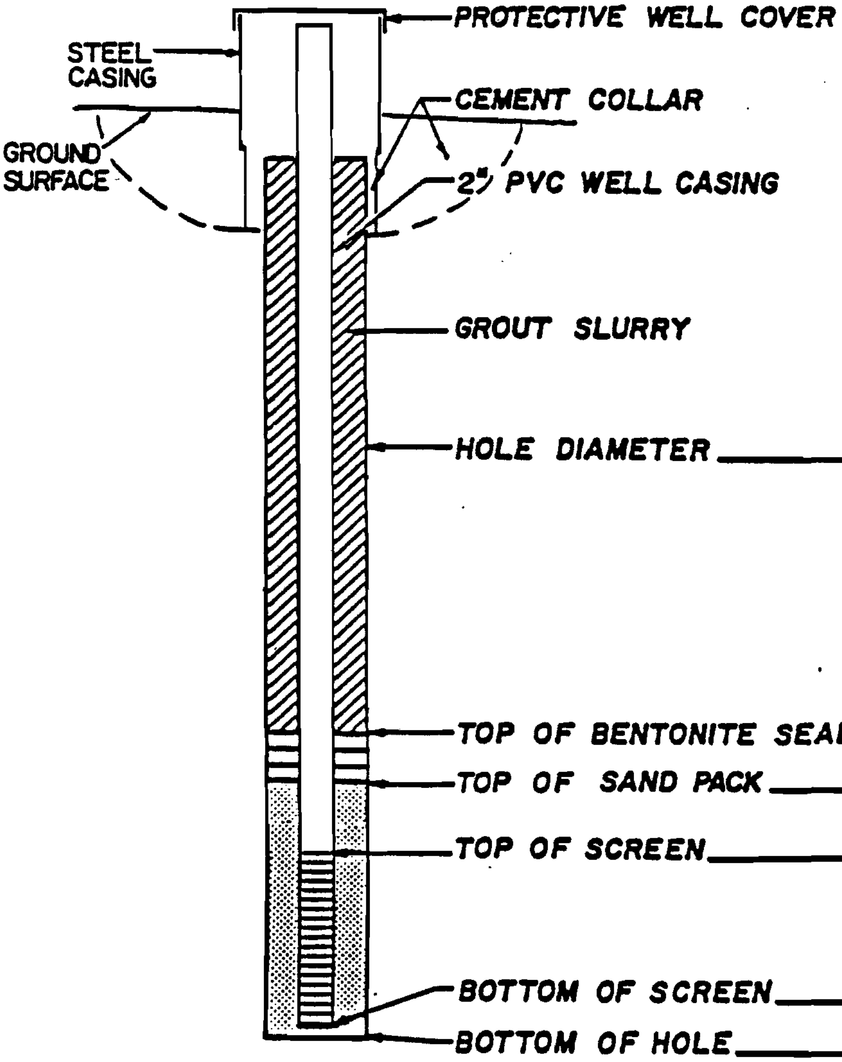
DRAWING NOT TO SCALE.

PIEZOMETER CONSTRUCTION ABOVE BED ROCK

WELL NO. 1118 DATE INSTALLED: July 1987

MAP NO. SWSA-7 EXT.

LOCATION NORTH: EAST:



HOLE DIAMETER 6 1/8"

TOP OF BENTONITE SEAL 3'

TOP OF SAND PACK 5'

TOP OF SCREEN 6'

BOTTOM OF SCREEN 11'

BOTTOM OF HOLE 11'

BEDROCK LEVEL 11'

NOTE: ALL DEPTHS ARE RELATIVE TO TOP OF GROUND.

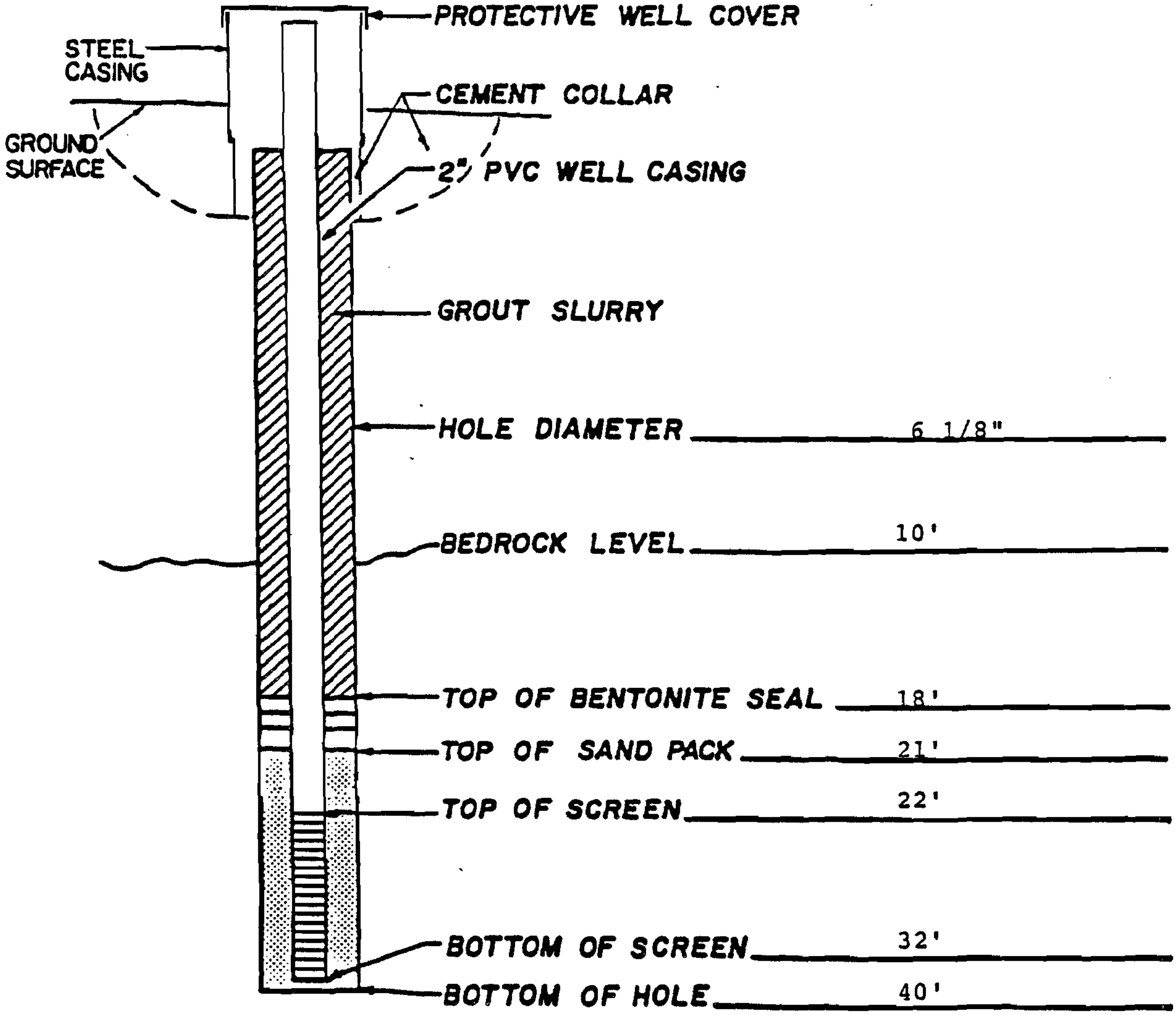
DRAWING NOT TO SCALE.

PIEZOMETER CONSTRUCTION IN ROCK

WELL NO. 1119 DATE INSTALLED: July 1987

MAP NO. SWSA-7 EXT

LOCATION NORTH: EAST:



HOLE DIAMETER 6 1/8"

BEDROCK LEVEL 10'

TOP OF BENTONITE SEAL 18'

TOP OF SAND PACK 21'

TOP OF SCREEN 22'

BOTTOM OF SCREEN 32'

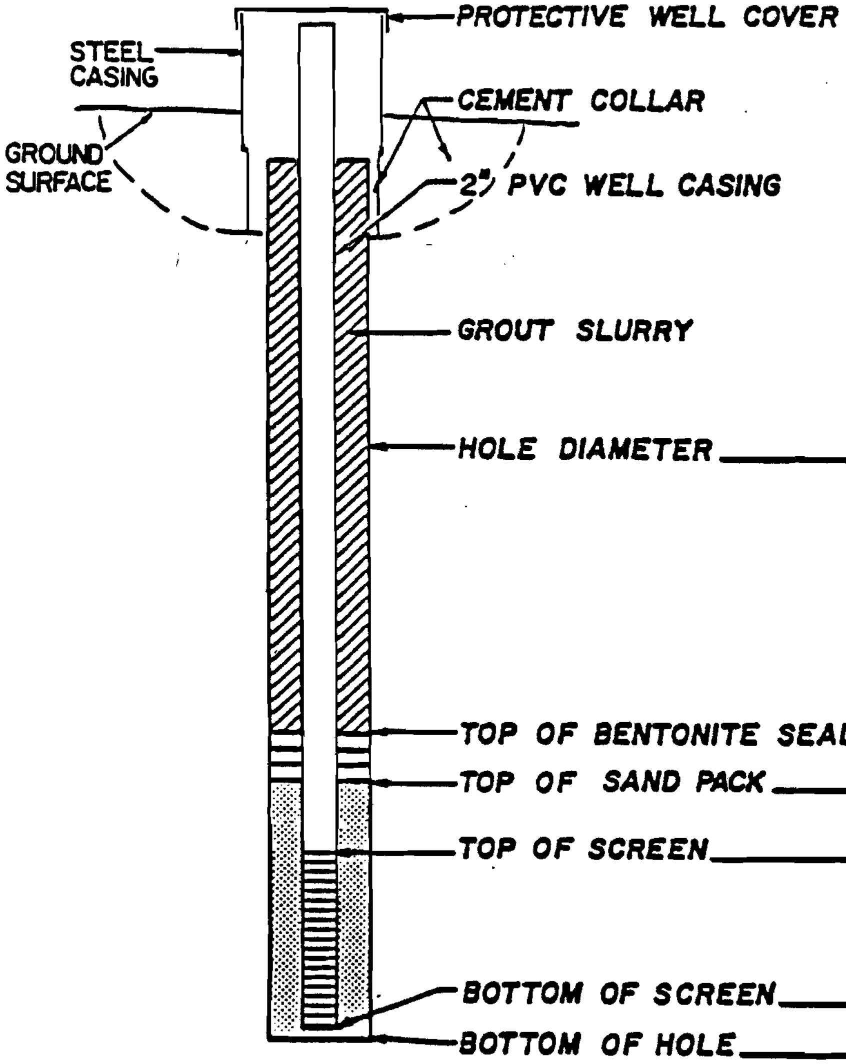
BOTTOM OF HOLE 40'

NOTE: ALL DEPTHS ARE RELATIVE TO TOP OF GROUND.

DRAWING NOT TO SCALE.

PIEZOMETER CONSTRUCTION ABOVE BED ROCK

WELL NO. 1120 DATE INSTALLED: July 1987
MAP NO. SWSA-7 EXT.
LOCATION NORTH: EAST:



HOLE DIAMETER 6 1/8"
TOP OF BENTONITE SEAL 1'
TOP OF SAND PACK 1.5'
TOP OF SCREEN 2'
BOTTOM OF SCREEN 7'
BOTTOM OF HOLE 9'
BEDROCK LEVEL 9'

NOTE: ALL DEPTHS ARE RELATIVE TO TOP OF GROUND.

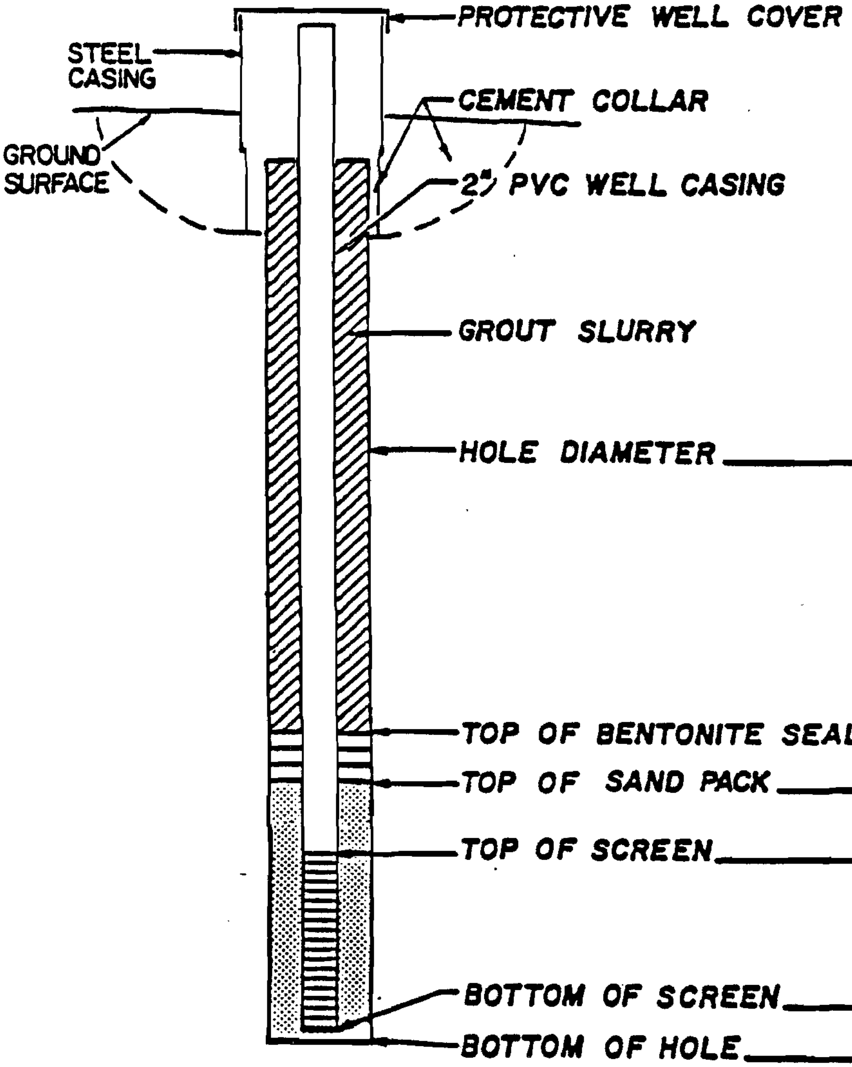
DRAWING NOT TO SCALE.

PIEZOMETER CONSTRUCTION ABOVE BED ROCK

WELL NO. 1121 DATE INSTALLED: July 1987

MAP NO. SWSA-7 EXT.

LOCATION NORTH: EAST:



HOLE DIAMETER 6 1/8"

TOP OF BENTONITE SEAL 6'

TOP OF SAND PACK 8'

TOP OF SCREEN 9'

BOTTOM OF SCREEN 14'

BOTTOM OF HOLE 14'

BEDROCK LEVEL 14'

NOTE: ALL DEPTHS ARE RELATIVE TO TOP OF GROUND.

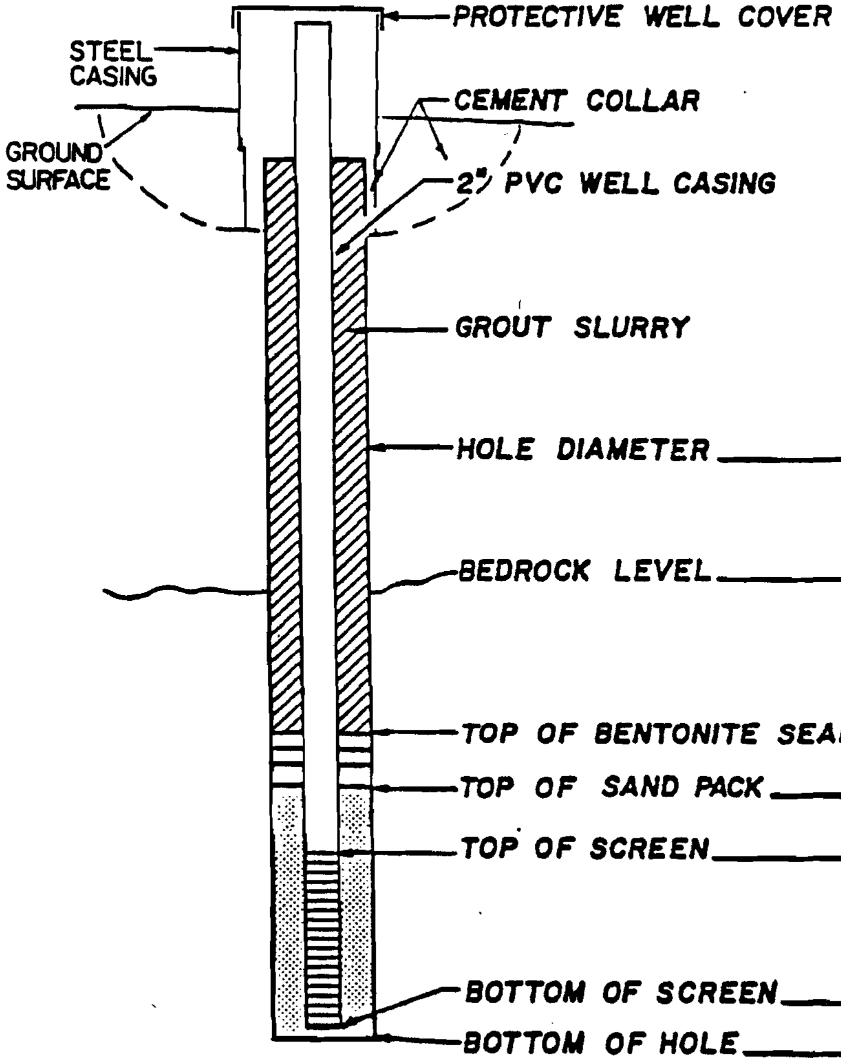
DRAWING NOT TO SCALE.

PIEZOMETER CONSTRUCTION IN ROCK

WELL NO. 1122 DATE INSTALLED: July 1987

MAP NO. SWSA-7 EXT.

LOCATION NORTH: EAST:



HOLE DIAMETER 6 1/8"

BEDROCK LEVEL 15'

TOP OF BENTONITE SEAL 33'

TOP OF SAND PACK 35'

TOP OF SCREEN 35.5'

BOTTOM OF SCREEN 45.5'

BOTTOM OF HOLE 45.5'

NOTE: ALL DEPTHS ARE RELATIVE TO TOP OF GROUND.

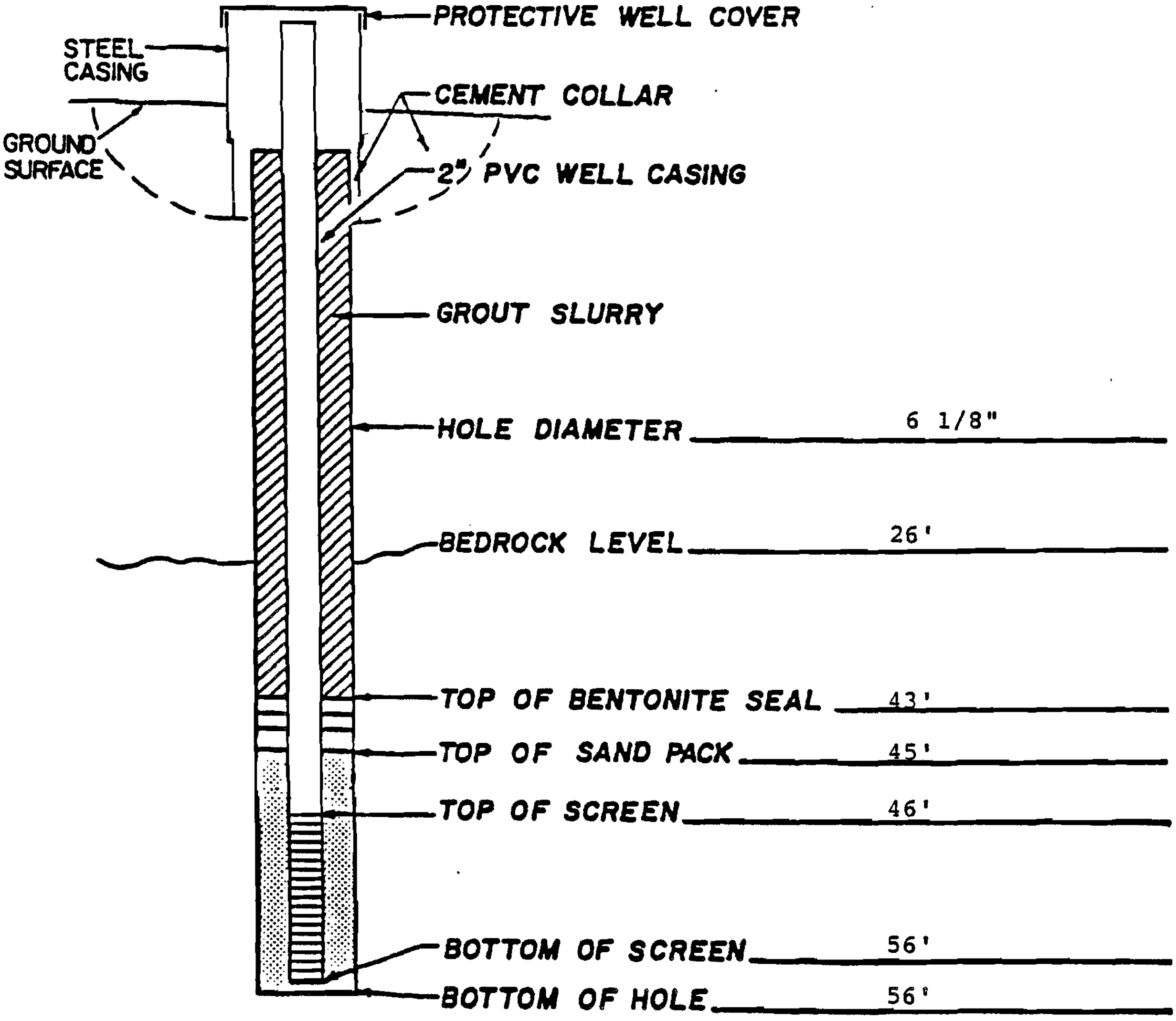
DRAWING NOT TO SCALE.

PIEZOMETER CONSTRUCTION IN ROCK

WELL NO. 1123 DATE INSTALLED: July 1987

MAP NO. SWSA-7 EXT.

LOCATION NORTH: EAST:



HOLE DIAMETER 6 1/8"

BEDROCK LEVEL 26'

TOP OF BENTONITE SEAL 43'

TOP OF SAND PACK 45'

TOP OF SCREEN 46'

BOTTOM OF SCREEN 56'

BOTTOM OF HOLE 56'

NOTE: ALL DEPTHS ARE RELATIVE TO TOP OF GROUND.

DRAWING NOT TO SCALE.

PIEZOMETER CONSTRUCTION ABOVE BED ROCK

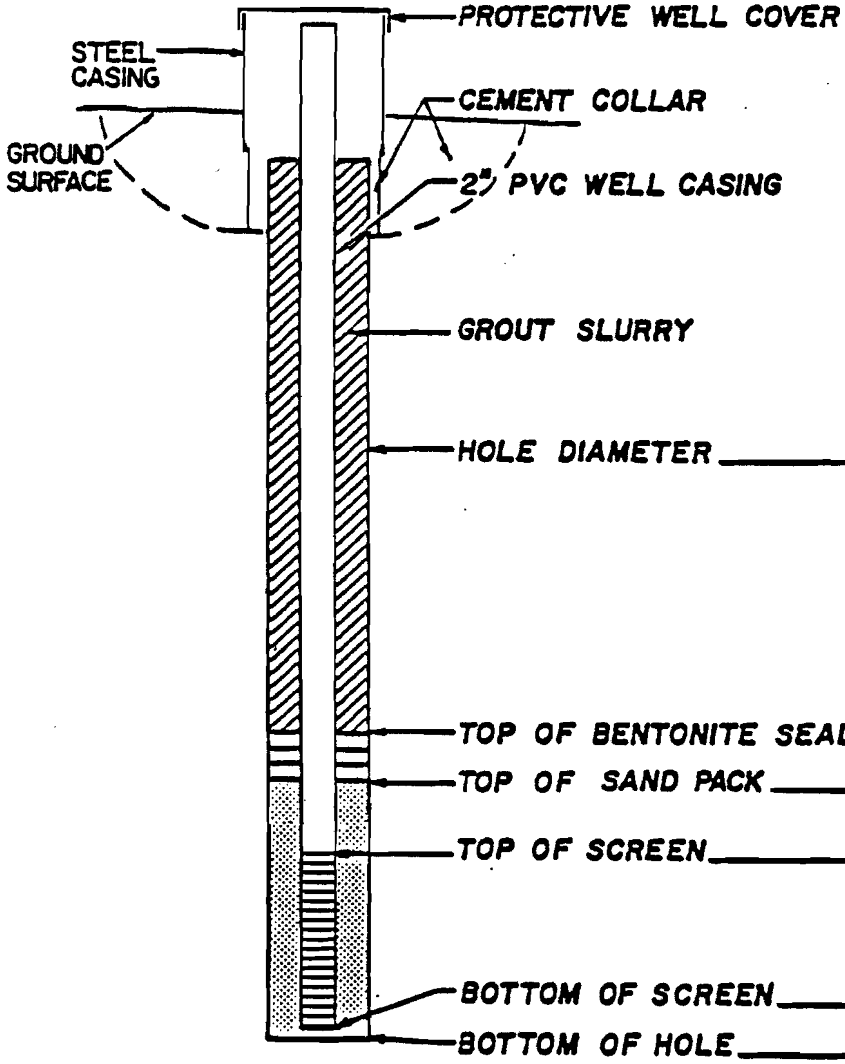
WELL NO. 1124

DATE INSTALLED: July 1987

MAP NO. SWSA-7 EXT.

LOCATION NORTH:

EAST:



HOLE DIAMETER 6 1/8"

TOP OF BENTONITE SEAL 3'

TOP OF SAND PACK 5'

TOP OF SCREEN 5.5'

BOTTOM OF SCREEN 10.5'

BOTTOM OF HOLE 10.5'

BEDROCK LEVEL 10.5'

NOTE: ALL DEPTHS ARE RELATIVE TO TOP OF GROUND.

DRAWING NOT TO SCALE.

PIEZOMETER CONSTRUCTION ABOVE BED ROCK

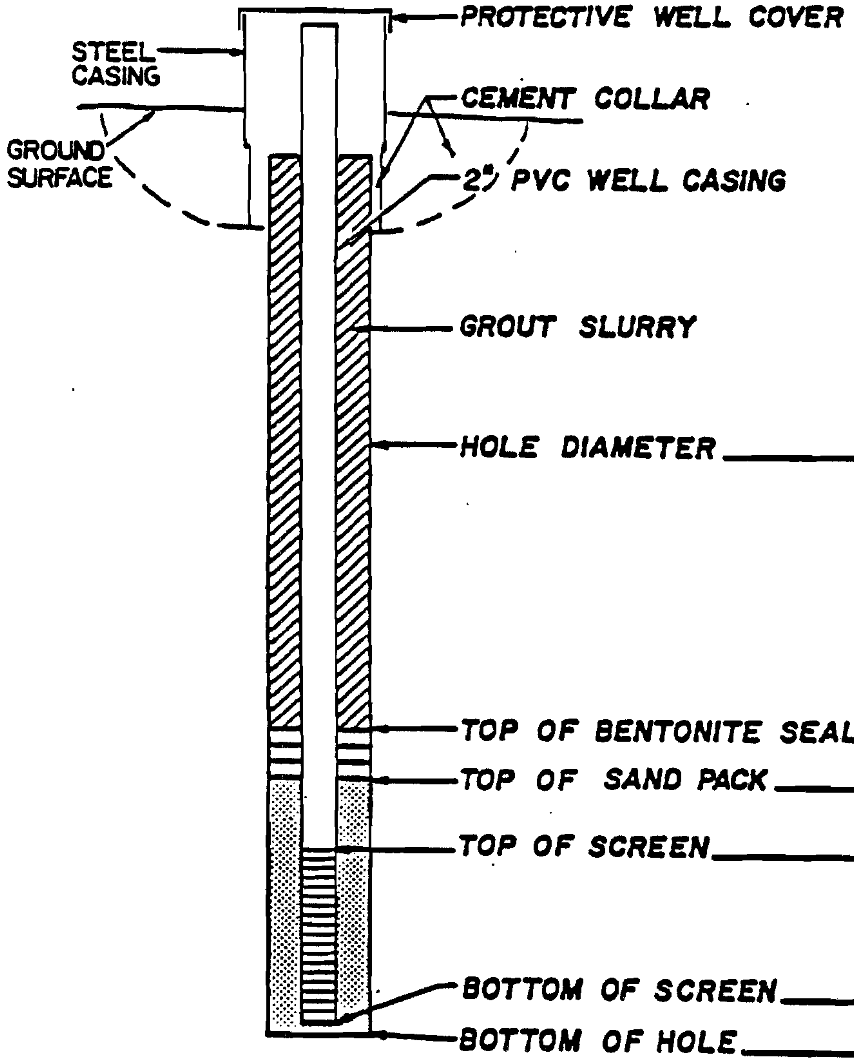
WELL NO. 1125

DATE INSTALLED: July 1987

MAP NO. SWSA-7 EXT.

LOCATION NORTH:

EAST:



HOLE DIAMETER 6 1/8"

TOP OF BENTONITE SEAL 12'

TOP OF SAND PACK 15'

TOP OF SCREEN 16.5'

BOTTOM OF SCREEN 26.5'

BOTTOM OF HOLE 26.5'

BEDROCK LEVEL 26.5'

NOTE: ALL DEPTHS ARE RELATIVE TO TOP OF GROUND.

DRAWING NOT TO SCALE.

PIEZOMETER CONSTRUCTION IN ROCK

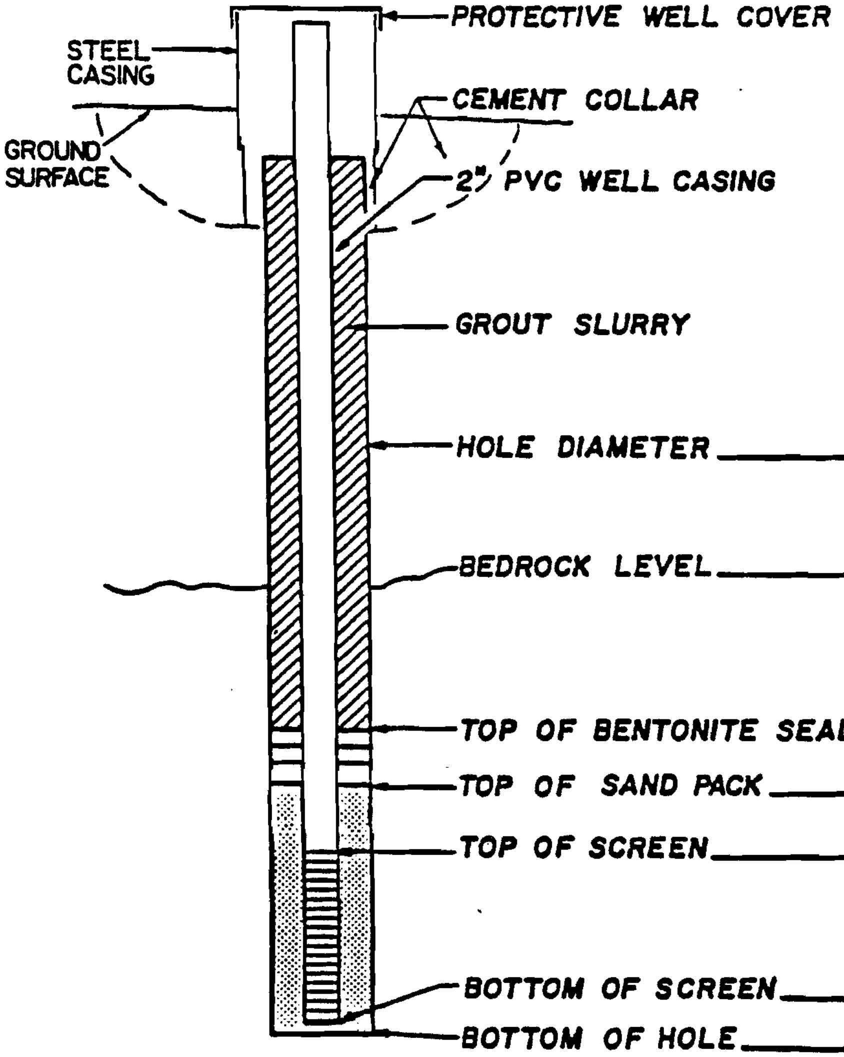
WELL NO. 1126

DATE INSTALLED: July 1987

MAP NO. SWSA-7 EXT.

LOCATION NORTH:

EAST:



HOLE DIAMETER 6 1/8"

BEDROCK LEVEL 25'

TOP OF BENTONITE SEAL 41'

TOP OF SAND PACK 44'

TOP OF SCREEN 45'

BOTTOM OF SCREEN 55'

BOTTOM OF HOLE 55'

NOTE: ALL DEPTHS ARE RELATIVE TO TOP OF GROUND.

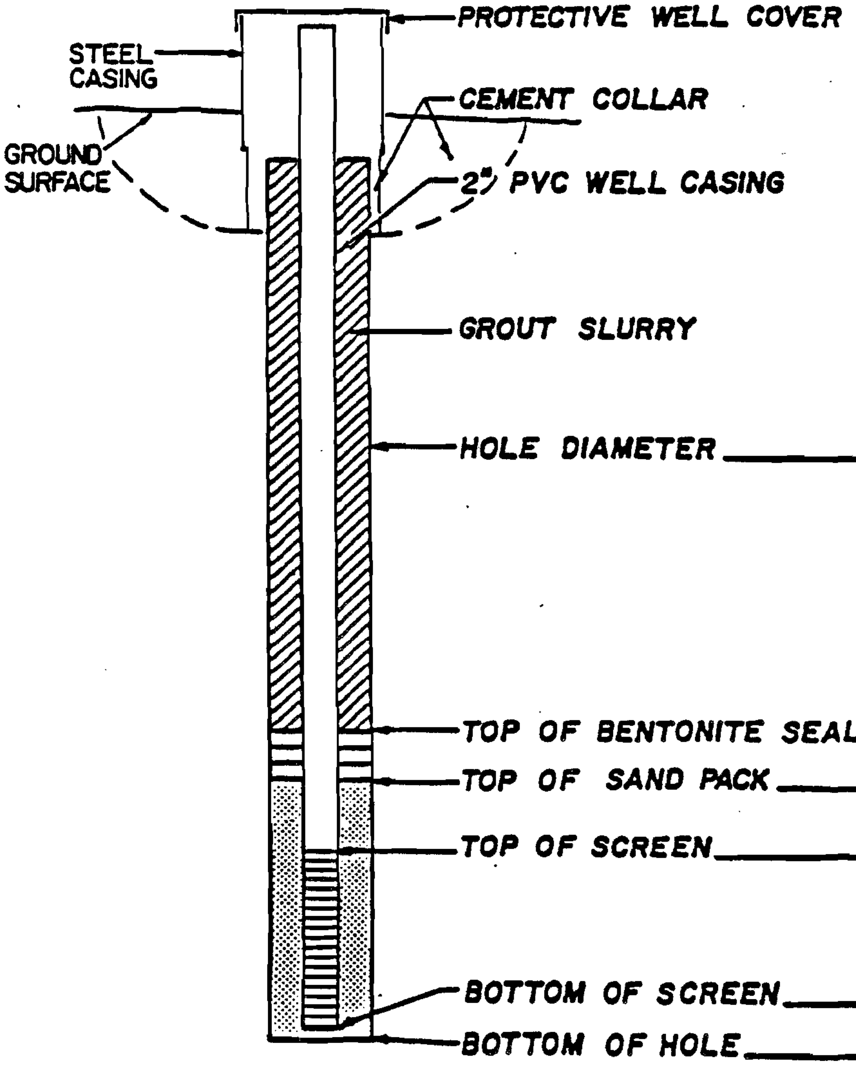
DRAWING NOT TO SCALE.

PIEZOMETER CONSTRUCTION ABOVE BED ROCK

WELL NO. 1127 DATE INSTALLED: July 1987

MAP NO. SWSA-7 EXT.

LOCATION NORTH: EAST:



HOLE DIAMETER 6 1/8"

TOP OF BENTONITE SEAL 7'

TOP OF SAND PACK 9'

TOP OF SCREEN 10'

BOTTOM OF SCREEN 20'

BOTTOM OF HOLE 25'

BEDROCK LEVEL 25'

NOTE: ALL DEPTHS ARE RELATIVE TO TOP OF GROUND.

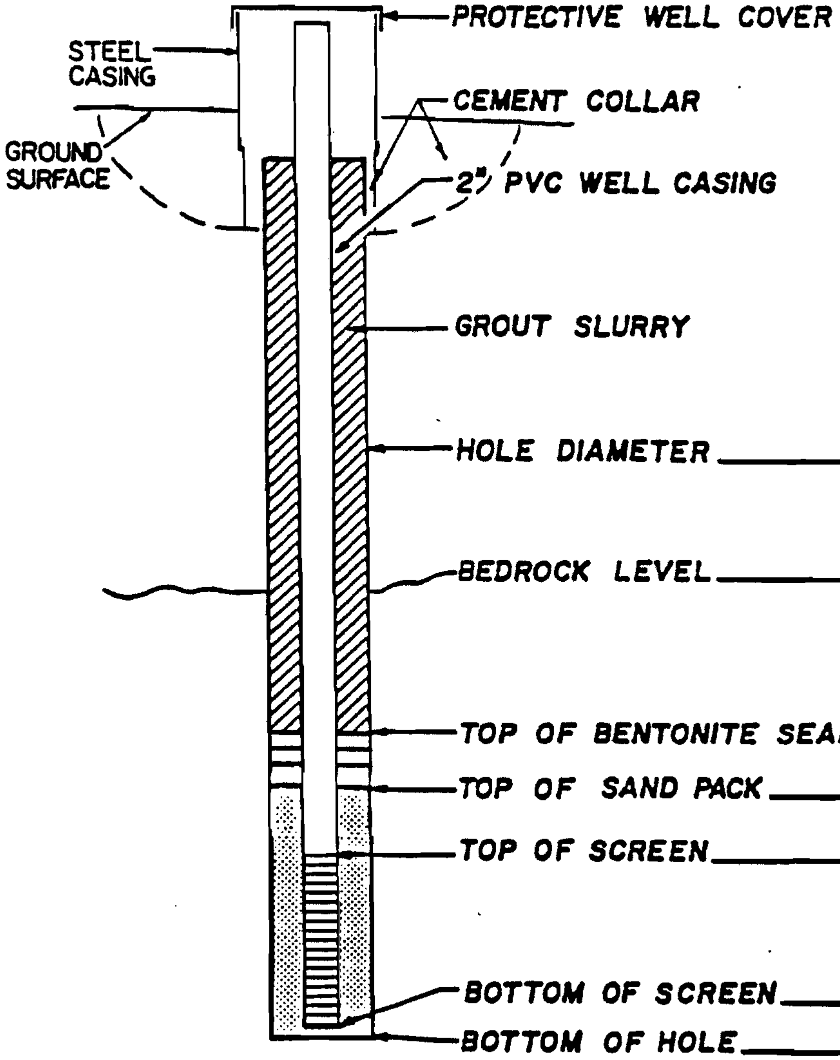
DRAWING NOT TO SCALE.

PIEZOMETER CONSTRUCTION IN ROCK

WELL NO. 1128 DATE INSTALLED: July 1987

MAP NO. SWSA-7 EXT.

LOCATION NORTH: EAST:



HOLE DIAMETER 6 1/8"

BEDROCK LEVEL 25'

TOP OF BENTONITE SEAL 41'

TOP OF SAND PACK 43'

TOP OF SCREEN 45'

BOTTOM OF SCREEN 55'

BOTTOM OF HOLE 55'

NOTE: ALL DEPTHS ARE RELATIVE TO TOP OF GROUND.

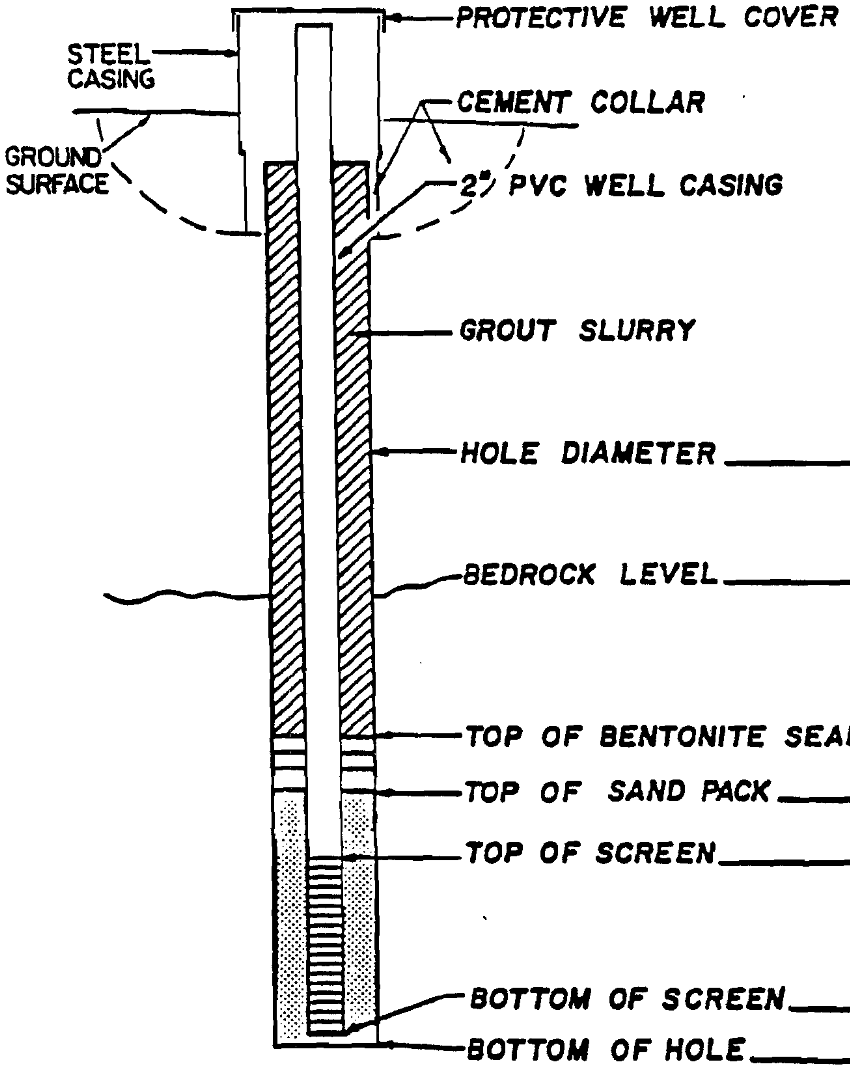
DRAWING NOT TO SCALE.

PIEZOMETER CONSTRUCTION IN ROCK

WELL NO. 1129 DATE INSTALLED: July 1987

MAP NO. SWSA-7 EXT.

LOCATION NORTH: EAST:



HOLE DIAMETER 6 1/8"

BEDROCK LEVEL 19'

TOP OF BENTONITE SEAL 26'

TOP OF SAND PACK 28'

TOP OF SCREEN 29.5'

BOTTOM OF SCREEN 39.5'

BOTTOM OF HOLE 39.5'

NOTE: ALL DEPTHS ARE RELATIVE TO TOP OF GROUND.

DRAWING NOT TO SCALE.

APPENDIX C

SWSA 7 WELL HYDROGRAPHS

R. H. Ketelle

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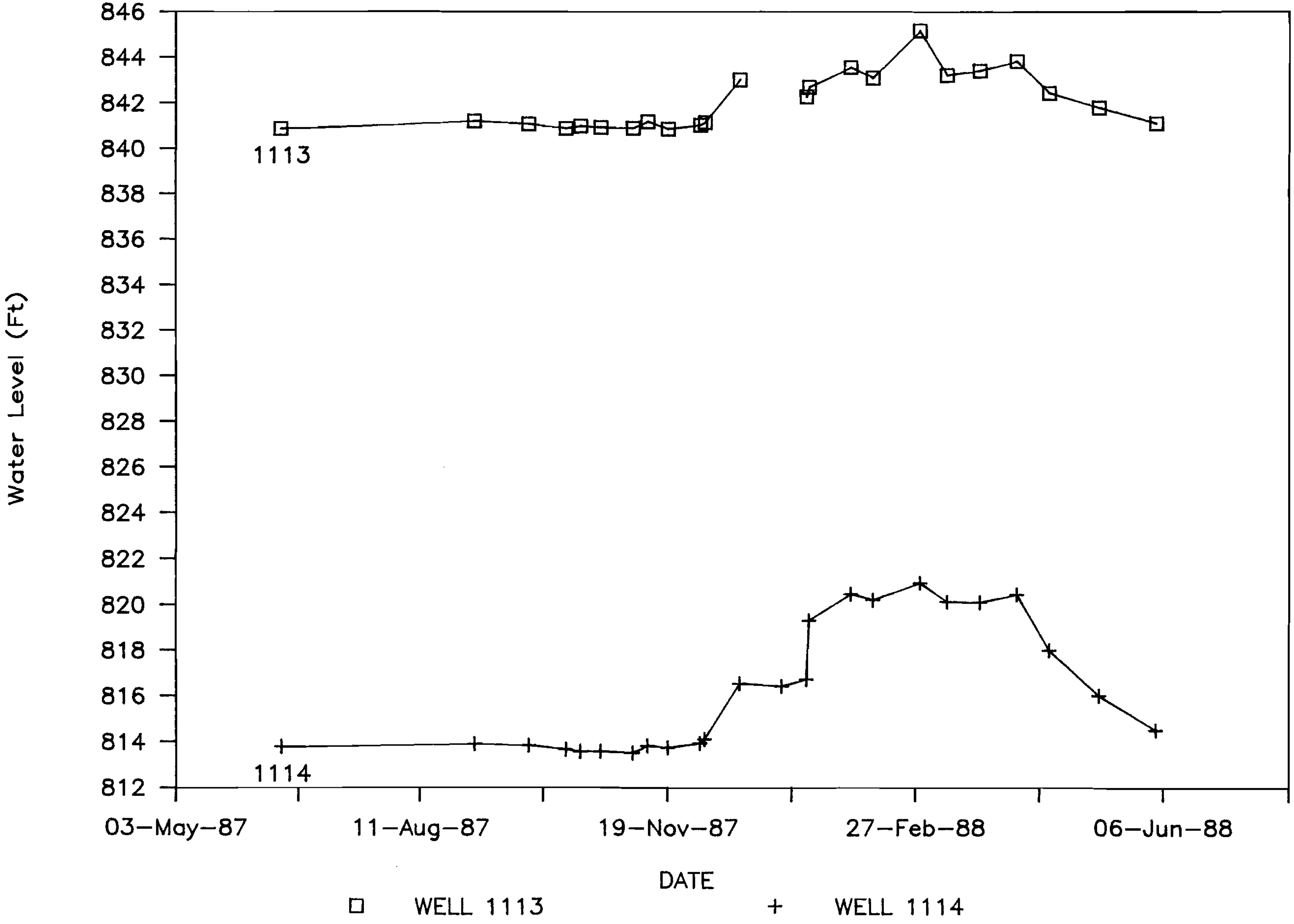
SWSA 7 HYDROGRAPHS



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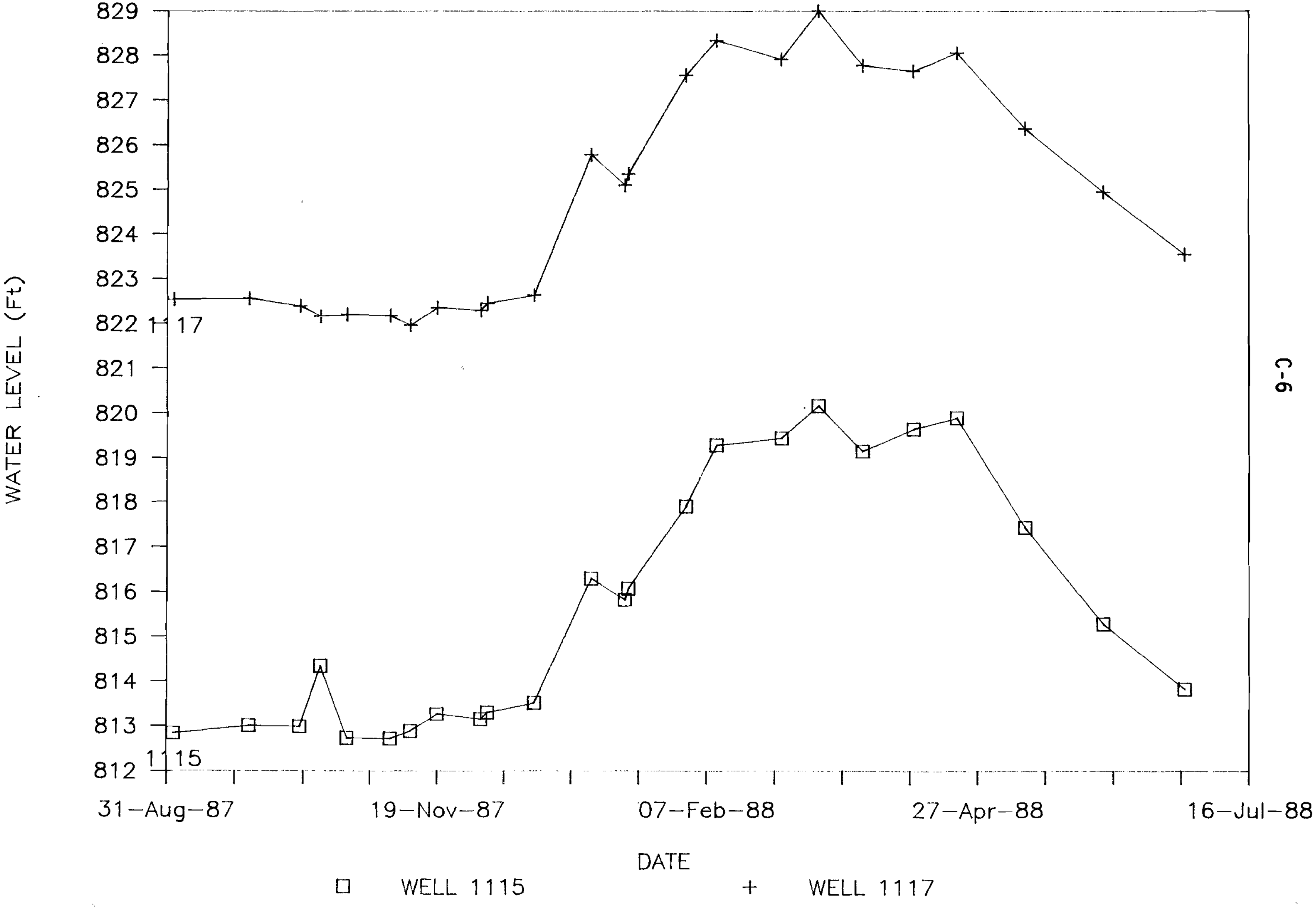

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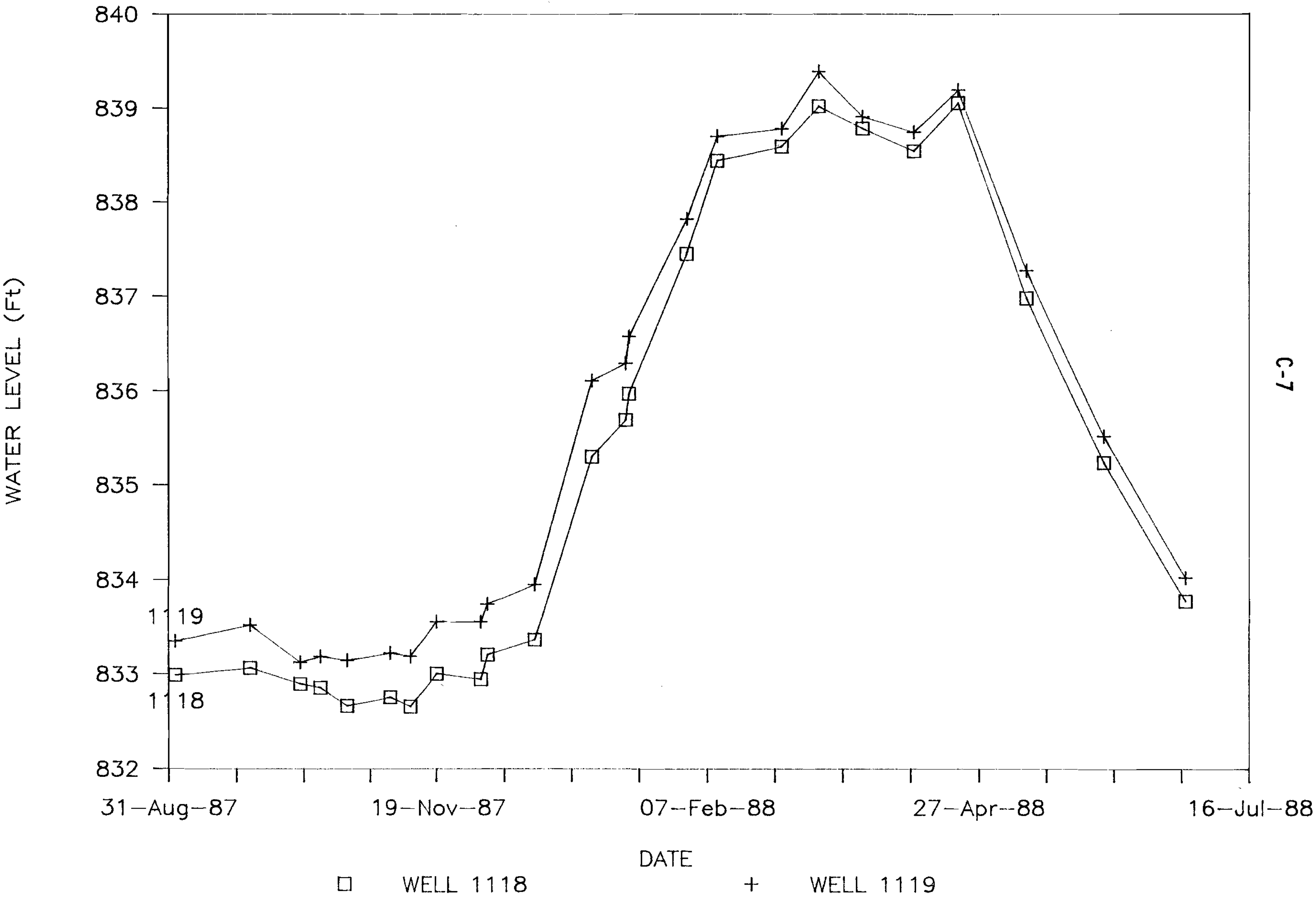

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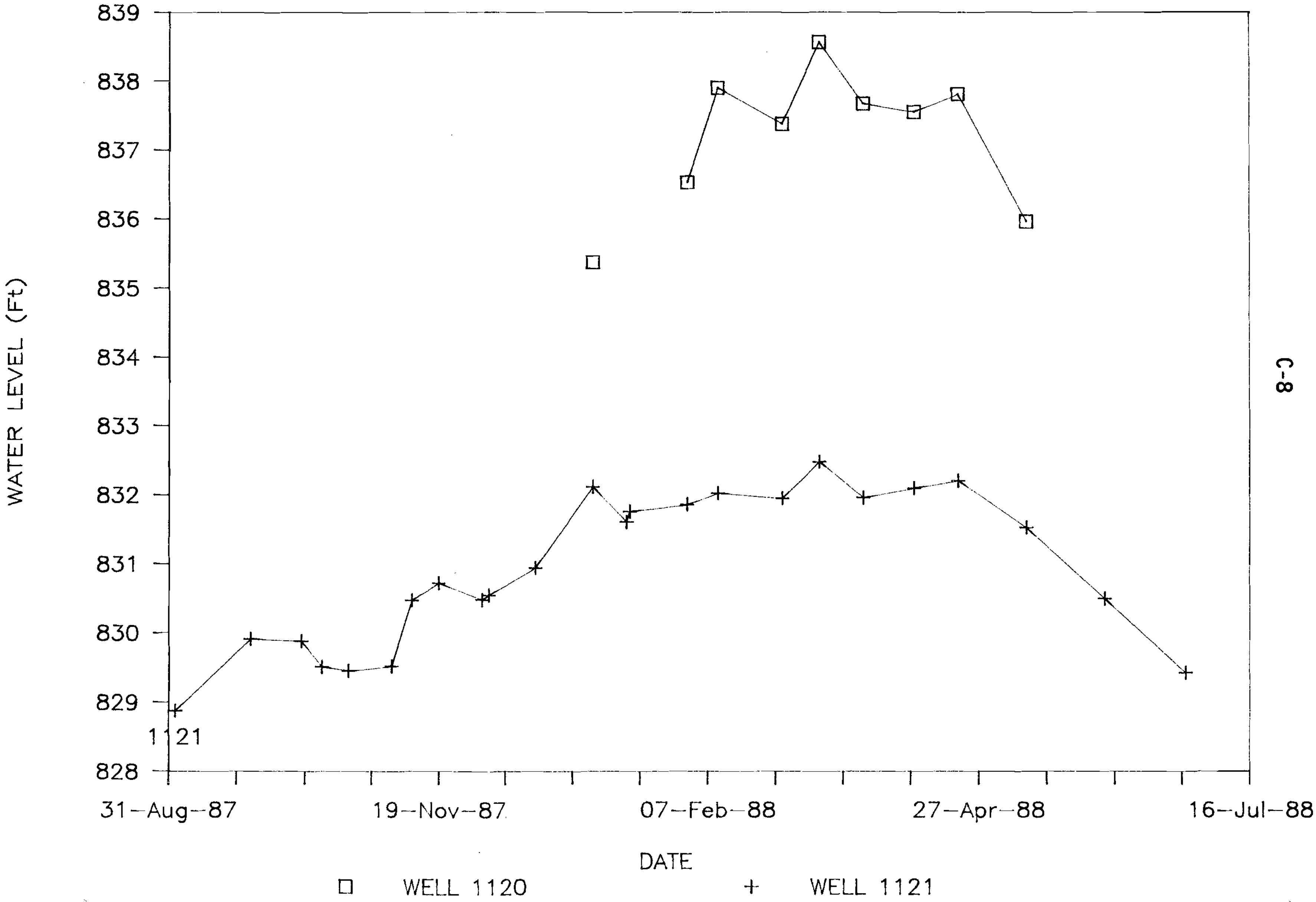

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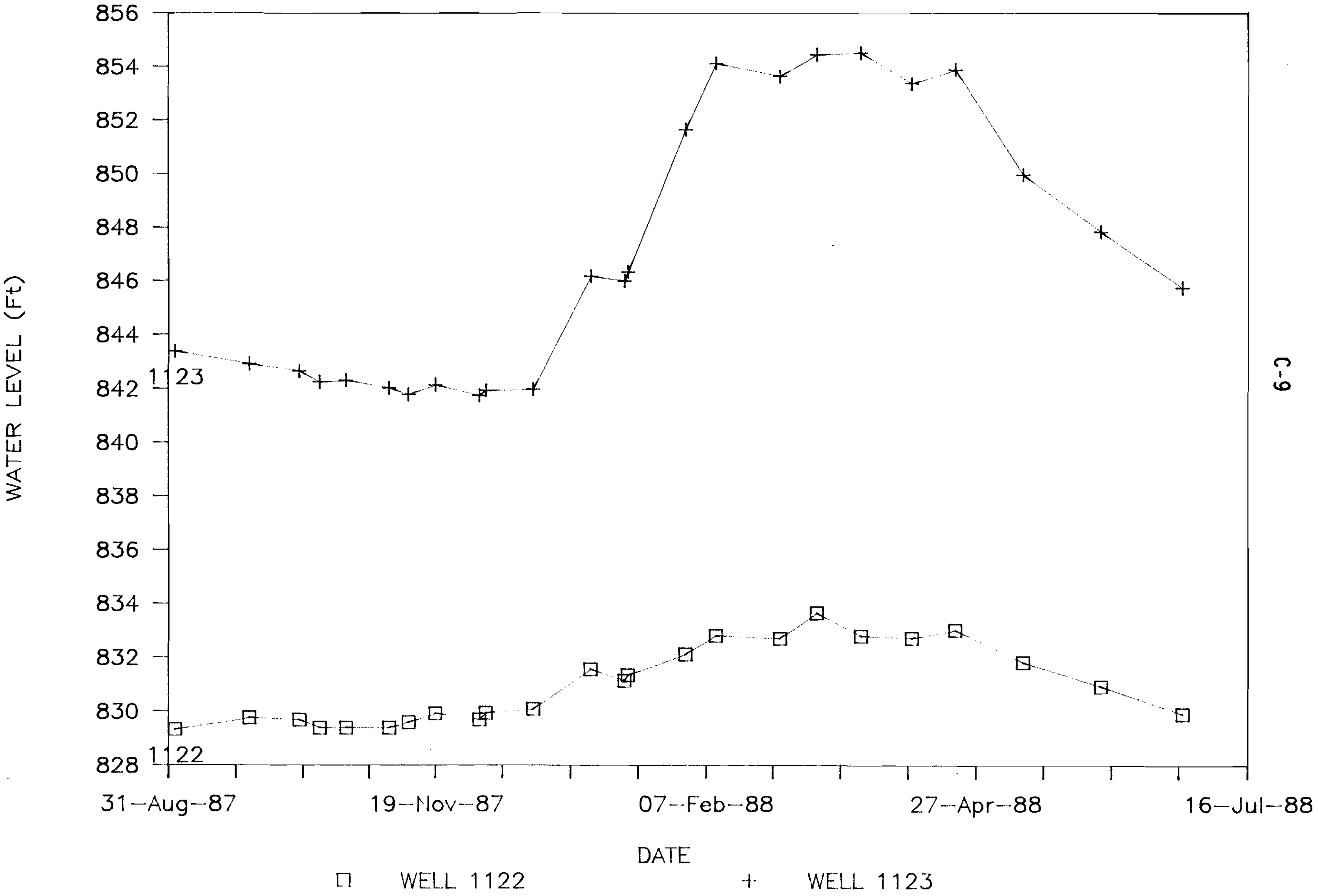

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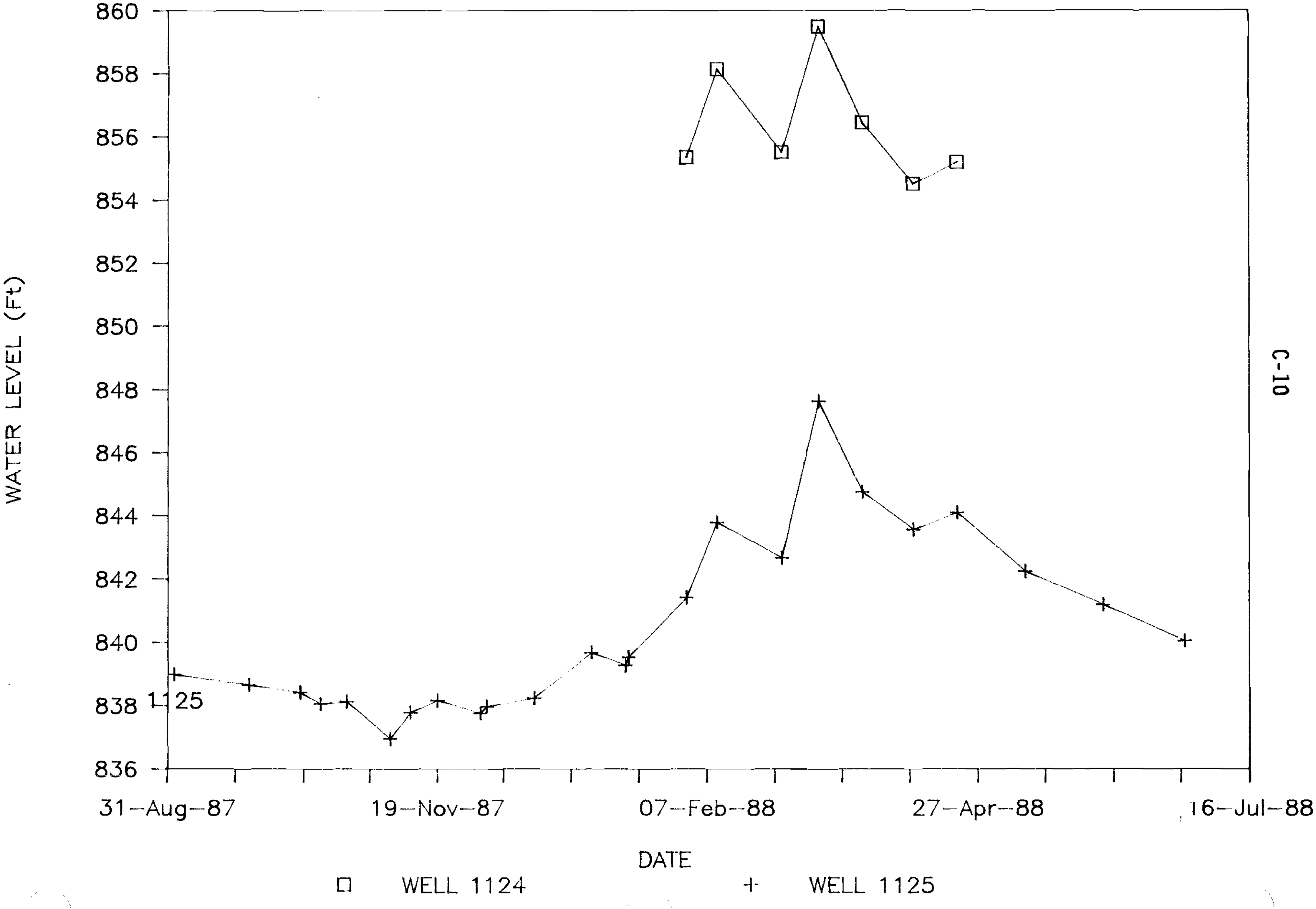
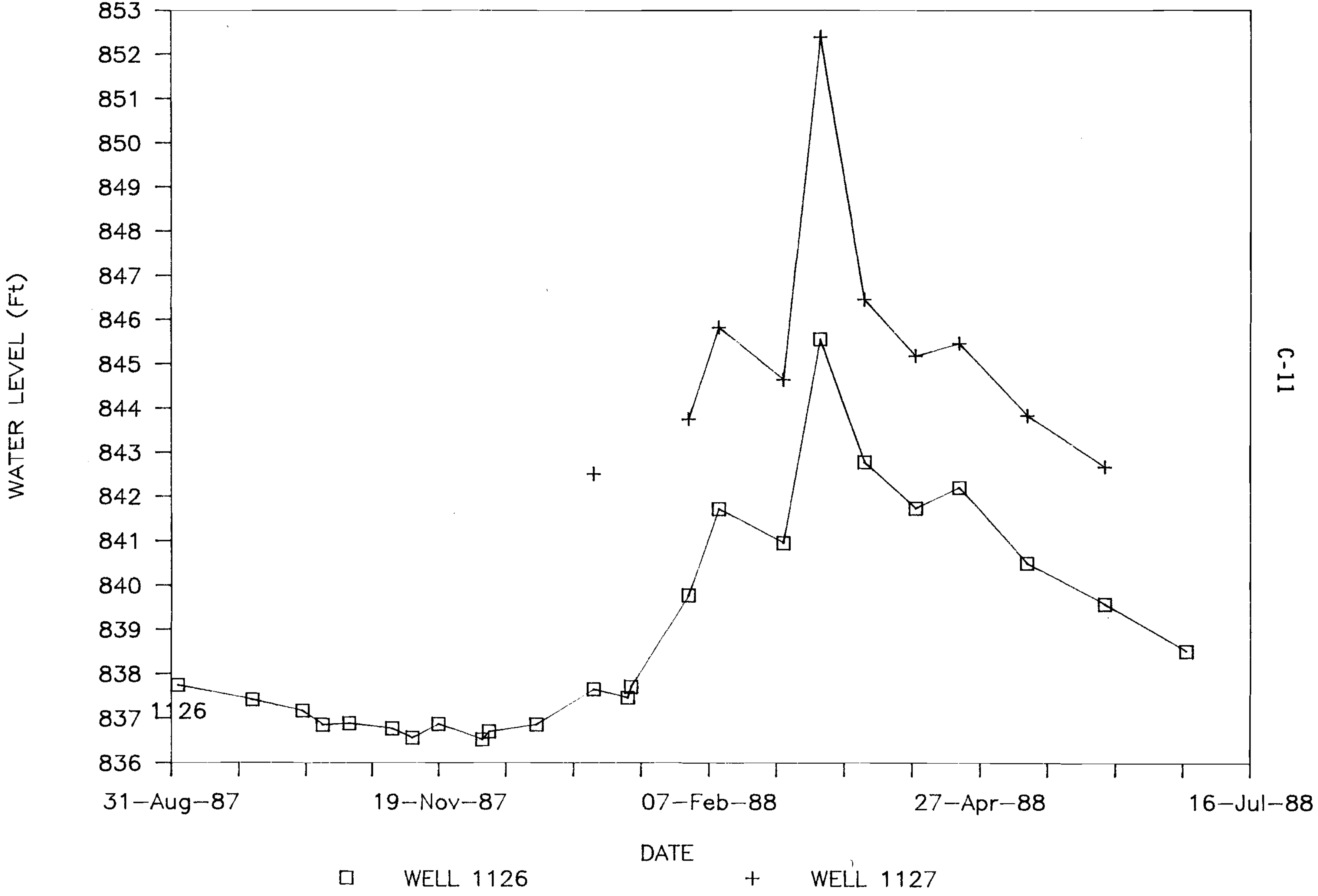
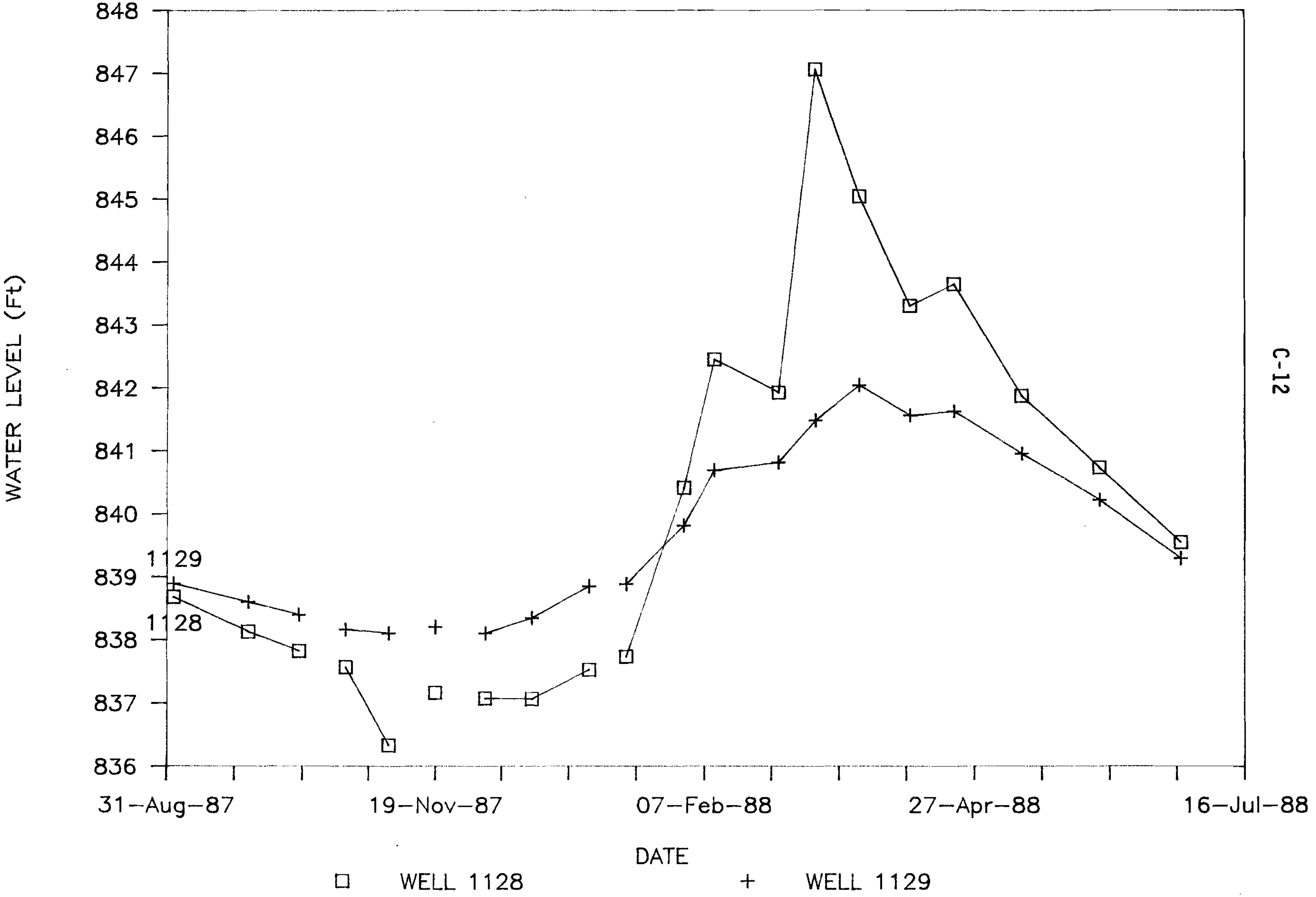


SWSA 7 HYDROGRAPHS



SWSA 7 HYDROGRAPHS



APPENDIX D

LLWDDD 1987-1988 WATER QUALITY DATA

K. L. Daniels

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LIST OF TABLES

LIST OF TABLES (continued)

APPENDIX D

LLWDDD 1987 AND 1988 WATER QUALITY DATA

1. SAMPLING AND ANALYSIS PROCEDURES

Surface water samples were collected from three areas, SWSA 7, Bear Creek Valley and West Chestnut Ridge during three sampling periods, December 1987, March, and May, 1988 (No groundwater samples were taken for the East Chestnut Ridge site during this time period). Groundwater samples were collected at the same time from the same areas, except that no samples were collected in Bear Creek Valley. Groundwater and surface water samples were collected using the procedures described in Appendix A. During the time of sample collection, in situ measurements of conductivity, dissolved oxygen (DO), pH, and temperature were made. Samples were preserved, when appropriate, according to EPA procedures. Samples were analyzed in the laboratory for organic compounds, inorganic elements, anions, and radionuclides. Thirty four volatile analytes were determined using a gas chromatograph-mass spectrometer. Thirty of the metals were determined using ICP analysis, while mercury (HG), selenium (SE), and arsenic (AS) were determined using atomic absorption. Nitrate (NO3), phosphate (PO4), sulfate (SO4), and total alkalinity were determined using ion chromatography. Total uranium was determined by fluorometric analysis. Gross alpha and gross beta are determined by direct counting. Total strontium and tritium are determined by radiochemical separations and specific counting to ascertain radionuclide activity. A more complete description of the analytical methods is found in Appendix B. Quality assurance measures used in the conduct of this sampling and analysis effort is given in Appendix C. In order to validate sampling data, field quality control samples consisting of duplicate samples and field blanks were collected. One or two each of duplicate and blank samples (approximately 5 to 10 percent) were collected each sampling period and analyzed as blind samples by the analytical laboratory. Blanks were prepared with deionized/distilled water that met or exceeded ASTM Type II water. Blank samples were containerized in appropriate containers, transported to the field, and handled in the same manner as the field samples. This handling included adding appropriate preservatives and filtering any samples requiring filtration. Additionally, in order to determine the accuracy of the analytical measurements, a deionized/distilled water sample was spiked and submitted each sampling period. Results of analysis of these QC samples are given in Appendix C.

1.1 SAMPLING AND ANALYTICAL RESULTS

This section summarizes the results of the sampling and analysis efforts. Results were screened for the first three sampling periods to determine which analytes were not detected. Summary statistics (number of samples, maximum, minimum, and mean) are given for each analyte that was detected at least once during the three quarters of sampling. Values at the analytical limit of detection are used at face value to calculate the average value. A "less than" qualifier is placed on the average value if at least one of the numbers used to calculated the average was below the analytical detection limit. For example, if there were three values for arsenic, 10, <10, and 40, then the average value is <20.

For summarization purposes, the metals, anions, total alkalinity, and total uranium analyses (38 analytes) were grouped together as "Inorganics". Other groupings included the volatile organics (34 analytes) - "Organics", four radiochemical analyses - "Radionuclides", and the four field measurements - "Field."

1.1.1 Summary

This section summarizes the results of sample analysis. Summary tables contain statistics (number of samples, maximum, minimum, and mean values) of analytes that were detected at least once. Values less than the analytical detection limit are taken at face value for calculation of the mean value. If any one of the values used to calculate the mean were less than the detection limit, then the mean value has a "less than" qualifier. Radionuclide concentrations have been corrected for instrument background. As a result, there are no "less than" detectable values and the values may be negative. This implies that the sample concentration is the same as the background. Negative values are a result of natural variability in the measurement of background concentrations.

Table 1.1 lists analytes that were not detected in any area during any of the three sampling periods in either ground water or surface water samples. Approximately 40% of the analytes (31) measured were not detected. Of these, about 60% of the volatile organics were not detected. Tables 1.2 and 1.3 list the analytes that were not detected in the ground water and surface water, respectively. In addition to the analytes not detected anywhere, nitrate was not found in any of the ground water samples (Table 1.2). Forty-four analytes were not found in any of the surface water samples. Only four volatile organic compounds were detected. Tables 1.4-1.6 list the analytes that were not detected in each of the three areas sampled.

1.1.1.1 Ground water

Overall summaries of the analytes measured in the ground water for all areas are given in Table 1.7. Table 1.8 summarizes the analyte concentrations in ground water for each of the areas. Table 1.9 is a well-specific summary of analyte concentrations.

SWSA 7

Seven volatile organic compounds were found in SWSA 7 samples: acetone, carbon disulfide, chlormethane, trichloroethane, ethylbenzene, methylene chloride, and xylene (see Table 1.8). Of these, acetone and methylene chloride are considered common laboratory contaminants that may be introduced into the samples. The EPA has suggested that if the quantity in the sample is more than 5 times the quantitation limit (5 mg/L for methylene chloride and 10 mg/L for acetone), then it is possible that the compound is present in the sample and is not derived from the laboratory. Using this criteria, methylene chloride may be present in wells 1117, 1126, and 7-12. Methylene chloride was detected in all eight wells, with the highest concentrations in wells 1126 (61 μg/L) and 7-12 (67 μg/L). Acetone is not believed to be present in the well samples based on this criteria and the results of analysis of field and method blanks. It was present in both of these blanks. The presence of trichloroethene in one well sample (1117) from the SWSA 7 is questionable. It was found in the field blank at a concentration exceeding that in the highest well sample. Because the other compounds were not found in either the field or method blank, they are believed to be present in the well samples.

Alkalinity, calcium magnesium, sulfate, and dissolved oxygen were highest in well 7-12. Sodium and conductivity were also high in this well relative to the other wells, except number 1126. Sodium was highly variable in well 7-7, ranging from 0.2 to 93 mg/L. Sulfate was consistently high in well 7-12, ranging from 1200 to 1400 mg/L.

Mercury was found in all wells in SWSA 7 except 1117, with the highest concentrations in well 7-7 (0.001 mg/L). No arsenic, lead, or selenium were found in any of the wells in SWSA 7. Zinc in well 7-16 ranged from 0.02 to 0.21 mg/L.

Gross alpha, gross beta, and total strontium concentrations were similar to those in the field blank. Tritium ranged from -20 to 49 Bq/L in SWSA 7. The highest concentrations of tritium were found all three sampling periods in well 7-4. Concentrations ranged from 30-49 Bq/L.

West Chestnut Ridge (WCR)

Eight volatile organic compounds were found in samples from WCR. There were from none to 5 compounds in each of the 9 wells. No organic compounds were found in well 18-A. Duplicate samples collected from well 18-B had concentrations of methylene chloride of 7 and 50 μg/L. It is suspected that there was some laboratory contamination of one of these duplicates. Methylene chloride was found in detectable quantities in all wells in WCR, except 18-A. No other compounds were found in wells 18-B, 9-A, 9-B, and PW6. Four and five volatile compounds were found in wells 3-B, 6-A, and 6-B (Table 1.9). There was 2-butanone found in well 3-B. This compound was also found at a high level (910 μg/L) in one of the field blanks. It is suspected that this was due to laboratory contamination. Carbon tetrachloride was also detected in one of the field blanks (12 μg/L) and in one of these well samples (well 6-B).

Alkalinity was highly variable during the three sampling periods in well 9-B. Concentrations ranged from 0.5 to 160 mg/L. Manganese was also variable in well 6-A, ranging from 0.011 to 180 mg/L.

Mercury was found in four of the wells. In comparing the duplicate analyses for well 18-B, mercury was found in only one of these samples. No lead, arsenic, or selenium were found in any of the well samples from WCR.

Gross alpha, gross beta, and total strontium concentrations were similar to those in the field blanks. Tritium in WCR ranged from -40 to 36 Bq/L. It was above the background concentration in all wells, except 18-A.

1.1.1.2 Surface water

Overall summaries of the analytes measured in the surface water for all areas are given in Table 1.10. Table 1.11 summarizes the analyte concentrations in surface water for each of the areas. Table 1.12 is a station-specific summary of analyte concentrations.

Bear Creek Valley (BCV)

Ethylbenzene, methylene chloride, and xylene were the only volatile compounds detected in the surface waters of BCV. Concentrations of these compounds were low and close to the analytical detection limit.

No mercury, arsenic, selenium, or lead were found in any of the surface water samples collected from BCV. Beryllium was detected at all stations except for the duplicate from Flume 672. Concentrations ranged up to 0.001 mg/L. Cadmium was found in all samples except those from flumes 672 and 673. The maximum concentration of cadmium in BCV was 0.003 mg/L. Nickel was present in the water from only two locations, flumes 273 and 673. Zinc was detected at all stations, with the maximum concentration observed at Flume 677 (0.067 mg/L).

Gross alpha, gross beta, and total strontium concentrations were similar to the concentrations in the field blanks. Tritium concentrations ranged from -7 to 34 Bq/L and were about the same at all stations.

SWSA 7

Only two volatile organics were found in surface waters in SWSA 7: acetone and methylene chloride. Methylene chloride was found at all stations ranging from <3 to 320 μg/L (Table 1.11). Acetone was found at all stations except the east flume. Concentrations ranged from <10 to 400 μg/L (Table 1.11). The highest concentrations of both compounds were found at the Upper Melton Branch Flume (Table 1.12).

No mercury, arsenic, lead, or selenium were detected in any of the surface water samples in SWSA 7. Beryllium was detected at all stations except the West Flume, with maximum concentrations of 0.001 mg/L. Cadmium was detected only at the Central Flume. Nickel was present only at the Central and East Flume waters.

Gross alpha, gross beta, and total strontium concentrations were similar to the concentrations in the field blanks. Tritium was above background in all samples. The concentrations were about the same at all stations, ranging from 17 to 72 Bq/L.

West Chestnut Ridge (WCR)

Three volatile organic compounds were found in the surface waters of WCR: ethylbenzene, methylene chloride, and xylene (Table 1.11). Ethylbenzene was found in concentrations ranging from 2 to 5 μg/L in samples collected from Flume 7, Flume 8, and Weir 4. It was detected in only one of the field duplicates from Flume 7. Methylene chloride was found in samples from weirs 1, 3, and 4, with the maximum concentration found in water from weir 3 (23 μg/L). Xylene was found only in samples from Flumes 7 and 8. It was detected in both duplicates from Flume 7. Detectable concentrations ranged from 2 to 5 μg/L.

No mercury, arsenic, selenium, or lead were found in any of the surface water samples collected from WCR. Beryllium was detected at all stations except Flume 8. Concentrations ranged up to 0.001 mg/L. Cadmium was found in only one of the duplicate samples from Flume 7. The maximum concentration of cadmium at this station was 0.003 mg/L. Nickel was present at all locations, except Flume 7 and Weir 4. The highest concentrations (0.036 mg/L) were observed at weirs 1 and 3.

Gross alpha, gross beta, and total strontium concentrations were similar to the concentrations in the field blanks. Tritium concentrations ranged from -2 to 50 Bq/L and were about the same at all stations.

Table 1.1. List of analytes that were not detected anywhere during the 1st - 3rd quarters of sampling

Analyte
1,1,1-TRICHLOROETHANE
1,1,2,2-TETRACHLOROETHANE
1,1,2-TRICHLOROETHANE
1,1-DICHLOROETHANE
1,1-DICHLOROETHENE
1,2-DICHLOROETHANE
1,2-DICHLOROETHENE (TOTAL)
1,2-DICHLOROPROPANE
2-HEXANONE
4-METHYL-2-PENTANONE
AG
AS
BENZENE
BROMOFORM
BROMOMETHANE
CHLOROBENZENE
CHLOROETHANE
CIS-1,3-DICHLOROPROPENE
DIBROMOCHLOROMETHANE
GA
PB
PO4
SB
SE
SN
STYRENE
TETRACHLOROETHENE
TRANS-1,3-DICHLOROPROPENE
VINYL ACETATE
VINYL CHLORIDE
ZR

Table 1.2. List of analytes that were not detected in ground water during the 1st - 3rd quarters of sampling

Analyte
1,1,1-TRICHLOROETHANE
1,1,2,2-TETRACHLOROETHANE
1,1,2-TRICHLOROETHANE
1,1-DICHLOROETHANE
1,1-DICHLOROETHENE
1,2-DICHLOROETHANE
1,2-DICHLOROETHENE (TOTAL)
1,2-DICHLOROPROPANE
2-HEXANONE
4-METHYL-2-PENTANONE
AG
AS
BENZENE
BROMOFORM
BROMOMETHANE
CHLOROBENZENE
CHLOROETHANE
CIS-1,3-DICHLOROPROPENE
DIBROMOCHLOROMETHANE
GA
NO3
PB
PO4
SB
SE
SN
STYRENE
TETRACHLOROETHENE
TRANS-1,3-DICHLOROPROPENE
VINYL ACETATE
VINYL CHLORIDE
ZR

Table 1.3. List of analytes that were <u>not detected</u> in surface water during the 1st - 3rd quarters of sampling

Analyte
1,1,1-TRICHLOROETHANE
1,1,2,2-TETRACHLOROETHANE
1,1,2-TRICHLOROETHANE
1,1-DICHLOROETHANE
1,1-DICHLOROETHENE
1,2-DICHLOROETHANE
1,2-DICHLOROETHENE (TOTAL)
1,2-DICHLOROPROPANE
2-BUTANONE
2-HEXANONE
4-METHYL-2-PENTANONE
AG
AS
BENZENE
BROMODICHLOROMETHANE
BROMOFORM
BROMOMETHANE
CARBON DISULFIDE
CARBON TETRACHLORIDE
CHLOROBENZENE
CHLOROETHANE
CHLOROFORM
CHLOROMETHANE
CIS-1,3-DICHLOROPROPENE
CO
DIBROMOCHLOROMETHANE
F
GA
HG
MO
P
PB
PO4
SB
SE
SN
STYRENE
TETRACHLOROETHENE
TOLUENE
TRANS-1,3-DICHLOROPROPENE
TRICHLOROETHENE
VINYL ACETATE
VINYL CHLORIDE
ZR

Table 1.4. List of analytes that were <u>not detected</u> in each area during the 1st - 3rd quarters of sampling

AREA=SWSA 7

Analyte
1,1,1-TRICHLOROETHANE
1,1,2,2-TETRACHLOROETHANE
1,1,2-TRICHLOROETHANE
1,1-DICHLOROETHANE
1,1-DICHLOROETHENE
1,2-DICHLOROETHANE
1,2-DICHLOROETHENE (TOTAL)
1,2-DICHLOROPROPANE
2-BUTANONE
2-HEXANONE
4-METHYL-2-PENTANONE
AG
AS
BENZENE
BROMODICHLOROMETHANE
BROMOFORM
BROMOMETHANE
CARBON TETRACHLORIDE
CHLOROBENZENE
CHLOROETHANE
CHLOROFORM
CIS-1,3-DICHLOROPROPENE
DIBROMOCHLOROMETHANE
GA
MO
NO3
PB
PO4
SB
SE
SN
STYRENE
TETRACHLOROETHENE
TOLUENE
TRANS-1,3-DICHLOROPROPENE
VINYL ACETATE
VINYL CHLORIDE
ZR

Table 1.5. List of analytes that were not detected in each area during the 1st - 3rd quarters of sampling

AREA=WEST CHESTNUT RIDGE

Analyte
1,1,1-TRICHLOROETHANE
1,1,2,2-TETRACHLOROETHANE
1,1,2-TRICHLOROETHANE
1,1-DICHLOROETHANE
1,1-DICHLOROETHENE
1,2-DICHLOROETHANE
1,2-DICHLOROETHENE (TOTAL)
1,2-DICHLOROPROPANE
2-HEXANONE
4-METHYL-2-PENTANONE
ACETONE
AG
AS
B
BENZENE
BROMOFORM
BROMOMETHANE
CARBON DISULFIDE
CHLOROBENZENE
CHLOROETHANE
CHLOROMETHANE
CIS-1,3-DICHLOROPROPENE
DIBROMOCHLOROMETHANE
F
GA
LI
NO3
P
PB
PO4
SB
SE
SN
STYRENE
TETRACHLOROETHENE
TRANS-1,3-DICHLOROPROPENE
TRICHLOROETHENE
VINYL ACETATE
VINYL CHLORIDE
ZR

Table 1.6. List of analytes that were <u>not detected</u> in each area during the 1st - 3rd quarters of sampling

AREA=BEAR CREEK VALLEY

Analyte
1,1,1-TRICHLOROETHANE
1,1,2,2-TETRACHLOROETHANE
1,1,2-TRICHLOROETHANE
1,1-DICHLOROETHANE
1,1-DICHLOROETHENE
1,2-DICHLOROETHANE
1,2-DICHLOROETHENE (TOTAL)
1,2-DICHLOROPROPANE
2-BUTANONE
2-HEXANONE
4-METHYL-2-PENTANONE
ACETONE
AG
AS
BENZENE
BROMODICHLOROMETHANE
BROMOFORM
BROMOMETHANE
CARBON DISULFIDE
CARBON TETRACHLORIDE
CHLOROBENZENE
CHLOROETHANE
CHLOROFORM
CHLOROMETHANE
CIS-1,3-DICHLOROPROPENE
CO
DIBROMOCHLOROMETHANE
F
GA
HG
MO
P
PB
PO4
SB
SE
SN
STYRENE
TETRACHLOROETHENE
TOLUENE
TRANS-1,3-DICHLOROPROPENE
TRICHLOROETHENE
VINYL ACETATE
VINYL CHLORIDE
ZR

Table 1.7. Summary of the 1st - 3rd quarters of LLWDDD sampling (Note: Radionuclides are in Bq/L - Inorganics are in mg/L - Organics are in μg/L - Conductivity is in ms/cm and Temperature is in degrees C)

MEDIA=GROUND WATER

Analyte	No. of samples	Max	Qualifier	Min	Qual-	Ave
2-BUTANONE	52	14	<	10	<	10
ACETONE	52	38	<	10	<	11
BROMODICHLOROMETHANE	52	5.0	<	2.0	<	4.9
CARBON DISULFIDE	52	5.0	<	5.0	<	5.0
CARBON TETRACHLORIDE	52	9.0	<	5.0	<	5.1
CHLOROFORM	52	10	<	5.0	<	5.1
CHLOROMETHANE	52	10	<	10	<	10
ETHYLBENZENE	52	5.0	<	2.0	<	4.8
METHYLENE CHLORIDE	52	67	<	4.0	<	11
TOLUENE	52	5.0	<	2.0	<	4.9
TRICHLOROETHENE	52	10	<	5.0	<	5.1
XYLENE (TOTAL)	52	10	<	2.0	<	4.9
GROSS ALPHA	51	3.4		0		.26
GROSS BETA	51	2.5		0		0.40
TOTAL SR	51	0.39		-0.10		0.048
TRITIUM	51	49		-40		7.6
AL	51	0.73	<	0.036	<	0.14
ALKALINITY	51	370	<	0.50	<	170
B	51	0.45	<	0.048	<	0.072
BA	51	0.31		0.0082		0.075
BE	51	0.0028	<	0.00018	<	0.00077
CA	51	420		5.8		65
CD	51	0.0030	<	0.0012	<	0.0018
CL	51	14	<	1.0	<	3.2
CO	51	0.023	<	0.0018	<	0.0040
CR	51	0.024	<	0.0036	<	0.011
CU	51	0.021	<	0.0060	<	0.0090
F	51	10	<	1.0	<	1.2
FE	51	0.42	<	0.012	<	0.062
HG	51	0.00050	<	0.00010	<	0.00013
LI	51	0.36	<	0.12	<	0.14
MG	51	160		3.4		21
MN	51	180	<	0.0030	<	3.8
MO	51	0.040	<	0.024	<	0.026
NA	51	93	<	0.20	<	10
NI	51	0.036	<	0.0036	<	0.014
P	51	0.30	<	0.18	<	0.19
SI	51	25	<	0.12	<	3.5
SO4	51	1400	<	5.0	<	100
SR	51	3.9		0.0098		0.36

Table 1.7 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L - Organics are in µg/L - Conductivity is in ms/cm and Temperature is in degrees C)

MEDIA=GROUND WATER

Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
TI	51	0.039	<	0.012	<	0.014
TOTAL URANIUM	51	0.0040	<	0.0010	<	0.0011
V	51	0.012	<	0.0024	<	0.0084
ZN	51	0.21	<	0.0018	<	0.016
CONDUCTIVITY	50	2.4		0.070		0.55
DO	50	11		1.2		6.6
PH	50	8.8		6.8		7.6
TEMPERATURE	50	20		12		16

Table 1.8. Summary of the 1st - 3rd quarters of LLWDDD sampling (Note: Radionuclides are in Bq/L - Inorganics are in mg/L - Organics are in μg/L - Conductivity is in ms/cm and Temperature is in degrees C)

MEDIA=GROUND WATER AREA=SWSA 7

Analyte	No. of samples	Max	Qual- ifier	Min	Qual- fier	Ave
ACETONE	25	38	<	10	<	11
CARBON DISULFIDE	25	5.0	<	5.0	<	5.0
CHLOROMETHANE	25	10	<	10	<	10
ETHYLBENZENE	25	5.0	<	3.0	<	4.9
METHYLENE CHLORIDE	25	67	<	4.0	<	12
TRICHLOROETHENE	25	10	<	5.0	<	5.2
XYLENE (TOTAL)	25	10	<	4.0	<	5.2
GROSS ALPHA	25	0.90		0		0.18
GROSS BETA	25	1.2		0		0.36
TOTAL SR	25	0.16		-0.10		0.018
TRITIUM	25	49		-20		10
AL	25	0.30	<	0.036	<	0.13
ALKALINITY	25	370		110		240
B	25	0.45	<	0.048	<	0.096
BA	25	0.31		0.017		0.11
BE	25	0.0028	<	0.00018	<	0.00090
CA	25	420		5.8		100
CD	25	0.0030	<	0.0012	<	0.0019
CL	25	14		1.0		3.9
CO	25	0.0081	<	0.0018	<	0.0033
CR	25	0.024	<	0.0036	<	0.011
CU	25	0.021	<	0.0060	<	0.0099
F	25	1.9	<	1.0	<	1.1
FE	25	0.33	<	0.012	<	0.057
HG	25	0.00050	<	0.00010	<	0.00016
LI	25	0.36	<	0.12	<	0.16
MG	25	160		3.4		30
MN	25	0.54	<	0.0030	<	0.12
NA	25	93	<	0.20	<	19
NI	25	0.036	<	0.0036	<	0.014
P	25	0.30	<	0.18	<	0.20
SI	25	25	<	0.12	<	4.8
SO4	25	1400	<	5.0	<	200
SR	25	3.9		0.070		0.69
TI	25	0.022	<	0.012	<	0.015
TOTAL URANIUM	25	0.0040	<	0.0010	<	0.0011
V	25	0.012	<	0.0024	<	0.0083
ZN	25	0.21	<	0.0018	<	0.022
CONDUCTIVITY	24	2.4		0.070		0.62
DO	24	9.2		1.2		6.3

Table 1.8 (continued)

(Note: Radionuclides are in Bq/L - Inorganics are in mg/L - Organics are in μg/L - Conductivity is in ms/cm and Temperature is in degrees C)

MEDIA=GROUND WATER   AREA-SWSA 7

Analyte	No. of samples	Max	Qual-ifier	Min	Qual-fier	Ave
PH	24	8.8		6.8		7.8
TEMPERATURE	24	20		12		17

MEDIA=GROUND WATER   AREA=WEST CHESTNUT RIDGE

Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
2-BUTANONE	27	14	<	10	<	10
BROMODICHLOROMETHANE	27	5.0	<	2.0	<	4.9
CARBON TETRACHLORIDE	27	9.0	<	5.0	<	5.1
CHLOROFORM	27	10	<	5.0	<	5.2
ETHYLBENZENE	27	5.0	<	2.0	<	4.7
METHYLENE CHLORIDE	27	50	<	4.0	<	9.1
TOLUENE	27	5.0	<	2.0	<	4.8
XYLENE (TOTAL)	27	5.0	<	2.0	<	4.7
GROSS ALPHA	26	3.4		0		0.33
GROSS BETA	26	2.5		0		0.43
TOTAL SR	26	0.39		-0.070		0.076
TRITIUM	26	36		40		5.0
AL	26	0.73	<	0.036	<	0.15
ALKALINITY	26	180	<	0.50	<	110
BA	26	0.18		0.0082		0.041
BE	26	0.0012	<	0.00018	<	0.00064
CA	26	50		11		27
CD	26	0.0030	<	0.0012	<	0.0018
CL	26	14	<	1.0	<	2.5
CO	26	0.023	<	0.0018	<	0.0046
CR	26	0.024	<	0.0036	<	0.011
CU	26	0.012	<	0.0060	<	0.0082
FE	26	0.42	<	0.012	<	0.066
HG	26	0.00020	<	0.00010	<	0.00011
MG	26	21		5.3		12
MN	26	180	<	0.0030	<	7.4
MO	26	0.024	<	0.024	<	0.024
NA	26	6.3		0.45		2.1

Table 1.8 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L - Organics are in μg/L - Conductivity is in ms/cm and Temperature is in degrees C)

MEDIA=GROUND WATER AREA=WEST CHESTNUT RIDGE

Analyte	No. of samples	Max	Qualifier	Min	Qualifier	Ave
NI	26	0.036	<	0.0036	<	0.014
SI	26	3.9	<	0.12	<	2.2
SO4	26	50	<	5.0	<	7.6
SR	26	0.14		0.0098		0.041
TI	26	0.039	<	0.012	<	0.014
TOTAL URANIUM	26	0.0010	<	0.0010	<	0.0010
V	26	0.012	<	0.0044	<	0.0085
ZN	26	0.032	<	0.0018	<	0.010
CONDUCTIVITY	26	0.90		0.10		0.49
DO	26	11		3.6		6.9
PH	26	7.9		6.8		7.4
TEMPERATURE	26	20		12		15

Table 1.9. Summary of the 1st - 3rd quarters of LLWDDD sampling
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in µg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Ground water Area=SWSA 7

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
WELL 1117	CARBON DISULFIDE	4	5.0	<	5.0	<	5.0
WELL 1117	METHYLENE CHLORIDE	4	37	<	5.0	<	13
WELL 1117	TRICHLOROETHENE	4	10	<	5.0	<	6.3
WELL 1117	GROSS ALPHA	4	0.49		0		0.20
WELL 1117	GROSS BETA	4	1.1		0.25		0.64
WELL 1117	TOTAL SR	4	0.050		-0.10		-0.010
WELL 1117	TRITIUM	4	8.0		-2.0		2.0
WELL 1117	AL	4	0.22	<	0.054	<	0.15
WELL 1117	ALKALINITY	4	290		270		280
WELL 1117	B	4	0.055	<	0.048	<	0.050
WELL 1117	BA	4	0.092		0.064		0.073
WELL 1117	BE	4	0.0013	<	0.00018	<	0.0010
WELL 1117	CA	4	97		87		92
WELL 1117	CD	4	0.0030	<	0.0012	<	0.0017
WELL 1117	CL	4	1.9		1.0		1.4
WELL 1117	CR	4	0.024	<	0.0036	<	0.011
WELL 1117	CU	4	0.012	<	0.0060	<	0.0076
WELL 1117	FE	4	0.33		0.028		0.13
WELL 1117	MG	4	13		13		13
WELL 1117	MN	4	0.071		0.012		0.046
WELL 1117	NA	4	12		8.5		11
WELL 1117	SI	4	2.1	<	0.12	<	1.2
WELL 1117	SO4	4	35		33		34
WELL 1117	SR	4	0.68		0.64		0.66
WELL 1117	TI	4	0.012	<	0.012	<	0.012
WELL 1117	TOTAL URANIUM	4	0.0040		0.0010		0.0018
WELL 1117	V	4	0.012	<	0.0066	<	0.0086
WELL 1117	ZN	4	0.026	<	0.0018	<	0.016
WELL 1117	CONDUCTIVITY	3	0.55		0.26		0.44
WELL 1117	DO	3	8.8		2.1		6.5
WELL 1117	PH	3	7.6		7.2		7.4
WELL 1117	TEMPERATURE	3	20		13		17
WELL 1126	ACETONE	3	12	<	10	<	11
WELL 1126	METHYLENE CHLORIDE	3	61	<	5.0	<	24
WELL 1126	GROSS ALPHA	3	0.24		0		0.081
WELL 1126	GROSS BETA	3	0.050		0		0.026
WELL 1126	TOTAL SR	3	0.10		-0.040		0.042
WELL 1126	TRITIUM	3	35		13		21
WELL 1126	AL	3	0.17		0.037		0.12
WELL 1126	ALKALINITY	3	120		110		110
WELL 1126	BA	3	0.31		0.13		0.19

Table 1.9 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in μg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Ground water Area=SWSA 7

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
WELL 1126	BE	3	0.0012	<	0.00018	<	0.00079
WELL 1126	CA	3	47		35		41
WELL 1126	CL	3	1.2		1.0		1.1
WELL 1126	CR	3	0.024	<	0.0036	<	0.012
WELL 1126	CU	3	0.021		0.013		0.018
WELL 1126	FE	3	0.028	<	0.012	<	0.018
WELL 1126	HG	3	0.00020	<	0.00010	<	0.00013
WELL 1126	MG	3	4.4		3.4		3.8
WELL 1126	MN	3	0.015		0.0033		0.0089
WELL 1126	NA	3	6.4		3.6		4.6
WELL 1126	NI	3	0.036	<	0.0036	<	0.018
WELL 1126	SI	3	25		0.77		9.0
WELL 1126	SO4	3	7.1	<	5.0	<	6.1
WELL 1126	SR	3	0.11		0.070		0.085
WELL 1126	TI	3	0.020	<	0.012	<	0.015
WELL 1126	TOTAL URANIUM	3	0.0010		0.0010		0.0010
WELL 1126	V	3	0.012	<	0.0030	<	0.0062
WELL 1126	ZN	3	0.045		0.019		0.033
WELL 1126	CONDUCTIVITY	3	0.50		0.070		0.28
WELL 1126	DO	3	8.4		1.2		5.8
WELL 1126	PH	3	8.5		7.9		8.2
WELL 1126	TEMPERATURE	3	20		14		17
WELL 7-12	CHLOROMETHANE	3	10	<	10	<	10
WELL 7-12	METHYLENE CHLORIDE	3	67	<	5.0	<	26
WELL 7-12	GROSS ALPHA	3	0.90		0.067		0.43
WELL 7-12	GROSS BETA	3	1.2		0.050		0.44
WELL 7-12	TOTAL SR	3	0.084		-0.0010		0.031
WELL 7-12	TRITIUM	3	10		-20		-3.0
WELL 7-12	AL	3	0.30	<	0.12	<	0.19
WELL 7-12	ALKALINITY	3	370		360		370
WELL 7-12	B	3	0.080	<	0.052	<	0.062
WELL 7-12	BA	3	0.018		0.017		0.017
WELL 7-12	BE	3	0.0028	<	0.0011	<	0.0017
WELL 7-12	CA	3	420		380		410
WELL 7-12	CL	3	14		13		14
WELL 7-12	CO	3	0.0081	<	0.0018	<	0.0043
WELL 7-12	CR	3	0.024	<	0.0039	<	0.011
WELL 7-12	F	3	1.9		1.5		1.8
WELL 7-12	FE	3	0.11		0.058		0.076
WELL 7-12	HG	3	0.00030	<	0.00010	<	0.00017
WELL 7-12	LI	3	0.36		0.28		0.31

Table 1.9 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in $\mu g/L$ - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Ground water Area=SWSA 7

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
WELL 7-12	MG	3	160		140		150
WELL 7-12	MN	3	0.46		0.16		0.35
WELL 7-12	NA	3	61	<	0.20	<	37
WELL 7-12	NI	3	0.036	<	0.0037	<	0.015
WELL 7-12	SI	3	13		0.80		6.1
WELL 7-12	SO4	3	1400		1200		1300
WELL 7-12	SR	3	3.9		2.0		3.0
WELL 7-12	TI	3	0.020	<	0.012	<	0.017
WELL 7-12	TOTAL URANIUM	3	0.0010	<	0.0010	<	0.0010
WELL 7-12	V	3	0.012	<	0.0024	<	0.0085
WELL 7-12	ZN	3	0.014	<	0.0083	<	0.011
WELL 7-12	CONDUCTIVITY	3	2.4		1.0		1.5
WELL 7-12	DO	3	8.7		7.5		7.9
WELL 7-12	PH	3	7.3		7.0		7.1
WELL 7-12	TEMPERATURE	3	20		16		18
WELL 7-13	ETHYLBENZENE	3	5.0	<	3.0	<	4.3
WELL 7-13	METHYLENE CHLORIDE	3	10	<	5.0	<	7.0
WELL 7-13	XYLENE (TOTAL)	3	10	<	4.0	<	6.3
WELL 7-13	GROSS ALPHA	3	0.17		0		0.075
WELL 7-13	GROSS BETA	3	0.42		0		0.27
WELL 7-13	TOTAL SR	3	0.050		0.010		0.023
WELL 7-13	TRITIUM	3	8.0		-2.0		3.0
WELL 7-13	AL	3	0.16	<	0.060	<	0.11
WELL 7-13	ALKALINITY	3	150		150		150
WELL 7-13	B	3	0.080	<	0.048	<	0.060
WELL 7-13	BA	3	0.25		0.16		0.21
WELL 7-13	BE	3	0.0012	<	0.00030	<	0.00082
WELL 7-13	CA	3	35		26		31
WELL 7-13	CL	3	1.0		1.0		1.0
WELL 7-13	CR	3	0.024	<	0.0060	<	0.013
WELL 7-13	FE	3	0.046	<	0.018	<	0.028
WELL 7-13	HG	3	0.00050	<	0.00010	<	0.00023
WELL 7-13	MG	3	12		9.6		11
WELL 7-13	MN	3	0.043		0.0052		0.022
WELL 7-13	NA	3	16		11		14
WELL 7-13	SI	3	9.2		3.1		6.6
WELL 7-13	SO4	3	9.6		9.0		9.3
WELL 7-13	SR	3	0.69		0.54		0.60
WELL 7-13	TOTAL URANIUM	3	0.0010	<	0.0010	<	0.0010
WELL 7-13	V	3	0.012	<	0.0079	<	0.010
WELL 7-13	ZN	3	0.012	<	0.0030	<	0.008

Table 1.9 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in µg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Ground water Area=SWSA 7

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
WELL 7-13	CONDUCTIVITY	3	0.70		0.17		0.46
WELL 7-13	DO	3	8.8		5.2		6.8
WELL 7-13	PH	3	8.3		7.8		8.1
WELL 7-13	TEMPERATURE	3	20		12		15
WELL 7-16	METHYLENE CHLORIDE	3	5.0	<	4.0	<	4.7
WELL 7-16	GROSS ALPHA	3	0.70		0.090		0.35
WELL 7-16	GROSS BETA	3	0.71		0.29		0.45
WELL 7-16	TOTAL SR	3	0.033		-0.030		-0.0060
WELL 7-16	TRITIUM	3	9.0		-6.0		1.3
WELL 7-16	AL	3	0.22	<	0.047	<	0.13
WELL 7-16	ALKALINITY	3	290		260		280
WELL 7-16	B	3	0.051	<	0.048	<	0.049
WELL 7-16	BA	3	0.026		0.021		0.023
WELL 7-16	BE	3	0.0013	<	0.00018	<	0.00089
WELL 7-16	CA	3	120		93		110
WELL 7-16	CL	3	2.4		2.4		2.4
WELL 7-16	CR	3	0.024	<	0.0036	<	0.012
WELL 7-16	CU	3	0.012	<	0.0066	<	0.0089
WELL 7-16	F	3	1.0	<	1.0	<	1.0
WELL 7-16	FE	3	0.13	<	0.012	<	0.072
WELL 7-16	HG	3	0.00020	<	0.00010	<	0.00013
WELL 7-16	MG	3	48		40		43
WELL 7-16	MN	3	0.54		0.41		0.48
WELL 7-16	NA	3	22		7.9		17
WELL 7-16	NI	3	0.036	<	0.0036	<	0.015
WELL 7-16	SI	3	3.6		0.64		2.2
WELL 7-16	SO4	3	250		210		230
WELL 7-16	SR	3	0.38		0.33		0.36
WELL 7-16	TI	3	0.015	<	0.012	<	0.013
WELL 7-16	TOTAL URANIUM	3	0.0010	<	0.0010	<	0.0010
WELL 7-16	V	3	0.012	<	0.0052	<	0.0084
WELL 7-16	ZN	3	0.21		0.021		0.084
WELL 7-16	CONDUCTIVITY	3	0.62		0.50		0.56
WELL 7-16	DO	3	8.5		4.8		7.3
WELL 7-16	PH	3	7.7		7.3		7.5
WELL 7-16	TEMPERATURE	3	20		13		17
WELL 7-4	ACETONE	3	12	<	10	<	11
WELL 7-4	METHYLENE CHLORIDE	3	5.0	<	4.0	<	4.7
WELL 7-4	GROSS ALPHA	3	0.34		0		0.14
WELL 7-4	GROSS BETA	3	1.2		0.19		0.62
WELL 7-4	TOTAL SR	3	0.087		-0.070		0.0013

Table 1.9 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in µg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Ground water Area=SWSA 7

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
WELL 7-4	TRITIUM	3	49		30		42
WELL 7-4	AL	3	0.20	<	0.080	<	0.13
WELL 7-4	ALKALINITY	3	250		250		250
WELL 7-4	BA	3	0.15		0.10		0.12
WELL 7-4	BE	3	0.0012	<	0.00030	<	0.00083
WELL 7-4	CA	3	99		82		92
WELL 7-4	CL	3	2.9		1.9		2.3
WELL 7-4	CR	3	0.024	<	0.0060	<	0.012
WELL 7-4	CU	3	0.012	<	0.0079	<	0.010
WELL 7-4	FE	3	0.064	<	0.020	<	0.039
WELL 7-4	HG	3	0.00020	<	0.00010	<	0.00013
WELL 7-4	MG	3	12		9.5		11
WELL 7-4	MN	3	0.056		0.0042		0.022
WELL 7-4	NA	3	5.6		3.9		4.7
WELL 7-4	NI	3	0.036	<	0.0057	<	0.016
WELL 7-4	SI	3	6.4		4.2		5.3
WELL 7-4	SO4	3	21		11		14
WELL 7-4	SR	3	0.15		0.12		0.14
WELL 7-4	TOTAL URANIUM	3	0.0010	<	0.0010	<	0.0010
WELL 7-4	V	3	0.012	<	0.0065	<	0.0088
WELL 7-4	ZN	3	0.019		0.0034		0.013
WELL 7-4	CONDUCTIVITY	3	0.90		0.34		0.58
WELL 7-4	DO	3	6.5		4.4		5.7
WELL 7-4	PH	3	7.7		6.8		7.3
WELL 7-4	TEMPERATURE	3	20		15		17
WELL 7-5	ACETONE	3	38	<	10	<	19
WELL 7-5	METHYLENE CHLORIDE	3	10		4.0		6.3
WELL 7-5	XYLENE (TOTAL)	3	5.0	<	5.0	<	5.0
WELL 7-5	GROSS ALPHA	3	0.33		0.039		0.18
WELL 7-5	GROSS BETA	3	0.68		0		0.28
WELL 7-5	TOTAL SR	3	0.16		-0.020		0.041
WELL 7-5	TRITIUM	3	22		5.0		14
WELL 7-5	AL	3	0.19	<	0.071	<	0.13
WELL 7-5	ALKALINITY	3	200		170		190
WELL 7-5	BA	3	0.13		0.11		0.12
WELL 7-5	BE	3	0.0012	<	0.00030	<	0.00080
WELL 7-5	CA	3	75		57		64
WELL 7-5	CL	3	1.8		1.0		1.3
WELL 7-5	CR	3	0.024	<	0.0060	<	0.012
WELL 7-5	FE	3	0.084	<	0.012	<	0.039
WELL 7-5	HG	3	0.00020	<	0.00010	<	0.00013

Table 1.9 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in μg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Ground water   Area=SWSA 7

Station	Analyte	No. of samples	Max	Qual- ifier	Min	Qual- ifier	Ave
WELL 7-5	MG	3	11		8.4		9.7
WELL 7-5	MN	3	0.057		0.013		0.031
WELL 7-5	NA	3	7.1		5.5		6.4
WELL 7-5	P	3	0.30	<	0.18	<	0.22
WELL 7-5	SI	3	9.1		3.9		6.5
WELL 7-5	SO4	3	11		8.5		10
WELL 7-5	SR	3	0.20		0.12		0.16
WELL 7-5	TI	3	0.022	<	0.012	<	0.018
WELL 7-5	TOTAL URANIUM	3	0.0010	<	0.0010	<	0.0010
WELL 7-5	V	3	0.012	<	0.0071	<	0.010
WELL 7-5	ZN	3	0.014	<	0.0045	<	0.010
WELL 7-5	CONDUCTIVITY	3	0.90		0.17		0.52
WELL 7-5	DO	3	5.5		3.7		4.5
WELL 7-5	PH	3	7.9		7.6		7.8
WELL 7-5	TEMPERATURE	3	20		15		17
WELL 7-7	METHYLENE CHLORIDE	3	21	<	5.0	<	11
WELL 7-7	XYLENE (TOTAL)	3	5.0	<	5.0	<	5.0
WELL 7-7	GROSS ALPHA	3	0.049		0		0.016
WELL 7-7	GROSS BETA	3	0.20		0		0.090
WELL 7-7	TOTAL SR	3	0.080		0.010		0.038
WELL 7-7	TRITIUM	3	11		1.0		4.7
WELL 7-7	AL	3	0.060	<	0.036	<	0.049
WELL 7-7	ALKALINITY	3	250		240		250
WELL 7-7	B	3	0.45		0.37		0.40
WELL 7-7	BA	3	0.16		0.14		0.15
WELL 7-7	BE	3	0.00061	<	0.00018	<	0.00036
WELL 7-7	CA	3	6.5		5.8		6.1
WELL 7-7	CL	3	10		8.1		9.0
WELL 7-7	CR	3	0.0066	<	0.0036	<	0.0054
WELL 7-7	F	3	1.2	<	1.0	<	1.1
WELL 7-7	FE	3	0.060	<	0.016	<	0.032
WELL 7-7	HG	3	0.00050	<	0.00010	<	0.00023
WELL 7-7	LI	3	0.20	<	0.12	<	0.15
WELL 7-7	MG	3	7.7		6.7		7.1
WELL 7-7	NA	3	93	<	0.20	<	62
WELL 7-7	SI	3	6.8		0.30		2.8
WELL 7-7	SO4	3	13		10		12
WELL 7-7	SR	3	0.53		0.46		0.49
WELL 7-7	TOTAL URANIUM	3	0.0010	<	0.0010	<	0.0010
WELL 7-7	V	3	0.0072	<	0.0042	<	0.0060
WELL 7-7	ZN	3	0.0067	<	0.0030	<	0.0050

Table 1.9 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in μg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Ground water Area=SWSA 7

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
WELL 7-7	CONDUCTIVITY	3	1.0		0.37		0.62
WELL 7-7	DO	3	9.2		3.7		5.8
WELL 7-7	PH	3	8.8		8.4		8.6
WELL 7-7	TEMPERATURE	3	20		14		16
Media=Ground water Area=West Chestnut Ridge							
WELL 18-A	GROSS ALPHA	1	0.027		0.027		0.027
WELL 18-A	GROSS BETA	1	0.91		0.91		0.91
WELL 18-A	TOTAL SR	1	0.33		0.33		0.33
WELL 18-A	TRITIUM	1	-30		-30		-30
WELL 18-A	AL	1	0.039		0.039		0.039
WELL 18-A	ALKALINITY	1	85		85		85
WELL 18-A	BA	1	0.017		0.017		0.017
WELL 18-A	CA	1	29		29		29
WELL 18-A	CL	1	1.0		1.0		1.0
WELL 18-A	MG	1	6.3		6.3		6.3
WELL 18-A	MN	1	0.0055		0.0055		0.0055
WELL 18-A	NA	1	0.72		0.72		0.72
WELL 18-A	SI	1	2.8		2.8		2.8
WELL 18-A	SO4	1	5.8		5.8		5.8
WELL 18-A	SR	1	0.026		0.026		0.026
WELL 18-A	V	1	0.0058		0.0058		0.0058
WELL 18-A	CONDUCTIVITY	1	0.30		0.30		0.30
WELL 18-A	DO	1	8.9		8.9		8.9
WELL 18-A	PH	1	7.4		7.4		7.4
WELL 18-A	TEMPERATURE	1	12		12		12
WELL 18-B	METHYLENE CHLORIDE	5	50	<	5.0	<	14
WELL 18-B	GROSS ALPHA	5	0.84		0.0079		0.31
WELL 18-B	GROSS BETA	5	2.5		0		0.74
WELL 18-B	TOTAL SR	5	0.29		-0.020		0.10
WELL 18-B	TRITIUM	5	16		-40		-7.0
WELL 18-B	AL	5	0.19	<	0.045	<	0.11
WELL 18-B	ALKALINITY	5	170		130		150
WELL 18-B	BA	5	0.051		0.023		0.035
WELL 18-B	BE	5	0.0012	<	0.00018	<	0.00075
WELL 18-B	CA	5	50		40		46

Table 1.9 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in μg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Ground water Area=SWSA 7

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
WELL 18-B	CL	5	2.1		1.6		1.9
WELL 18-B	CR	5	0.024	<	0.0036	<	0.013
WELL 18-B	HG	5	0.00020	<	0.00010	<	0.00012
WELL 18-B	MG	5	13		8.5		11
WELL 18-B	MN	5	0.018		0.0050		0.011
WELL 18-B	NA	5	3.1		2.3		2.6
WELL 18-B	SI	5	3.3		1.3		2.5
WELL 18-B	SO4	5	8.2		5.0		7.2
WELL 18-B	SR	5	0.14		0.092		0.12
WELL 18-B	TOTAL URANIUM	5	0.0010	<	0.0010	<	0.0010
WELL 18-B	V	5	0.012	<	0.0069	<	0.0091
WELL 18-B	ZN	5	0.015	<	0.0029	<	0.0087
WELL 18-B	CONDUCTIVITY	5	0.80		0.40		0.52
WELL 18-B	DO	5	7.3		5.3		6.1
WELL 18-B	PH	5	7.5		7.2		7.4
WELL 18-B	TEMPERATURE	5	17		14		15
WELL 3-A	ETHYLBENZENE	3	5.0	<	2.0	<	4.0
WELL 3-A	METHYLENE CHLORIDE	3	18	<	5.0	<	9.3
WELL 3-A	TOLUENE	3	5.0	<	2.0	<	4.0
WELL 3-A	GROSS ALPHA	3	3.4		0		1.1
WELL 3-A	GROSS BETA	3	0.37		0.050		0.18
WELL 3-A	TOTAL SR	3	0.39		-0.010		0.16
WELL 3-A	TRITIUM	3	22		4.0		11
WELL 3-A	AL	3	0.14	<	0.036	<	0.099
WELL 3-A	ALKALINITY	3	160		110		130
WELL 3-A	BA	3	0.077		0.013		0.037
WELL 3-A	BE	3	0.0012	<	0.00018	<	0.00071
WELL 3-A	CA	3	30		21		26
WELL 3-A	CL	3	3.6		1.0		1.9
WELL 3-A	CO	3	0.023		0.0096		0.017
WELL 3-A	CR	3	0.024	<	0.0036	<	0.011
WELL 3-A	CU	3	0.012	<	0.0075	<	0.0094
WELL 3-A	FE	3	0.037	<	0.012	<	0.023
WELL 3-A	MG	3	15		9.3		11
WELL 3-A	MN	3	5.4		2.0		4.1
WELL 3-A	NA	3	3.2		1.5		2.1
WELL 3-A	NI	3	0.036	<	0.0036	<	0.015
WELL 3-A	SI	3	3.3		0.72		2.2
WELL 3-A	SO4	3	8.3	<	5.0	<	6.1
WELL 3-A	SR	3	0.047		0.034		0.039
WELL 3-A	TOTAL URANIUM	3	0.0010	<	0.0010	<	0.0010

Table 1.9 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in μg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Ground water Area=SWSA 7

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
WELL 3-A	V	3	0.012	<	0.0069	<	0.0089
WELL 3-A	ZN	3	0.019		0.014		0.017
WELL 3-A	CONDUCTIVITY	4	0.90		0.20		0.53
WELL 3-A	DO	4	8.6		4.9		6.5
WELL 3-A	PH	4	7.7		6.8		7.1
WELL 3-A	TEMPERATURE	4	17		13		15
WELL 3-B	2-BUTANONE	3	14	<	10	<	11
WELL 3-B	ETHYLBENZENE	3	5.0	<	2.0	<	4.0
WELL 3-B	METHYLENE CHLORIDE	3	18	<	5.0	<	9.3
WELL 3-B	TOLUENE	3	5.0	<	5.0	<	5.0
WELL 3-B	XYLENE (TOTAL)	3	5.0	<	2.0	<	4.0
WELL 3-B	GROSS ALPHA	3	0.25		0		0.11
WELL 3-B	GROSS BETA	3	1.2		0.020		0.51
WELL 3-B	TOTAL SR	3	0.19		0.011		0.080
WELL 3-B	TRITIUM	3	14		1.0		5.7
WELL 3-B	AL	3	0.15	<	0.061	<	0.11
WELL 3-B	ALKALINITY	3	180		170		170
WELL 3-B	BA	3	0.18		0.023		0.077
WELL 3-B	BE	3	0.0012	<	0.00018	<	0.00073
WELL 3-B	CA	3	36		29		34
WELL 3-B	CL	3	3.2		1.0		1.9
WELL 3-B	CR	3	0.024	<	0.0036	<	0.011
WELL 3-B	CU	3	0.012	<	0.0060	<	0.0089
WELL 3-B	FE	3	0.054	<	0.012	<	0.039
WELL 3-B	MG	3	21		19		20
WELL 3-B	MN	3	0.10		0.034		0.062
WELL 3-B	NA	3	5.9		0.73		3.8
WELL 3-B	SI	3	3.9		1.5		2.8
WELL 3-B	SO4	3	6.6	<	5.0	<	5.5
WELL 3-B	SR	3	0.041		0.021		0.029
WELL 3-B	TOTAL URANIUM	3	0.0010	<	0.0010	<	0.0010
WELL 3-B	V	3	0.012	<	0.0056	<	0.0087
WELL 3-B	ZN	3	0.012	<	0.0018	<	0.0072
WELL 3-B	CONDUCTIVITY	2	0.90		0.30		0.60
WELL 3-B	DO	2	8.9		4.4		6.7
WELL 3-B	PH	2	7.8		7.4		7.6
WELL 3-B	TEMPERATURE	2	18		14		16
WELL 6-A	ETHYLBENZENE	3	5.0	<	2.0	<	4.0
WELL 6-A	METHYLENE CHLORIDE	3	9.0	<	5.0	<	6.3
WELL 6-A	TOLUENE	3	5.0	<	3.0	<	4.3
WELL 6-A	XYLENE (TOTAL)	3	5.0	<	2.0	<	4.0

Table 1.9 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in μg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Ground water Area=SWSA 7

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
WELL 6-A	GROSS ALPHA	3	0.044		0		0.015
WELL 6-A	GROSS BETA	3	0.91		0.053		0.60
WELL 6-A	TOTAL SR	3	0.14		-0.020		0.057
WELL 6-A	TRITIUM	3	7.0		3.0		4.7
WELL 6-A	AL	3	0.27	<	0.036	<	0.13
WELL 6-A	ALKALINITY	3	89		46		71
WELL 6-A	BA	3	0.059		0.015		0.043
WELL 6-A	BE	3	0.0012	<	0.00018	<	0.00057
WELL 6-A	CA	3	18		11		14
WELL 6-A	CL	3	1.0		1.0		1.0
WELL 6-A	CR	3	0.024	<	0.0036	<	0.012
WELL 6-A	FE	3	0.13	<	0.012	<	0.051
WELL 6-A	HG	3	0.00020	<	0.00010	<	0.00013
WELL 6-A	MG	3	10		5.3		7.7
WELL 6-A	MN	3	180		0.011		60
WELL 6-A	MO	3	0.024	<	0.024	<	0.024
WELL 6-A	NA	3	6.3		0.53		2.5
WELL 6-A	SI	3	3.1	<	0.12	<	1.7
WELL 6-A	SR	3	0.014		0.011		0.013
WELL 6-A	TOTAL URANIUM	3	0.0010	<	0.0010	<	0.0010
WELL 6-A	V	3	0.012	<	0.0044	<	0.0077
WELL 6-A	ZN	3	0.013		0.0033		0.0091
WELL 6-A	CONDUCTIVITY	3	0.80		0.20		0.43
WELL 6-A	DO	3	7.8		5.3		6.9
WELL 6-A	PH	3	7.6		7.1		7.4
WELL 6-A	TEMPERATURE	3	18		14		16
WELL 6-B	BROMODICHLOROMETHANE	3	5.0	<	2.0	<	4.0
WELL 6-B	CARBON TETRACHLORIDE	3	9.0	<	5.0	<	6.3
WELL 6-B	CHLOROFORM	3	10	<	5.0	<	6.7
WELL 6-B	METHYLENE CHLORIDE	3	22	<	4.0	<	10
WELL 6-B	XYLENE (TOTAL)	3	5.0	<	4.0	<	4.7
WELL 6-B	GROSS ALPHA	3	0.41		0		0.15
WELL 6-B	GROSS BETA	3	0.88		0.12		0.47
WELL 6-B	TOTAL SR	3	0.12		-0.020		0.041
WELL 6-B	TRITIUM	3	18		5.0		13
WELL 6-B	AL	3	0.12	<	0.036	<	0.079
WELL 6-B	ALKALINITY	3	120		50		96
WELL 6-B	BA	3	0.13		0.023		0.084
WELL 6-B	BE	3	0.0012	<	0.00018	<	0.00055
WELL 6-B	CA	3	26		15		22
WELL 6-B	CL	3	4.8		1.0		2.3

Table 1.9 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in μg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Ground water Area=SWSA 7

Station	Analyte	No. of samples	Max	Qualifier	Min	Qualifier	Ave
WELL 6-B	CR	3	0.024	<	0.0036	<	0.011
WELL 6-B	CU	3	0.012	<	0.0060	<	0.0080
WELL 6-B	FE	3	0.42	<	0.012	<	0.15
WELL 6-B	HG	3	0.00020	<	0.00010	<	0.00013
WELL 6-B	MG	3	14		5.4		11
WELL 6-B	MN	3	0.011	<	0.0030	<	0.0073
WELL 6-B	NA	3	2.5		0.52		1.2
WELL 6-B	SI	3	2.2	<	0.12	<	1.4
WELL 6-B	SO4	3	10	<	5.0	<	6.7
WELL 6-B	SR	3	0.035		0.016		0.023
WELL 6-B	TI	3	0.019	<	0.012	<	0.014
WELL 6-B	TOTAL URANIUM	3	0.0010		0.0010		0.0010
WELL 6-B	V	3	0.012	<	0.0054	<	0.0088
WELL 6-B	ZN	3	0.032	<	0.0059	<	0.017
WELL 6-B	CONDUCTIVITY	3	0.70		0.30		0.50
WELL 6-B	DO	3	8.9		5.4		7.5
WELL 6-B	PH	3	7.9		7.4		7.6
WELL 6-B	TEMPERATURE	3	17		14		16
WELL 9-A	METHYLENE CHLORIDE	3	5.0	<	5.0	<	5.0
WELL 9-A	GROSS ALPHA	2	0.70		0.34		0.52
WELL 9-A	GROSS BETA	2	0.090		0		0.045
WELL 9-A	TOTAL SR	2	0.019		0.010		0.015
WELL 9-A	TRITIUM	2	26		-4.0		11
WELL 9-A	AL	2	0.11	<	0.036	<	0.073
WELL 9-A	ALKALINITY	2	90		73		81
WELL 9-A	BA	2	0.012		0.0092		0.011
WELL 9-A	BE	2	0.00052	<	0.00018	<	0.00035
WELL 9-A	CA	2	22		17		20
WELL 9-A	CL	2	2.6		1.2		1.9
WELL 9-A	CR	2	0.0081	<	0.0036	<	0.0059
WELL 9-A	FE	2	0.019	<	0.012	<	0.016
WELL 9-A	HG	2	0.00010	<	0.00010	<	0.00010
WELL 9-A	MG	2	9.7		8.3		9.0
WELL 9-A	MN	2	0.027		0.0086		0.018
WELL 9-A	NA	2	1.8		0.50		1.2
WELL 9-A	SI	2	2.6		2.5		2.6
WELL 9-A	SO4	2	6.4	<	5.0	<	5.7
WELL 9-A	SR	2	0.028		0.0098		0.019
WELL 9-A	TOTAL URANIUM	2	0.0010	<	0.0010	<	0.0010
WELL 9-A	V	2	0.0078		0.0069		0.0074
WELL 9-A	ZN	2	0.011		0.0043		0.0077

Table 1.9 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in μg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Ground water Area=SWSA 7

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
WELL 9-A	CONDUCTIVITY	2	0.62		0.60		0.61
WELL 9-A	DO	2	11		8.0		9.3
WELL 9-A	PH	2	7.5		7.0		7.3
WELL 9-A	TEMPERATURE	2	20		16		18
WELL 9-B	METHYLENE CHLORIDE	3	6.0	<	5.0	<	5.3
WELL 9-B	GROSS ALPHA	3	0.70		0		0.27
WELL 9-B	GROSS BETA	3	0.68		0		0.26
WELL 9-B	TOTAL SR	3	0.064		-0.070		0.015
WELL 9-B	TRITIUM	3	11		-9.0		-0.70
WELL 9-B	AL	3	0.68	<	0.12	<	0.32
WELL 9-B	ALKALINITY	3	160	<	0.50	<	110
WELL 9-B	BA	3	0.046		0.0082		0.022
WELL 9-B	BE	3	0.0012	<	0.00018	<	0.00079
WELL 9-B	CA	3	31		31		31
WELL 9-B	CD	3	0.0030	<	0.0012	<	0.0019
WELL 9-B	CL	3	10	<	1.0	<	4.0
WELL 9-B	CR	3	0.024	<	0.0069	<	0.013
WELL 9-B	CU	3	0.012	<	0.0060	<	0.0084
WELL 9-B	FE	3	0.33	<	0.018	<	0.13
WELL 9-B	MG	3	19		18		19
WELL 9-B	MN	3	0.097		0.011		0.044
WELL 9-B	NA	3	3.5		1.1		2.5
WELL 9-B	NI	3	0.036	<	0.0036	<	0.017
WELL 9-B	SI	3	3.6	<	0.12	<	2.3
WELL 9-B	SR	3	0.018		0.013		0.016
WELL 9-B	TI	3	0.039	<	0.012	<	0.021
WELL 9-B	TOTAL URANIUM	3	0.0010	<	0.0010	<	0.0010
WELL 9-B	V	3	0.012	<	0.0068	<	0.010
WELL 9-B	ZN	3	0.012	<	0.0083	<	0.010
WELL 9-B	CONDUCTIVITY	3	0.70		0.30		0.47
WELL 9-B	DO	3	8.1		7.0		7.6
WELL 9-B	PH	3	7.9		7.7		7.8
WELL 9-B	TEMPERATURE	3	16		13		15
WELL PW6	METHYLENE CHLORIDE	3	22	<	5.0	<	11
WELL PW6	GROSS ALPHA	3	0.55		0.043		0.28
WELL PW6	GROSS BETA	3	0.25		0.10		0.18
WELL PW6	TOTAL SR	3	0.10		-0.060		0.018
WELL PW6	TRITIUM	3	36		19		26
WELL PW6	AL	3	0.73	<	0.036	<	0.28
WELL PW6	ALKALINITY	3	59		48		53
WELL PW6	BA	3	0.030		0.014		0.020

Table 1.9 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in μg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Ground water Area=SWSA 7

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
WELL PW6	BE	3	0.0012	<	0.00018	<	0.00061
WELL PW6	CA	3	13		11		12
WELL PW6	CL	3	14		1.3		5.6
WELL PW6	CR	3	0.024	<	0.0036	<	0.012
WELL PW6	CU	3	0.012	<	0.0060	<	0.0081
WELL PW6	FE	3	0.39	<	0.012	<	0.14
WELL PW6	MG	3	7.0		5.8		6.5
WELL PW6	MN	3	0.042		0.0052		0.018
WELL PW6	NA	3	0.74		0.45		0.61
WELL PW6	SI	3	2.6	<	0.12	<	1.7
WELL PW6	SR	3	0.013		0.011		0.012
WELL PW6	TI	3	0.026	<	0.012	<	0.017
WELL PW6	TOTAL URANIUM	3	0.0010	<	0.0010	<	0.0010
WELL PW6	V	3	0.012	<	0.0045	<	0.0074
WELL PW6	ZN	3	0.012	<	0.0018	<	0.0086
WELL PW6	CONDUCTIVITY	3	0.60		0.10		0.33
WELL PW6	DO	3	8.1		3.6		5.8
WELL PW6	PH	3	7.6		7.2		7.3
WELL PW6	TEMPERATURE	3	16		14		15

Table 1.10. Summary of the 1st - 3rd quarters of LLWDDD sampling (Note: Radionuclides are in Bq/L - Inorganics are in mg/L - Organics are in µg/L - Conductivity is in ms/cm and Temperature is in degrees C)

MEDIA=SURFACE WATER

Analyte	No. of samples	Max	Qual- ifier	Min	Qual- ifier	Ave
ACETONE	42	400	<	10	<	21
ETHYLBENZENE	42	5.0	<	2.0	<	4.5
METHYLENE CHLORIDE	42	320	<	3.0	<	14
XYLENE (TOTAL)	42	5.0	<	2.0	<	4.6
GROSS ALPHA	28	1.6		0		0.33
GROSS BETA	28	3.8		0		0.87
TOTAL SR	28	0.27		-0.060		0.038
TRITIUM	28	72		-7.0		28
AL	42	0.21	<	0.036	<	0.11
ALKALINITY	42	160		11		81
B	42	0.52	<	0.048	<	0.093
BA	42	0.27	<	0.010	<	0.060
BE	42	0.0012	<	0.00018	<	0.00070
CA	42	91		3.5		31
CD	42	0.0030	<	0.0012	<	0.0019
CL	42	30		1.0		6.3
CR	42	0.024	<	0.0036	<	0.012
CU	42	0.012	<	0.0060	<	0.0082
FE	42	0.15	<	0.012	<	0.041
LI	42	0.24	<	0.12	<	0.13
MG	42	17		1.9		7.1
MN	42	0.21	<	0.0030	<	0.041
NA	42	15		0.42		4.2
NI	42	0.036	<	0.0036	<	0.015
NO3	42	130	<	5.0	<	16
SI	42	4.8		0.77		2.4
SO4	42	83	<	5.0	<	17
SR	33	0.22		0.0093		0.067
TI	42	0.11	<	0.012	<	0.016
TOTAL URANIUM	42	0.0030	<	0.0010	<	0.0011
V	42	0.012	<	0.0024	<	0.0071
ZN	42	0.067	<	0.0018	<	0.013
CONDUCTIVITY	33	0.90		0		0.28
DO	33	12		1.6		9.0
PH	33	8.8		5.9		7.9
TEMPERATURE	33	22		6.1		15

Table 1.11. Summary of the 1st - 3rd quarters of LLWDDD sampling (Note: Radionuclides are in Bq/L - Inorganics are in mg/L - Organics are in μg/L - Conductivity is in ms/cm and Temperature is in degrees C)

MEDIA=SURFACE WATER AREA=BEAR CREEK VALLEY

Analyte	No. of samples	Max	Qual-ifier	Min	Qual-fier	Ave
ETHYLBENZENE	16	5.0	<	2.0	<	4.3
METHYLENE CHLORIDE	16	9.0	<	5.0	<	5.4
XYLENE (TOTAL)	16	5.0	<	2.0	<	4.4
GROSS ALPHA	11	1.6		0		0.43
GROSS BETA	11	3.8		0.25		1.3
TOTAL SR	11	0.27		-0.050		0.075
TRITIUM	11	34		-7.0		14
AL	16	0.20	<	0.036	<	0.12
ALKALINITY	16	160		23		85
B	16	0.52	<	0.048	<	0.17
BA	16	0.27	<	0.012	<	0.067
BE	16	0.0012	<	0.00018	<	0.00076
CA	16	91		14		39
CD	16	0.0030	<	0.0012	<	0.0019
CL	16	30		1.0		9.9
CR	16	0.024	<	0.0036	<	0.012
CU	16	0.012	<	0.0060	<	0.0086
FE	16	0.15	<	0.012	<	0.034
LI	16	0.24	<	0.12	<	0.14
MG	16	16		2.1		7.3
MN	16	0.16		0.0056		0.030
NA	16	15		2.7		6.0
NI	16	0.036	<	0.0036	<	0.016
NO3	16	130	<	5.0	<	35
SI	16	4.8		1.1		2.3
SO4	16	44		5.4		19
SR	11	0.22		0.040		0.095
TI	16	0.039	<	0.012	<	0.015
TOTAL URANIUM	16	0.0030	<	0.0010	<	0.0014
V	16	0.012	<	0.0024	<	0.0074
ZN	16	0.067	<	0.0018	<	0.012
CONDUCTIVITY	11	0.80		0		0.23
DO	11	12		1.6		9.5
PH	11	8.7		7.0		8.1
TEMPERATURE	11	20		6.1		14

Table 1.11 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in μg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

MEDIA=SURFACE WATER AREA=SWSA 7

Analyte	No. of samples	Max	Qual-ifier	Min	Qual-fier	Ave
ACETONE	11	400	<	10	<	52
METHYLENE CHLORIDE	11	320	<	3.0	<	36
GROSS ALPHA	8	0.58		0.0090		0.17
GROSS BETA	8	1.5		0		0.35
TOTAL SR	8	0.18		-0.010		0.041
TRITIUM	8	72		17		44
AL	11	0.19	<	0.036	<	0.11
ALKALINITY	11	160		27		94
BA	11	0.21		0.031		0.082
BE	11	0.0012	<	0.00018	<	0.00077
CA	11	56		20		40
CD	11	0.0030	<	0.0012	<	0.0020
CL	11	15		1.4		5.7
CR	11	0.024	<	0.0036	<	0.012
CU	11	0.012	<	0.0060	<	0.0085
FE	11	0.083		0.022		0.046
MG	11	7.9		4.0		5.4
MN	11	0.21	<	0.0030	<	0.073
NA	11	8.2		4.3		6.0
NI	11	0.036	<	0.0036	<	0.017
SI	11	4.2		1.6		2.8
SO4	11	83		11		29
SR	11	0.12		0.060		0.087
TI	11	0.017	<	0.012	<	0.013
TOTAL URANIUM	11	0.0010	<	0.0010	<	0.0010
V	11	0.012	<	0.0024	<	0.0068
ZN	11	0.041	<	0.0035	<	0.018
CONDUCTIVITY	11	0.90		0.050		0.44
DO	11	11		3.5		8.0
PH	11	7.8		6.8		7.5
TEMPERATURE	11	22		6.2		16

Table 1.11 (Continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L - Organics are in µg/L - Conductivity is in ms/cm and Temperature is in degrees C)

MEDIA=SURFACE WATER AREA=WEST CHESTNUT RIDGE

Analyte	No. of samples	Max	Qual-ifier	Min	Qual-fier	Ave
ETHYLBENZENE	15	5.0	<	2.0	<	4.5
METHYLENE CHLORIDE	15	23	<	3.0	<	6.2
XYLENE (TOTAL)	15	5.0	<	2.0	<	4.6
GROSS ALPHA	9	1.0		0.080		0.34
GROSS BETA	9	1.7		0		0.74
TOTAL SR	9	0.035		-0.060		-0.0080
TRITIUM	9	50		-2.0		32
AL	15	0.21	<	0.036	<	0.10
ALKALINITY	15	140		11		67
BA	15	0.13	<	0.010	<	0.037
BE	15	0.0012	<	0.00018	<	0.00060
CA	15	28		3.5		16
CD	15	0.0030	<	0.0012	<	0.0017
CL	15	8.9		1.0		2.8
CR	15	0.024	<	0.0036	<	0.011
CU	15	0.012	<	0.0060	<	0.0077
FE	15	0.13	<	0.012	<	0.044
MG	15	17		1.9		8.1
MN	15	0.17	<	0.0030	<	0.028
NA	15	3.1		0.42		1.1
NI	15	0.036	<	0.0036	<	0.012
SI	15	3.1		0.77		2.2
SO4	15	8.3	<	5.0	<	5.2
SR	11	0.039		0.0093		0.019
TI	15	0.11	<	0.012	<	0.019
TOTAL URANIUM	15	0.0010	<	0.0010	<	0.0010
V	15	0.012	<	0.0024	<	0.0070
ZN	15	0.048	<	0.0018	<	0.011
CONDUCTIVITY	11	0.50		0		0.16
DO	11	12		6.3		9.5
PH	11	8.8		5.9		8.0
TEMPERATURE	11	21		6.7		15

Table 1.12. Summary of the 1st - 3rd quarters of LLWDDD sampling
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in μg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Surface water Area=Bear Creek Valley

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
FLUME 272	ETHYLBENZENE	3	5.0	<	2.0	<	4.0
FLUME 272	XYLENE (TOTAL)	3	5.0	<	2.0	<	4.0
FLUME 272	GROSS ALPHA	2	0		0		0
FLUME 272	GROSS BETA	2	1.0		0.48		0.74
FLUME 272	TOTAL SR	2	0.010		-0.040		-0.020
FLUME 272	TRITIUM	2	20		5.0		13
FLUME 272	AL	3	0.13	<	0.062	<	0.10
FLUME 272	ALKALINITY	3	61		23		39
FLUME 272	BA	3	0.056	<	0.012	<	0.034
FLUME 272	BE	3	0.0012	<	0.00018	<	0.00064
FLUME 272	CA	3	20		15		18
FLUME 272	CD	3	0.0030	<	0.0012	<	0.0019
FLUME 272	CL	3	26		1.3		9.6
FLUME 272	CR	3	0.024	<	0.0036	<	0.011
FLUME 272	FE	3	0.062	<	0.012	<	0.031

Table 1.12 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in μg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Surface water Area=Bear Creek Valley

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
FLUME 272	MG	3	3.6		2.1		2.8
FLUME 272	MN	3	0.16		0.0056		0.057
FLUME 272	NA	3	3.1		2.8		2.9
FLUME 272	SI	3	3.7		1.1		2.2
FLUME 272	SO4	3	23		10		15
FLUME 272	SR	2	0.042		0.040		0.041
FLUME 272	TOTAL URANIUM	3	0.0010	<	0.0010	<	0.0010
FLUME 272	V	3	0.012	<	0.0024	<	0.0061
FLUME 272	ZN	3	0.012	<	0.0044	<	0.0091
FLUME 272	CONDUCTIVITY	2	0.20		0.030		0.12
FLUME 272	DO	2	11		2.4		6.9
FLUME 272	PH	2	8.7		7.0		7.9
FLUME 272	TEMPERATURE	2	20		6.1		13
FLUME 273	ETHYLBENZENE	3	5.0	<	2.0	<	4.0
FLUME 273	XYLENE (TOTAL)	3	5.0	<	4.0	<	4.7
FLUME 273	GROSS ALPHA	2	0.90		0.54		0.72
FLUME 273	GROSS BETA	2	2.9		0.73		1.8
FLUME 273	TOTAL SR	2	0.12		0.11		0.12
FLUME 273	TRITIUM	2	19		6.0		13
FLUME 273	AL	3	0.19	<	0.063	<	0.12
FLUME 273	ALKALINITY	3	160		110		130
FLUME 273	B	3	0.28		0.24		0.26
FLUME 273	BA	3	0.27		0.076		0.14
FLUME 273	BE	3	0.0012	<	0.00018	<	0.00078
FLUME 273	CA	3	71		54		60
FLUME 273	CD	3	0.0030	<	0.0012	<	0.0018
FLUME 273	CL	3	26		14		18
FLUME 273	CR	3	0.024	<	0.0036	<	0.012
FLUME 273	FE	3	0.018	<	0.012	<	0.015
FLUME 273	LI	3	0.13	<	0.12	<	0.12
FLUME 273	MG	3	15		11		13
FLUME 273	MN	3	0.015		0.012		0.013
FLUME 273	NA	3	12		5.7		8.5
FLUME 273	NI	3	0.036	<	0.0036	<	0.014
FLUME 273	NO3	3	88		46		60
FLUME 273	SI	3	2.4		1.8		2.1
FLUME 273	SO4	3	34		14		23
FLUME 273	SR	2	0.16		0.11		0.14
FLUME 273	TI	3	0.014	<	0.012	<	0.013
FLUME 273	TOTAL URANIUM	3	0.0020		0.0010		0.0017
FLUME 273	V	3	0.012	<	0.0066	<	0.0084

Table 1.12 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in μg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Surface water Area=Bear Creek Valley

Station	Analyte	No. of samples	Max	Qualifier	Min	Qualifier	Ave
FLUME 273	ZN	3	0.012	<	0.0018	<	0.0072
FLUME 273	CONDUCTIVITY	2	0.80		0.30		0.55
FLUME 273	DO	2	11		1.6		6.5
FLUME 273	PH	2	8.3		7.3		7.8
FLUME 273	TEMPERATURE	2	20		8.2		14
FLUME 672	ETHYLBENZENE	4	5.0	<	3.0	<	4.5
FLUME 672	METHYLENE CHLORIDE	4	8.0	<	5.0	<	5.8
FLUME 672	XYLENE (TOTAL)	4	5.0	<	2.0	<	4.3
FLUME 672	GROSS ALPHA	3	0.12		0		0.043
FLUME 672	GROSS BETA	3	1.0		0.25		0.70
FLUME 672	TOTAL SR	3	0.17		-0.050		0.074
FLUME 672	TRITIUM	3	6.0		-7.0		0.67
FLUME 672	AL	4	0.20	<	0.036	<	0.15
FLUME 672	ALKALINITY	4	80		38		59
FLUME 672	BA	4	0.065	<	0.012	<	0.035
FLUME 672	BE	4	0.0012	<	0.00018	<	0.00080
FLUME 672	CA	4	21		14		19
FLUME 672	CL	4	1.8		1.3		1.5
FLUME 672	CR	4	0.024	<	0.0036	<	0.014
FLUME 672	FE	4	0.15	<	0.012	<	0.076
FLUME 672	MG	4	5.0		2.8		4.3
FLUME 672	MN	4	0.025		0.012		0.017
FLUME 672	NA	4	4.6		2.7		4.1
FLUME 672	SI	4	4.8		1.5		2.6
FLUME 672	SO4	4	26		10		18
FLUME 672	SR	3	0.071		0.045		0.062
FLUME 672	TI	4	0.039	<	0.012	<	0.019
FLUME 672	TOTAL URANIUM	4	0.0010	<	0.0010	<	0.0010
FLUME 672	V	4	0.012	<	0.0035	<	0.0080
FLUME 672	ZN	4	0.012	<	0.0018	<	0.0084
FLUME 672	CONDUCTIVITY	3	0.11		0.10		0.11
FLUME 672	DO	3	12		10		12
FLUME 672	PH	3	8.7		8.4		8.5
FLUME 672	TEMPERATURE	3	20		7.6		16
FLUME 673	ETHYLBENZENE	3	5.0	<	3.0	<	4.3
FLUME 673	GROSS ALPHA	2	1.6		1.6		1.6
FLUME 673	GROSS BETA	2	3.8		2.1		3.0
FLUME 673	TOTAL SR	2	0.27		0		0.14
FLUME 673	TRITIUM	2	34		27		31
FLUME 673	AL	3	0.20	<	0.058	<	0.13
FLUME 673	ALKALINITY	3	150		120		130

Table 1.12 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in μg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Surface water Area=Bear Creek Valley

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
FLUME 673	B	3	0.52		0.37		0.46
FLUME 673	BA	3	0.10		0.076		0.091
FLUME 673	BE	3	0.0012	<	0.00018	<	0.00079
FLUME 673	CA	3	91		69		77
FLUME 673	CL	3	30		16		22
FLUME 673	CR	3	0.024	<	0.0036	<	0.012
FLUME 673	LI	3	0.24		0.18		0.21
FLUME 673	MG	3	16		13		15
FLUME 673	MN	3	0.016		0.0093		0.012
FLUME 673	NA	3	15		8.4		11
FLUME 673	NI	3	0.036	<	0.0036	<	0.015
FLUME 673	NO3	3	130		77		110
FLUME 673	SI	3	2.5		1.6		2.0
FLUME 673	SO4	3	44		22		29
FLUME 673	SR	2	0.22		0.16		0.19
FLUME 673	TI	3	0.028	<	0.012	<	0.017
FLUME 673	TOTAL URANIUM	3	0.0030		0.0020		0.0023
FLUME 673	V	3	0.012	<	0.0066	<	0.0084
FLUME 673	ZN	3	0.012	<	0.0018	<	0.0065
FLUME 673	CONDUCTIVITY	2	0.44		0.40		0.42
FLUME 673	DO	2	12		10		11
FLUME 673	PH	2	8.4		8.3		8.4
FLUME 673	TEMPERATURE	2	20		7.9		14
FLUME 677	ETHYLBENZENE	3	5.0	<	3.0	<	4.3
FLUME 677	METHYLENE CHLORIDE	3	9.0	<	5.0	<	6.3
FLUME 677	XYLENE (TOTAL)	3	5.0	<	2.0	<	4.0
FLUME 677	GROSS ALPHA	2	0		0		0
FLUME 677	GROSS BETA	2	1.3		0.41		0.86
FLUME 677	TOTAL SR	2	0.090		0.040		0.065
FLUME 677	TRITIUM	2	31		12		22
FLUME 677	AL	3	0.17	<	0.036	<	0.11
FLUME 677	ALKALINITY	3	100		45		72
FLUME 677	B	3	0.072	<	0.048	<	0.056
FLUME 677	BA	3	0.070		0.026		0.045
FLUME 677	BE	3	0.0012	<	0.00018	<	0.00075
FLUME 677	CA	3	34		18		27
FLUME 677	CD	3	0.0030	<	0.0012	<	0.0018
FLUME 677	CL	3	2.2		1.0		1.6
FLUME 677	CR	3	0.024	<	0.0036	<	0.011
FLUME 677	CU	3	0.012	<	0.0060	<	0.0097
FLUME 677	FE	3	0.034	<	0.012	<	0.021

Table 1.12 (continued)

(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in μg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Surface water   Area=Bear Creek Valley

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
FLUME 677	MG	3	3.1		2.1		2.7
FLUME 677	MN	3	0.10		0.033		0.057
FLUME 677	NA	3	4.8		2.8		3.8
FLUME 677	SI	3	4.1		1.5		2.8
FLUME 677	SO4	3	21		5.4		12
FLUME 677	SR	2	0.078		0.052		0.065
FLUME 677	TI	3	0.014	<	0.012	<	0.013
FLUME 677	TOTAL URANIUM	3	0.0010	<	0.0010	<	0.0010
FLUME 677	V	3	0.012	<	0.0025	<	0.0059
FLUME 677	ZN	3	0.067	<	0.0094	<	0.029
FLUME 677	CONDUCTIVITY	2	0.060		0		0.030
FLUME 677	DO	2	11		9.9		11
FLUME 677	PH	2	8.2		7.9		8.1
FLUME 677	TEMPERATURE	2	20		7.2		14

Media=Surface water   Area=SWSA 7

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
CENT FLUME	ACETONE	3	33	<	10	<	18
CENT FLUME	METHYLENE CHLORIDE	3	12	<	3.0	<	6.7
CENT FLUME	GROSS ALPHA	2	0.25		0.0090		0.13
CENT FLUME	GROSS BETA	2	0.25		0		0.13
CENT FLUME	TOTAL SR	2	0.18		-0.010		0.084
CENT FLUME	TRITIUM	2	56		54		55
CENT FLUME	AL	3	0.19	<	0.058	<	0.12
CENT FLUME	ALKALINITY	3	120		70		100
CENT FLUME	BA	3	0.096		0.056		0.071
CENT FLUME	BE	3	0.0012	<	0.00018	<	0.00078
CENT FLUME	CA	3	49		37		43
CENT FLUME	CD	3	0.0030	<	0.0012	<	0.0023
CENT FLUME	CL	3	2.3		1.4		1.9
CENT FLUME	CR	3	0.024	<	0.0036	<	0.012
CENT FLUME	CU	3	0.012	<	0.0060	<	0.0082
CENT FLUME	FE	3	0.078		0.022		0.048
CENT FLUME	MG	3	5.8		5.1		5.3
CENT FLUME	MN	3	0.21		0.043		0.10
CENT FLUME	NA	3	5.3		4.3		4.7
CENT FLUME	NI	3	0.036	<	0.0036	<	0.016

Table 1.12 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in μg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Surface water Area=Bear Creek Valley

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
CENT FLUME	SI	3	4.2		1.7		3.2
CENT FLUME	SO4	3	42		12		27
CENT FLUME	SR	3	0.089		0.080		0.086
CENT FLUME	TI	3	0.014	<	0.012	<	0.013
CENT FLUME	TOTAL URANIUM	3	0.0010	<	0.0010	<	0.0010
CENT FLUME	V	3	0.012	<	0.0024	<	0.0066
CENT FLUME	ZN	3	0.024		0.0076		0.016
CENT FLUME	CONDUCTIVITY	3	0.80		0.090		0.49
CENT FLUME	DO	3	11		4.9		7.9
CENT FLUME	PH	3	7.8		7.4		7.6
CENT FLUME	TEMPERATURE	3	22		6.3		16
EAST FLUME	METHYLENE CHLORIDE	3	11	<	3.0	<	6.3
EAST FLUME	GROSS ALPHA	2	0.25		0.065		0.16
EAST FLUME	GROSS BETA	2	0.24		0		0.12
EAST FLUME	TOTAL SR	2	0.023		0.016		0.020
EAST FLUME	TRITIUM	2	53		17		35
EAST FLUME	AL	3	0.17	<	0.053	<	0.11
EAST FLUME	ALKALINITY	3	130		56		100
EAST FLUME	BA	3	0.19		0.031		0.093
EAST FLUME	BE	3	0.0012	<	0.00018	<	0.00079
EAST FLUME	CA	3	49		30		42
EAST FLUME	CL	3	15		3.3		8.5
EAST FLUME	CR	3	0.024	<	0.0036	<	0.012
EAST FLUME	CU	3	0.012	<	0.0060	<	0.0088
EAST FLUME	FE	3	0.083		0.032		0.049
EAST FLUME	MG	3	6.4		4.1		5.4
EAST FLUME	MN	3	0.21		0.0050		0.082
EAST FLUME	NA	3	8.2		7.0		7.7
EAST FLUME	NI	3	0.036	<	0.0036	<	0.019
EAST FLUME	SI	3	3.1		1.6		2.6
EAST FLUME	SO4	3	30		14		22
EAST FLUME	SR	3	0.11		0.066		0.092
EAST FLUME	TI	3	0.017	<	0.012	<	0.014
EAST FLUME	TOTAL URANIUM	3	0.0010	<	0.0010	<	0.0010
EAST FLUME	V	3	0.012	<	0.0024	<	0.0067
EAST FLUME	ZN	3	0.041		0.0066		0.027
EAST FLUME	CONDUCTIVITY	3	0.90		0.34		0.58
EAST FLUME	DO	3	11		3.5		7.7
EAST FLUME	PH	3	7.4		6.8		7.1
EAST FLUME	TEMPERATURE	3	21		8.6		17
USGS FLUME	ACETONE	3	400	<	10	<	140

Table 1.12 (continued)

(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in μg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Surface water Area=Bear Creek Valley

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
USGS FLUME	METHYLENE CHLORIDE	3	320	<	3.0	<	110
USGS FLUME	GROSS ALPHA	2	0.58		0.043		0.31
USGS FLUME	GROSS BETA	2	1.5		0.34		0.92
USGS FLUME	TOTAL SR	2	0.065		-0.0020		0.032
USGS FLUME	TRITIUM	2	43		19		31
USGS FLUME	AL	3	0.19	<	0.054	<	0.12
USGS FLUME	ALKALINITY	3	160		77		120
USGS FLUME	BA	3	0.071		0.037		0.055
USGS FLUME	BE	3	0.0012	<	0.00018	<	0.00079
USGS FLUME	CA	3	56		39		47
USGS FLUME	CL	3	9.6		3.5		5.6
USGS FLUME	CR	3	0.024	<	0.0036	<	0.012
USGS FLUME	FE	3	0.074		0.030		0.052
USGS FLUME	MG	3	5.2		4.0		4.7
USGS FLUME	MN	3	0.12		0.0042		0.067
USGS FLUME	NA	3	6.0		4.8		5.2
USGS FLUME	SI	3	3.0		1.6		2.4
USGS FLUME	SO4	3	21		11		18
USGS FLUME	SR	3	0.12		0.074		0.094
USGS FLUME	TI	3	0.014	<	0.012	<	0.013
USGS FLUME	TOTAL URANIUM	3	0.0010	<	0.0010	<	0.0010
USGS FLUME	V	3	0.012	<	0.0025	<	0.0067
USGS FLUME	ZN	3	0.032	<	0.0035	<	0.013
USGS FLUME	CONDUCTIVITY	3	0.90		0.080		0.43
USGS FLUME	DO	3	11		4.3		7.7
USGS FLUME	PH	3	7.8		7.7		7.8
USGS FLUME	TEMPERATURE	3	20		6.2		15
WEST FLUME	ACETONE	2	66	<	10	<	38
WEST FLUME	METHYLENE CHLORIDE	2	16	<	5.0	<	11
WEST FLUME	GROSS ALPHA	2	0.17		0.031		0.10
WEST FLUME	GROSS BETA	2	0.29		0.21		0.25
WEST FLUME	TOTAL SR	2	0.042		0.012		0.027
WEST FLUME	TRITIUM	2	72		36		54
WEST FLUME	ALKALINITY	2	36		27		31
WEST FLUME	BA	2	0.21		0.039		0.12
WEST FLUME	CA	2	28		20		24
WEST FLUME	CL	2	10		5.4		7.7
WEST FLUME	FE	2	0.039		0.024		0.032
WEST FLUME	MG	2	7.9		5.2		6.6
WEST FLUME	MN	2	0.043	<	0.0030	<	0.023
WEST FLUME	NA	2	6.6		6.3		6.5

Table 1.12 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in μg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Surface water Area=Bear Creek Valley

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
WEST FLUME	SI	2	3.1		2.7		2.9
WEST FLUME	SO4	2	83		30		57
WEST FLUME	SR	2	0.083		0.060		0.072
WEST FLUME	TOTAL URANIUM	2	0.0010	<	0.0010	<	0.0010
WEST FLUME	V	2	0.012	<	0.0026	<	0.0073
WEST FLUME	ZN	2	0.020		0.0040		0.012
WEST FLUME	CONDUCTIVITY	2	0.30		0.050		0.18
WEST FLUME	DO	2	11		7.8		9.2
WEST FLUME	PH	2	7.7		7.6		7.7
WEST FLUME	TEMPERATURE	2	20		7.3		14

Media=Surface water Area=West Chestnut Ridge

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
FLUME 7	ETHYLBENZENE	4	5.0	<	2.0	<	4.3
FLUME 7	XYLENE (TOTAL)	4	5.0	<	2.0	<	4.3
FLUME 7	GROSS ALPHA	2	0.13		0.12		0.13
FLUME 7	GROSS BETA	2	0.70		0.32		0.51
FLUME 7	TOTAL SR	2	0.020		-0.010		0.0050
FLUME 7	TRITIUM	2	27		-2.0		13
FLUME 7	AL	4	0.16	<	0.045	<	0.12
FLUME 7	ALKALINITY	4	140		120		130
FLUME 7	BA	4	0.021	<	0.012	<	0.018
FLUME 7	BE	4	0.0012	<	0.00018	<	0.00074
FLUME 7	CA	4	28		27		27
FLUME 7	CD	4	0.0030	<	0.0012	<	0.0017
FLUME 7	CL	4	1.1		1.0		1.0
FLUME 7	CR	4	0.024	<	0.0036	<	0.011
FLUME 7	FE	4	0.018	<	0.012	<	0.015
FLUME 7	MG	4	17		15		16
FLUME 7	MN	4	0.0052	<	0.0030	<	0.0036
FLUME 7	NA	4	0.61		0.42		0.53
FLUME 7	SI	4	3.1		0.77		2.5
FLUME 7	SR	2	0.013		0.012		0.013
FLUME 7	TI	4	0.023	<	0.012	<	0.015
FLUME 7	TOTAL URANIUM	4	0.0010	<	0.0010	<	0.0010
FLUME 7	V	4	0.012	<	0.0070	<	0.0087
FLUME 7	ZN	4	0.012	<	0.0018	<	0.0086

Table 1.12 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L - Organics are in μg/L - Conductivity is in ms/cm and Temperature is in degrees C)

Media=Surface water Area=Bear Creek Valley

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
FLUME 7	CONDUCTIVITY	2	0.10		0.10		0.10
FLUME 7	DO	2	12		11		11
FLUME 7	PH	2	8.8		8.4		8.6
FLUME 7	TEMPERATURE	2	20		8.2		14
FLUME 8	ETHYLBENZENE	2	5.0	<	3.0	<	4.0
FLUME 8	XYLENE (TOTAL)	2	5.0	<	2.0	<	3.5
FLUME 8	GROSS ALPHA	1	1.0		1.0		1.0
FLUME 8	GROSS BETA	1	1.2		1.2		1.2
FLUME 8	TOTAL SR	1	0.0040		0.0040		0.0040
FLUME 8	TRITIUM	1	40		40		40
FLUME 8	AL	2	0.061		0.054		0.058
FLUME 8	ALKALINITY	2	24		12		18
FLUME 8	BA	2	0.023		0.013		0.018
FLUME 8	CA	2	4.5		3.5		4.0
FLUME 8	CL	2	1.2		1.2		1.2
FLUME 8	CR	2	0.0055	<	0.0036	<	0.0046
FLUME 8	CU	2	0.0072	<	0.0060	<	0.0066
FLUME 8	FE	2	0.050		0.037		0.044
FLUME 8	MG	2	2.6		2.0		2.3
FLUME 8	MN	2	0.17		0.0032		0.087
FLUME 8	NA	2	0.56		0.49		0.53
FLUME 8	NI	2	0.0036	<	0.0036	<	0.0036
FLUME 8	SI	2	2.5		2.4		2.5
FLUME 8	SR	1	0.0093		0.0093		0.0093
FLUME 8	TOTAL URANIUM	2	0.0010	<	0.0010	<	0.0010
FLUME 8	V	2	0.0027	<	0.0024	<	0.0026
FLUME 8	ZN	2	0.024		0.0053		0.015
FLUME 8	CONDUCTIVITY	1	0.10		0.10		0.10
FLUME 8	DO	1	9.2		9.2		9.2
FLUME 8	PH	1	5.9		5.9		5.9
FLUME 8	TEMPERATURE	1	7.2		7.2		7.2
WEIR 1	METHYLENE CHLORIDE	3	9.0	<	3.0	<	5.7
WEIR 1	GROSS ALPHA	2	0.17		0.080		0.13
WEIR 1	GROSS BETA	2	0.75		0.73		0.74
WEIR 1	TOTAL SR	2	0.024		0.0030		0.014
WEIR 1	TRITIUM	2	34		33		34
WEIR 1	AL	3	0.15	<	0.056	<	0.11
WEIR 1	ALKALINITY	3	120		65		93
WEIR 1	BA	3	0.065		0.021		0.044
WEIR 1	BE	3	0.0012	<	0.00018	<	0.00076
WEIR 1	CA	3	27		18		23

Table 1.12 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in μg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Surface water Area=Bear Creek Valley

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
WEIR 1	CL	3	4.3		1.4		2.6
WEIR 1	CR	3	0.024	<	0.0036	<	0.012
WEIR 1	FE	3	0.11	<	0.018	<	0.051
WEIR 1	MG	3	12		7.5		10
WEIR 1	MN	3	0.021		0.0073		0.014
WEIR 1	NA	3	1.5		0.65		1.1
WEIR 1	NI	3	0.036	<	0.0036	<	0.015
WEIR 1	SI	3	2.7		1.6		2.0
WEIR 1	SO4	3	8.3	<	5.0	<	6.1
WEIR 1	SR	3	0.039		0.023		0.032
WEIR 1	TI	3	0.013	<	0.012	<	0.012
WEIR 1	TOTAL URANIUM	3	0.0010	<	0.0010	<	0.0010
WEIR 1	V	3	0.012	<	0.0048	<	0.0079
WEIR 1	ZN	3	0.048		0.0035		0.019
WEIR 1	CONDUCTIVITY	3	0.50		0.20		0.32
WEIR 1	DO	3	11		6.4		9.4
WEIR 1	PH	3	8.7		8.0		8.3
WEIR 1	TEMPERATURE	3	20		8.7		16
WEIR 3	METHYLENE CHLORIDE	3	23	<	3.0	<	10
WEIR 3	GROSS ALPHA	2	0.70		0.17		0.44
WEIR 3	GROSS BETA	2	0.18		0		0.090
WEIR 3	TOTAL SR	2	0.035		-0.030		0.0025
WEIR 3	TRITIUM	2	44		34		39
WEIR 3	AL	3	0.14	<	0.036	<	0.087
WEIR 3	ALKALINITY	3	56		18		37
WEIR 3	BA	3	0.064		0.022		0.049
WEIR 3	BE	3	0.0012	<	0.00018	<	0.00061
WEIR 3	CA	3	11		8.9		9.7
WEIR 3	CL	3	6.3		2.0		3.5
WEIR 3	CR	3	0.024	<	0.0036	<	0.012
WEIR 3	FE	3	0.13	<	0.012	<	0.053
WEIR 3	MG	3	5.8		2.8		4.4
WEIR 3	MN	3	0.046		0.0068		0.023
WEIR 3	NA	3	2.0		0.74		1.3
WEIR 3	NI	3	0.036	<	0.0036	<	0.015
WEIR 3	SI	3	2.9		1.3		1.9
WEIR 3	SO4	3	5.0	<	5.0	<	5.0
WEIR 3	SR	3	0.019		0.012		0.017
WEIR 3	TI	3	0.11	<	0.012	<	0.045
WEIR 3	TOTAL URANIUM	3	0.0010	<	0.0010	<	0.0010
WEIR 3	V	3	0.012	<	0.0027	<	0.0072

Table 1.12 (continued)
(Note: Radionuclides are in Bq/L - Inorganics are in mg/L
- Organics are in μg/L - Conductivity is in ms/cm and
Temperature is in degrees C)

Media=Surface water Area=Bear Creek Valley

Station	Analyte	No. of samples	Max	Qual-ifier	Min	Qual-ifier	Ave
WEIR 3	ZN	3	0.012	<	0.0018	<	0.0064
WEIR 3	CONDUCTIVITY	3	0.20		0		0.083
WEIR 3	DO	3	10		6.3		8.7
WEIR 3	PH	3	8.3		7.8		8.1
WEIR 3	TEMPERATURE	3	21		8.4		16
WEIR 4	ETHYLBENZENE	3	5.0	<	2.0	<	4.0
WEIR 4	METHYLENE CHLORIDE	3	5.0	<	5.0	<	5.0
WEIR 4	GROSS ALPHA	2	0.54		0.17		0.36
WEIR 4	GROSS BETA	2	1.7		1.1		1.4
WEIR 4	TOTAL SR	2	-0.060		-0.060		-0.060
WEIR 4	TRITIUM	2	50		30		40
WEIR 4	AL	3	0.21	<	0.036	<	0.11
WEIR 4	ALKALINITY	3	35		11		25
WEIR 4	BA	3	0.13		0.010		0.058
WEIR 4	BE	3	0.0012	<	0.00018	<	0.00052
WEIR 4	CA	3	7.8		4.7		6.6
WEIR 4	CL	3	8.9		3.8		5.6
WEIR 4	CR	3	0.024	<	0.0036	<	0.011
WEIR 4	FE	3	0.11	<	0.012	<	0.064
WEIR 4	MG	3	3.8		1.9		3.0
WEIR 4	MN	3	0.068	<	0.0030	<	0.041
WEIR 4	NA	3	3.1		0.99		2.0
WEIR 4	SI	3	2.5		1.5		2.0
WEIR 4	SR	2	0.013		0.010		0.012
WEIR 4	TI	3	0.014	<	0.012	<	0.013
WEIR 4	TOTAL URANIUM	3	0.0010	<	0.0010	<	0.0010
WEIR 4	V	3	0.012	<	0.0028	<	0.0064
WEIR 4	ZN	3	0.012	<	0.0018	<	0.0086
WEIR 4	CONDUCTIVITY	2	0.12		0.10		0.11
WEIR 4	DO	2	10		8.4		9.4
WEIR 4	PH	2	8.1		7.4		7.8
WEIR 4	TEMPERATURE	2	20		6.7		13

APPENDIX A. FIELD SAMPLING METHODS

A-1. WELL SAMPLING

Wells were purged and sampled using standard RCRA groundwater quality monitoring procedures as outline in 1)"The RCRA Groundwater Monitoring Technical Enforcement Document", 2) the USEPA Region IV "Engineering Support Branch Standard Operating Procedures and Quality Assurance Manual", and 3) USDOE Environmental Survey Manual, section E4.4.4.1, "Submersible pump" and section E4.4.4.4 - "Bailer".

Wells were evacuated prior to sampling using a submersible pump. At least one column volume plus stable pH and conductivity were the standards used to assure evacuation. In most cases three column volumes were evacuated. All samples were collected by bailing using a stainless-steel bailer. Chain-of-custody was maintained and documented for all samples. Field measurements were taken with a Horiba Model U-7 Water Quality Checker following the procedures in SOP RCRA-WQ5. The instrument was standardized daily prior to use in the field. Measurements taken were temperature, dissolved oxygen, pH, and conductivity.

A-2 SURFACE WATER SAMPLING

All samples were collected using methods described in the USDOE Environmental Survey Manual. All samples were collected by immersion. Volatiles were collected as described in section E4.2.1 and E4.2.3 of the Manual. Chain-of-custody was maintained and documented for all samples. Preservatives and containers were used as prescribed in 40 CFR part 136. Field measurements were made as described in section A-1.

A-3 SAMPLE PREPARATION

Groundwater samples for dissolved metals and radiological constituents were filtered prior to preservation and submission for analysis. Samples were filtered through a 0.45 micron millipore filter. All surface water and groundwater samples for meals and radiological analyses (except tritium) were preserved to a pH of less than 2.0 with nitric acid. All samples were cooled to 4 degrees C after collection. Samples for volatiles were collected with no headspace. Samples were prepared and submitted to the analytical laboratories in a timely manner so that no holding times were exceeded. Request for Analytical Services Forms and chain-of-custody forms accompanied the samples to the analytical laboratory.

APPENDIX B. ANALYTICAL METHODS

B.1 ORGANIC ANALYSIS METHODS

Volatile Organics

Volatile organic contaminants in water, soil, or sediment are determined using the 10/86 Contract Laboratory Program Statement of Work for low level samples. The method is appropriate for the determination of volatile organics in typical environmental matrices, using purge and trap sample introduction into a gas chromatograph-mass spectrometer (GC-MS). Thirty-four volatile target compounds can be identified and quantitated with the technique. Table B.1 summarizes these analytes and their respective quantitation limits.

Volatile organics are purged from an aqueous sample or a mixture of soil and distilled water at ambient temperature using an inert gas. The vapor is swept through a sorbent column where the volatiles are trapped. After purging is completed, the sorbent column is heated and backflushed with the inert gas to desorb the volatiles onto a gas chromatographic column.

The gas chromatograph is temperature programmed to separate the volatiles which are then detected with a mass spectrometer. Target compounds are identified by (1) elution of the sample component at the same GC relative retention time as the standard component and (2) correspondence of the sample component and standard component mass spectra. A search of the 1985 National Bureau of Standards (NBS) Mass Spectral Library is used to tentatively identify up to ten non-target analytes of greatest concentration in the chromatogram.

Volatile organics are purged from an aqueous sample or a mixture of soil and distilled water at ambient temperature using an inert gas. The vapor is swept through a sorbent column where the volatiles are trapped. After purging is completed, the sorbent column is heated and backflushed with the inert gas to desorb the volatiles onto a gas chromatographic column.

Method interferences may be caused by contaminants in solvents, reagents, glassware, and other sample processing hardware that would lead to artifacts and/or elevated baselines in the total ion profile. Laboratory reagent blanks are used to monitor the presence of such interferences. Interferences introduced by the sample matrix are monitored by the use of internal standards and matrix and surrogate spike recoveries.

Interpretation of volatiles data requires the assessment of the impact of holding times on data quality. The CLP protocol requires the analysis be conducted within ten days of sample receipt. Samples which may exceed this holding time can still provide useful information as long as the data is interpreted with caution.

Table B.1. Analytes Determined by CLP Volatiles Analysis Method

			Contract Required Detection Limits[a]
Analyte	CAS Number	Water (µg/L)	Low Soil/Sediment[b] (µg/L)
1. Chloromethane	74-B7-3	10	10
2. Bromomethane	74-B3-9	10	10
3. Vinyl chloride	75-01-4	10	10
4. Chloromethane	75-00-3	10	10
5. Methylene chloride	75-09-2	5	5
6. Acetone	67-61-1	10	10
7. Carbon disulfide	76-16-0	5	5
8. 1,1-Dichloroethene	75-35-4	5	5
9. 1,1-Dichloroethane	75-35-3	5	5
10. 1,2-Dichloroethene (total)	540-59-0	5	5
11. Chloroform	67-66-3	5	5
12. 1,2-Dichloroethane	107-06-2	5	5
13. 2-Butanone	78-93-3	10	10
14. I,I,I-Trichloromethane	71-55-6	5	5
15. Carbon tetrachloride	56-23-5	5	5
16. Vinyl acetate	108-05-4	10	10
17. Bromodichloromethane	75-27-4	5	5
18. 1,1.2,2-Tetrachloroethane	79-34-5	5	5
19. 1,2-Dichloropropane	78-87-5	5	5
20. cis-1,3-Dichloropropene	0061-01-5	5	5
21. Trichloroethena	79-01-6	5	5
22. Dibromochloromethane	124-4B-1	5	5
23. 1,1,2-Trichloromethane	79-00-5	5	5
24. Benzene	71-43-2	6	6
25. trans-1,3-Dichloropropene	10061-02-6	5	5
26. Bromoform	75-25-2	5	5
27. 2-Hexanone	591-78-6	10	10
28. 4-Methyl-2-pentanone	108-10-1	10	10
29. Tetrachloroethene	127-18-4	5	5
30. Toluene	108-88-3	5	5
31. Chlorobenzene	108-90-7	5	5
32. Ethyl benzene	100-41-4	5	5
33. Styrene	100-42-5	5	5
34. Xylenes (total)	133-02-7	5	5

Table B.1 (continued)

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[a] Specific detection limits are highly matrix dependent. The detection limits listed herein are provided for guidance and may not always be achievable.

[b] Detection limits listed for soil/sediment are based on wet weight. The detection limits calculated by the laboratory for soil/sediment, calculated on dry weight basis as required by the contract, will be higher.

[c] Contract required detection limits (CRDL) for volatiles at medium levels in soil/sediment are 100 times the listed CRDL for volatiles at low levels in soil/sediment.

B.2 INORGANIC ANALYSIS METHODS

B.2.1. CLP Metals Determination by Atomic Emission or Absorption Techniques

The determination of low levels of metal contaminants was accomplished using protocol based on the U.S. EPA Contract Laboratory Program SOW No. 785 for Inorganic Analysis Multi-media, Multi-concentration. Table B.2 summarizes the analytical method and the required detection limit for specific metal contaminants. Sixteen elements were analyzed and reported using the inductively coupled plasma (ICP) technique according to the full CLP technical criteria. In addition, four elements (Sb, As, Se, and Pb) were also determined by ICP and were reported to detection levels which slightly exceeded the CLP requisite limits but were significantly below the ICP method detection limits. Graphite furnace atomic absorption (GFAA) was used to determine and report the concentrations of five elements (Ag, Be, Cd, Cr, and Pb). Mercury was determined by cold vapor flameless AA (CVAA) and potassium was determined using atomic emission (AE) photometry.

CLP protocol was used to monitor the precision and accuracy of the individual elemental results. Calibration data were verified during the course of an analytical run; interference check samples were used to determine the effectiveness of interelement corrections. The precision of the measurements was estimated using sample duplicates. Sample digestion efficiency and measurement accuracy were assessed by including laboratory control samples within each analytical run. Matrix spikes, analytical spikes, and serial dilutions of samples (for ICP only) were made to determine the presence of analytical interferences attributable to the sample matrix or preparation procedures.

B.2.1.1 ICP-Atomic Emission Spectrometry

The basis of this method is the simultaneous multi-element measurement of atomic emission by an optical spectroscopic technique. Samples are nebulized and the aerosol that is produced is transported to a high temperature plasma where excitation occurs. Characteristic atomic-line emission spectra are produced by a radio-frequency ICP. The spectra are dispersed by a grating spectrometer, and the line intensities, which are a

Table B.2. Elements Determined by Atomic Emission or Absorption Techniques

Element	Contract Required Detection Level (μg/L)	ICP Method Detection Limit	Analytical Method
Aluminum	200	200	ICP
Antimony	60	150	ICP
Arsenic	10	250	ICP
Barium	200	200	ICP
Beryllium	5	5	GFAA,ICP*
Cadmium	5	20	GFAA,ICP*
Calcium	5000	5000	ICP
Chromium	10	10	GFAA,ICP*
Cobalt	50	50	ICP
Copper	25	25	ICP
Iron	100	100	ICP
Lead	5	200	GFAA,ICP*
Magnesium	5000	5000	ICP
Manganese	15	15	ICP
Mercury	0.2	---	CVAA
Nickel	40	40	ICP
Potassium	5000	5000	AE
Selenium	5	400	ICP
Silver	10	30	GFAA,ICP*
Sodium	5000	5000	ICP
Vanadium	50	50	ICP
Zinc	20	20	ICP

ICP=Inductively Coupled Plasma Emission Spectrometry
GFAA=Graphite Furnace Atomic Absorption Spectrometry
AE=Flame Atomic Emission Photometry

* Only GFAA results were reported for this element

measure of elemental concentrations, are monitored by photomultiplier tubes. The photocurrents from the photomultiplier tubes are processed and controlled by a computer system. A background correction technique is required to compensate for variable background contributions to the determination of trace elements. Background is measured adjacent to analyte lines on samples during analysis. The position selected for the background intensity measurement, on either or both sides of the analytical line, is determined by the complexity of the spectrum adjacent to the analyte line. The position used should be free of spectral interference and reflect the same change in background intensity that occurs as the analyte wavelength is measured. Background correction is not required in cases of line broadening where a background correction measurement would actually degrade the analytical result. Additional interferences,i.e., spectral, physical, and/or chemical, are also possible; appropriate corrections are made when required and are documented in the ICP case narrative.

Acid digestion of water, soil, sediment, and sludge samples is performed according to CLP SOW No. 785 protocol prior to trace metal analysis by ICP. A 100-mL aliquot of an aqueous sample is digested with a mixture of nitric and hydrochloric acids. The acidified sample is heated below boiling for approximately two hours or until the sample volume is reduced to half of its initial volume. The sample is then cooled, filtered, and diluted volumetrically. For solid samples, a representative 1-g (wet weight) sample is digested with nitric acid and hydrogen peroxide. The digestate is then refluxed with nitric and hydrochloric acid, then allowed to cool prior to filtration and dilution. Elemental sample concentrations are reported on a dry weight basis.

B.2.1.2 Atomic Absorption, Furnace Technique

Graphite furnace atomic absorption is used to determine the concentration of Be, Cr, Pb, Cd, and Ag. When using the furnace technique in conjunction with an atomic absorption spectrophotometer, a representative aliquot of a sample is placed in the graphite tube of the furnace, evaporated to dryness, charred, and atomized. Analyte atoms are vaporized and dissociated light for absorption in the tube. Radiation from a light source, hollow cathode or electrodeless discharge lamp of the element being determined, is passed through the vapor containing ground-state atoms of that element. The intensity of the transmitted radiation decreases in proportion to the amount of the ground state element in the vapor. A grating monochromator isolates the characteristic radiation from the hollow cathode lamp and a photosensitive device measures the attenuated transmitted radiation.

Aqueous samples are prepared by digesting 100-mL aliquots with a mixture of nitric acid and hydrogen peroxide. The acidified sample is then heated below boiling for approximately two hours or until the sample volume is reduced to half of its initial volume. The sample is then cooled, filtered, and diluted volumetrically. Representative 1-g solid samples are prepared by digesting them in nitric acid and hydrogen peroxide. The digestate is refluxed with nitric acid and then allowed to settle for one week prior to dilution and analysis.

B.2.1.3 Mercury

Mercury is determined by cold vapor flameless atomic absorption. The flameless AA procedure is a physical method based on the absorption of radiation at 253.7 nm by mercury vapor. Organic mercury compounds are converted to inorganic forms by the oxidative digestion of the sample. An aliquot of the diluted digestate is transferred to a 50-mL closed reaction chamber where stannous chloride is used to reduce the mercury to the elemental form. The mercury vapor is then purged from the solution into a 90-cm absorption cell positioned in the light path of an atomic absorption spectrophotometer. Absorbance (peak height) is measured as a function of mercury concentration.

Soil samples are prepared using a method developed at ORNL. The method is capable of determining two nanograms (ng) of mercury. A perchloric acid/nitric acid wet-ashing procedure is used to convert the organic mercury contained in 0.2-gram samples to an inorganic form. Reagent blanks are very low (<2 ng) for this procedure. To obtain these low blanks, acids are preselected by analytical testing and washed glassware is baked overnight at 450°C. Samples are digested in a 250-mL borosilicate volumetric flask equipped with supplemental air condensers to prevent the loss of mercury. After digestion the sample volume is adjusted to 50 mL; an aliquot of this solution is introduced into the instrument reaction chamber for the subsequent determination of mercury.

B.2.2. Anions

B.2.2.1 Anions by Ion Chromatography

Ion chromatography is a rapid analytical technique for multi-ion analysis in a single solution scan. The method depends on the separation of a group of anions flowing through an anion exchange column, suppression of the eluant conductivity on an acid-form cation exchange column, and final conductimetric detection of the separated anions as they pass through the measurement cell. Identification of the ions present is made by characteristic retention times and is supported by sample spikes. The increase in conductivity caused by each electronegative anion is recorded using a peak integrator or strip chart recorder. Results are compared with those of standard solutions to determine anion concentration. Results are reported for chloride (Cl^-), fluoride (F^-), nitrate (NO_3^-), phosphate (PO_4^{-3}) and sulfate (SO_4^{-2}). Aqueous samples are allowed to come to ambient temperature before analysis. Twenty milliliters of carbonate-bicarbonate eluant is used to extract anions from 0.25-g portions of solid samples before they are analyzed. Holding times for sample analysis are limited to between 48 hours and 28 days, depending on the anions to be determined.

B.2.3. Radiochemistry

Radiochemical contamination in soil and water is determined by either direct counting or by radiochemical separations and specific counting to ascertain radionuclide activity. Water samples (other than those for tritium analysis) are acidified to pH 2 at collection time. Samples that are not acidified in the field are acidified when they are received and allowed to equilibrate overnight before sample aliquots are removed. Soil samples are dried at 105 oC to a constant weight, then pulverized and blended well before sample aliquots are removed. All soil samples except those for tritium are analyzed on a dry weight basis.

B.2.3.1 Determination of Gross Alpha and Beta Activity in Water

An aliquot of a preserved water sample is evaporated to a small volume and transferred quantitatively to a tared 2-inch stainless steel counting planchet. The sample residue is dried to constant weight, then reweighed to determine dry residue weight. The sample is counted independently for gross alpha and gross beta activity.

Counting is performed on a Tennelec LB-4000 system that is comprised of 12 gas-flow proportional counters and an IBM-PC controller. Counting efficiencies for both alpha and beta particle activities are determined according to the amount of sample solids from a standard curve of counting efficiency vs sample solids.

B.2.3.2 Total Uranium in Water

The total uranium content in drinking water, surface and ground waters, and domestic industrial wastes are determined by fluorometric analysis. Uranium is quantitatively extracted from acidified nitrate solutions using trioctylphosphine oxide (TOPO) dissolved in an organic solvent, such as dodecane. Aliquots of the resulting organic extract are pipetted onto pellets of sodium fluoride in small (22 mm) platinum dishes. The pellets are dried at 585^{o}C, fused at 990^{o}C, and annealed at 765^{o}C. The prepared pellets are then placed in a fluorophotometer for measurement of the uranium concentration.

The fluorophotometer was designed and fabricated at ORNL (Model 5198), but is typical of commercial units later available. The analyzer has two ultraviolet light sources for greater sensitivity, optical filters, multisampler turntable, and a photomultiplier tube for measuring the intensity of the uranium fluorescence light. In routine practice, a set of known uranium standards is prepared on pellets and exposed to the primary excitation radiation. The characteristic emitted uranium fluorescence is used to adjust the instrument to read directly in nanograms of uranium. The samples are similarly measured; the fluorescence of each is determined and the actual uranium concentration is read in nanograms of uranium. The method has a detection limit of 1 ng.

The procedure works equally well for aqueous and solid specimens. Uranium is directly extracted from 20-mL aliquots of aqueous samples. Fifty-gram portions of solid samples must be acid digested prior to TOPO extraction. The TOPO extract is placed on three identical NaF pellets to obtain triplicate analyses for both aqueous and solid samples.

B.2.3.3 Total Strontium in Water

Stable strontium carrier is added to an aliquot of water and the strontium precipitated from the sample as the carbonate. Interferences from calcium and some radionuclides are removed by one or more precipitations of the strontium carrier as strontium nitrate. Barium and radium are removed as the chromate; the yttrium-90 daughter of strontium-90 is removed by hydroxide precipitation. The separated strontium is counted immediately for beta particle activity. The counting result represents the total strontium activity (strontium-89 and strontium-90) plus an insignificant fraction of the yttrium-90 that has grown into the separated strontium-90. Counting is performed on a Tennelec Model LB 4000 computer-controlled system. The lowest reported concentration is 0.5 pCi/L for 250-mL samples.

B.2.3.4 Tritium in Water and Soil

Soil samples are prepared by leaching with equal or double portions of distilled water; water samples require no pretreatment. An aliquot of water or soil leachate is treated with a small amount of sodium hydroxide and potassium permanganate and distilled. The alkaline treatment prevents other radionuclides such as radioiodine and radiocarbon from co-distilling over with the tritium. Some water supplies will contain trace quantities of organic compounds (especially surface water sources that contain biota). The permanganate treatment oxidizes trace organics in the sample aliquot which could distill over and cause quenching interferences. A middle fraction of the distillate is collected for tritium analysis because the early and late fractions are more apt to contain materials that might interfere with the liquid scintillation counting process. The collected distillate fraction is thoroughly mixed and a portion is added to a liquid scintillator solution and counted in a scintillation counter for tritium beta particle activity. Detection limits depend on sample size, counting time, and counter background. The expected detection limit is approximately 500 pCi/L for water samples and 500 pCi/kg for soil samples.

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APPENDIX C. QUALITY ASSURANCE

INTRODUCTION

An adequate quality assurance (QA) program for environmental sampling requires the identification, quantification, and control of all sources of error associated with each step in the sampling and analysis program. Factors to consider as sources of error include those associated with sample collection, sample preparation, extraction, and analysis. Thus, QA requires systematic control of all phases of the measurement process.

The QA program for LLWDDD Sampling and Analysis consists of both field and laboratory measures to control and evaluate variability. In addition, ORNL participates in internal and external quality control programs. Table C.1 is a summary of QC activities for LLWDDD sampling and analysis. This table gives the area and station sampled, the type of QC sample, the type of analysis, and the sampling period for both the groundwater and surface water samples. These and other QA measures used during the time the LLWDDD samples were collected and analyzed and those implemented specifically for LLWDDD results will be described below.

C.1 FIELD SAMPLING

Field sampling quality assurance included the development of an outline for sampling and analysis prior to sample collection, use of Standard Operating Procedures for field sampling, calibration of field instruments, collecting quality control samples in the field, use of chain-of-custody forms, and documentation of field activities in logbooks.

Sample collection problems were minimized by using techniques, equipment, decontamination procedures, types of containers, and preservatives in ORNL's Standard Operating Procedures (SOPs) for the collection of surface water and groundwater samples were followed.

Measurements for pH, temperature, and conductivity were made in the field using an Horiba, model U-7 portable water quality checker. The instrument was routinely calibrated once every two weeks and checked daily before use. When daily check values were outside the prescribed acceptable limits (see Table C.2), the instrument was recalibrated before use in the field.

The Horiba thermistor used for measuring temperature was calibrated against an NBS traceable calibrated mercury thermometer. Calibration and daily checks for pH were made with commercially purchased NBS traceable buffers. Calibration and daily checks for conductivity were made with reference KCl solutions prepared as outlined in Standard Methods for the Examination of Water and Wastewater, 15th edition, 1980.

In order to evaluate and validate sampling data, field quality control samples were collected. These consisted of blanks and field duplicate samples.

Table C.1. QC sample collection and analysis activities

Station	Area	Type of QC sample	Type of analysis	Sampling period
		Groundwater		
FLUME 672	Bear Creek Valley	Duplicate	AA Metals	
			Radionuclides	
			Organics	
			ICP Metals	1
FLUME 7	West Chestnut Ridge	Duplicate	AA Metals	
			Radionuclides	
			Organics	
			ICP Metals	3
WELL B-01	SWSA 7	Blank	AA Metals	
			Radionuclides	
			Organics	
			ICP Metals	3
WELL B-02	SWSA 7	Blank	AA Metals	
			Radionuclides	
			Organics	
			ICP Metals	3
WELL S-01		Spike	AA Metals	1,3
			Radionuclides	1,2,3
			Organics	2,3
			ICP Metals	1,2,3
		Surface Water		
WELL 18-B	West Chestnut Ridge	Duplicate	AA Metals	
			Radionuclides	
			Organics	
			ICP Metals	1,2
WELL 1117	SWSA 7	Duplicate	AA Metals	
			Radionuclides	
			Organics	
			ICP Metals	3

Table C.2. Acceptance Limits for Field Measurements

Parameter	Daily Check Acceptance Limit	Calibration Acceptance Limit
Temperature	+/- 1 degree C	+/- 1 degree C
pH	+/ 0.2 pH units	+/- 0.1 pH units
Conductivity	Reference value +/- 0.1 ms/cm	Reference value +/- 0.1 ms/cm

Because of the low concentrations expected in the water samples, several distilled water blanks were included in the samples submitted to the analytical laboratory for analysis. The blank was prepared using deionized/distilled water with the appropriate preservatives added. The purpose of the field samples was to see if the handling of the samples, either in the field or in the laboratory, resulted in any contamination. Table C.3 lists the results of the analytical determinations of the field-prepared blanks. A significant amount of 2-butanone showed up as contamination in the first volatile sample submitted. A reagent blank was submitted with the second sample submitted. The results verified that the 2-butanone had been introduced into the sample. In addition to 2-butanone, acetone, carbon tetrachloride, and trichloethene were also detected in field blanks. Other elements that were detected in the field blanks were barium, chromium, zinc, and total uranium. Gross alpha, gross beta, total strontium, and tritium were near background levels.

Field samples were split onsite and submitted for duplicate analyses. The purpose of these samples was to look at the combined variability in the sampling methods, the media, and in the laboratory. Table C.4 gives the two duplicate measurements and the relative percent difference among the field splits. The table notes duplicates that differ by more than 20%. This value of 20% was arbitrarily chosen by the author in order to screen the results.

For some analytes, differences greater than 20% may be real (and not the result of analytical variability) due to the matrix effects and the properties of the analytes. The duplicate sample results were compared similar to the methods described in the CLP documents. The relative percent difference (RPD) for each analyte was calculated as follows:

$$\text{RPD} = \frac{[D1-D2] \times 100}{\{D1 + D2\}/2}$$

Where D1 = first sample result (original) and
D2 = second sample result (duplicate)

When either sample was below the CRDL, the RPD was not calculated. A high relative percent difference in one of the duplicate results for methylene chloride was noted (150% RPD). It is suspected that it was introduced into one of the samples during preparation. RPDs greater than 20 percent were calculated for silicon and zinc in both ground and surface water samples and for manganese, sulfate, and aluminum in ground water samples. During the first two sampling periods, and prior to ICP analysis, a water preparation which takes the sample from 100 mL to about 1 mL and then reconcentrates to 10 mL was used rather than the CLP water preparation procedure. It is believed that a significant amount of material was lost using this procedure. This may have produced the high variability in the duplicate results. During the third quarter, the CLP water preparation procedure was used and problems were noted only with silicon and zinc. A water preparation procedure provides only qualitative estimates for silicon because it does not stay in solution. It should be digested with Hf, if quantitative results are desired. Concentrations of Al, Mn, and Zn in all samples were all near the detection limit which affects the precision of the results.

Table C.3. Results of analysis of field blanks

Type of analysis=Organics (μg/L)

Blank id	Analyte	Sampling period	Qual-ifier	Result
WELL B-01	1,1,1-TRICHLOROETHANE	3	<	5.0
WELL B-01	1,1,2,2-TETRACHLOROETHANE	3	<	5.0
WELL B-01	1,1,2-TRICHLOROETHANE	3	<	5.0
WELL B-01	1,1-DICHLOROETHANE	3	<	5.0
WELL B-01	1,1-DICHLOROETHENE	3	<	5.0
WELL B-01	1,2-DICHLOROETHANE	3	<	5.0
WELL B-01	1,2-DICHLOROETHENE (TOTAL)	3	<	5.0
WELL B-01	1,2-DICHLOROPROPANE	3	<	5.0
WELL B-01	2-BUTANONE	3	<	10
WELL B-01	2-HEXANONE	3	<	10
WELL B-01	4-METHYL-2-PENTANONE	3	<	10
WELL B-01	ACETONE	3	<	10
WELL B-01	BENZENE	3	<	5.0
WELL B-01	BROMODICHLOROMETHANE	3	<	5.0
WELL B-01	BROMOFORM	3	<	5.0
WELL B-01	BROMOMETHANE	3	<	10
WELL B-01	CARBON DISULFIDE	3	<	5.0
WELL B-01	CARBON TETRACHLORIDE	3	<	5.0
WELL B-01	CHLOROBENZENE	3	<	5.0
WELL B-01	CHLOROETHANE	3	<	10
WELL B-01	CHLOROFORM	3	<	5.0
WELL B-01	CHLOROMETHANE	3	<	10
WELL B-01	CIS-1,3-DICHLOROPROPENE	3	<	5.0
WELL B-01	DIBROMOCHLOROMETHANE	3	<	5.0
WELL B-01	ETHYLBENZENE	3	<	5.0
WELL B-01	METHYLENE CHLORIDE	3	<	5.0
WELL B-01	STYRENE	3	<	5.0
WELL B-01	TETRACHLOROETHENE	3	<	5.0
WELL B-01	TOLUENE	3	<	5.0
WELL B-01	TRANS-1,3-DICHLOROPROPENE	3	<	5.0
WELL B-01	TRICHLOROETHENE	3	<	5.0
WELL B-01	VINYL ACETATE	3	<	10
WELL B-01	VINYL CHLORIDE	3	<	10
WELL B-01	XYLENE (TOTAL)	3	<	5.0
WELL B-02	1,1,1-TRICHLOROETHANE	3	<	5.0
WELL B-02	1,1,2,2-TETRACHLOROETHANE	3	<	5.0
WELL B-02	1,1,2-TRICHLOROETHANE	3	<	5.0
WELL B-02	1,1-DICHLOROETHANE	3	<	5.0
WELL B-02	1,1-DICHLOROETHENE	3	<	5.0
WELL B-02	1,2-DICHLOROETHANE	3	<	5.0
WELL B-02	1,2-DICHLOROETHENE (TOTAL)	3	<	5.0
WELL B-02	1,2-DICHLOROPROPANE	3	<	5.0
WELL B-02	2-BUTANONE	3	E	910
WELL B-02	2-HEXANONE	3	<	10
WELL B-02	4-METHYL-2-PENTANONE	3	<	10

Table C.3 (continued)

Type of analysis=Organics (μg/L)

Blank id	Analyte	Sampling period	Qual-ifier	Result
WELL B-02	ACETONE	3	B	10
WELL B-02	BENZENE	3	<	5.0
WELL B-02	BROMODICHLOROMETHANE	3	<	5.0
WELL B-02	BROMOFORM	3	<	5.0
WELL B-02	BROMOMETHANE	3	<	10
WELL B-02	CARBON DISULFIDE	3	<	5.0
WELL B-02	CARBON TETRACHLORIDE	3		12
WELL B-02	CHLOROBENZENE	3	<	5.0
WELL B-02	CHLOROETHANE	3	<	10
WELL B-02	CHLOROFORM	3	<	5.0
WELL B-02	CHLOROMETHANE	3	<	10
WELL B-02	CIS-1,3-DICHLOROPROPENE	3	<	5.0
WELL B-02	DIBROMOCHLOROMETHANE	3	<	5.0
WELL B-02	ETHYLBENZENE	3	<	5.0
WELL B-02	METHYLENE CHLORIDE	3	<	5.0
WELL B-02	STYRENE	3	<	5.0
WELL B-02	TETRACHLOROETHENE	3	<	5.0
WELL B-02	TOLUENE	3	<	5.0
WELL B-02	TRANS-1,3-DICHLOROPROPENE	3	<	5.0
WELL B-02	TRICHLOROETHENE	3		15
WELL B-02	VINYL ACETATE	3	<	10
WELL B-02	VINYL CHLORIDE	3	<	10
WELL B-02	XYLENE (TOTAL)	3	<	5.0

Table C.3 (continued)

Type of analysis=Radionuclides (Bq/L)

Blank id	Analyte	Sampling period	Qual- ifier	Result
WELL B-01	GROSS ALPHA	3		0.71
WELL B-01	GROSS BETA	3		0.25
WELL B-01	TOTAL SR	3		0.070
WELL B-01	TRITIUM	3		-1.0

Table C.3 (continued)

Type of analysis=Inorganics (mg/L)

Blank id	Analyte	Sampling period	Qual-ifier	Result
WELL B-01	ALKALINITY	3	<	2.5
WELL B-01	TOTAL URANIUM	3		0.0010
WELL B-01	AS	3	<	0.010
WELL B-01	HG	3	<	0.00010
WELL B-01	SE	3	<	0.0050
WELL B-01	AG	3	<	0.0036
WELL B-01	AL	3	<	0.036
WELL B-01	B	3	<	0.048
WELL B-01	BA	3		0.015
WELL B-01	BE	3	<	0.00018
WELL B-01	CA	3	<	0.12
WELL B-01	CD	3	<	0.0012
WELL B-01	CO	3	<	0.0018
WELL B-01	CR	3		0.0047
WELL B-01	CU	3	<	0.0060
WELL B-01	FE	3	<	0.012
WELL B-01	GA	3	<	0.18
WELL B-01	LI	3	<	0.12
WELL B-01	MG	3	<	0.0060
WELL B-01	MN	3	<	0.0030
WELL B-01	MO	3	<	0.024
WELL B-01	NA	3	<	0.12
WELL B-01	NI	3	<	0.0036
WELL B-01	P	3	<	0.18
WELL B-01	PB	3	<	0.030
WELL B-01	SB	3	<	0.030
WELL B-01	SI	3	<	0.12
WELL B-01	SN	3	<	0.030
WELL B-01	SR	3	<	0.0030
WELL B-01	TI	3	<	0.012
WELL B-01	V	3	<	0.0024
WELL B-01	ZN	3		0.029
WELL B-01	ZR	3	<	0.012
WELL B-01	CL	3	<	1.0
WELL B-01	F	3	<	1.0
WELL B-01	NO3	3	<	5.0
WELL B-01	PO4	3	<	5.0
WELL B-01	SO4	3	<	5.0

Table C.4. Results of analysis of duplicate field samples

Type of Analysis=Organics (μg/L) in water

Analyte	Station	Sampling Period	Original Value	Duplicate Value	Relative % Difference	Differs by more than 20%
Meth. chloride	WELL 18-B	1	7	50	150	*
Xylene (Total)	FLUME 7	3	5.0	2.0	86	*

Table C.4 (continued)

Type of Analysis=Inorganics (mg/L) in Ground water

Analyte	Station	Sampling Period	Original Value	Duplicate Value	Relative % Difference	Differs by more than 20%
AL	WELL 1117	3	0.22	0.20	9.5	
AL	WELL 18-B	2	0.063	0.045	33	*
ALKALINITY	WELL 1117	3	280	270	3.6	
ALKALINITY	WELL 18-B	1	170	170	0.80	
ALKALINITY	WELL 18-B	2	130	130	0.40	
BA	WELL 1117	3	0.068	0.069	1.5	
BA	WELL 18-B	1	0.051	0.044	15	
BA	WELL 18-B	2	0.026	0.023	12	
BE	WELL 1117	3	0.0013	0.0013	0	
CA	WELL 1117	3	87	89	2.3	
CA	WELL 18-B	1	49	47	4.2	
CA	WELL 18-B	2	42	40	4.9	
CL	WELL 1117	3	1.3	1.3	0	
CL	WELL 18-B	1	1.6	1.9	17	
CL	WELL 18-B	2	2.1	2.1	0	
CR	WELL 1117	3	0.0076	0.0076	0	
FE	WELL 1117	3	0.076	0.089	16	
MG	WELL 1117	3	13	13	0	
MG	WELL 18-B	1	13	13	0	
MG	WELL 18-B	2	8.9	8.5	4.6	
MN	WELL 1117	3	0.069	0.071	2.9	
MN	WELL 18-B	1	0.0086	0.015	54	*
MN	WELL 18-B	2	0.0083	0.0050	50	*
NA	WELL 1117	3	12	12	0	
NA	WELL 18-B	1	3.1	2.9	6.7	
NA	WELL 18-B	2	2.4	2.3	4.3	
SI	WELL 18-B	1	3.2	3.3	3.1	
SI	WELL 18-B	2	1.7	1.3	27	*
SO4	WELL 1117	3	35	35	0	
SO4	WELL 18-B	1	5.0	6.8	31	*
SO4	WELL 18-B	2	8.1	8.2	1.2	
SR	WELL 1117	3	0.64	0.66	3.1	
SR	WELL 18-B	1	0.14	0.14	0	
SR	WELL 18-B	2	0.096	0.092	4.3	
TOTAL URANIUM	WELL 1117	3	0.0010	0.0010	0	
TOTAL URANIUM	WELL 18-B	1	0.0010	0.0010	0	
V	WELL 1117	3	0.0069	0.0066	4.4	
V	WELL 18-B	2	0.0069	0.0070	1.4	
ZN	WELL 1117	3	0.024	0.026	8.0	
ZN	WELL 18-B	2	0.0057	0.0029	65	*

Table C.4 (continued)

Type of Analysis=Inorganics (mg/L) in Surface water

Analyte	Station	Sampling Period	Original Value	Duplicate Value	Relative % Difference	Differs by more than 20%
AL	FLUME 672	1	0.20	0.20	0	
AL	FLUME 7	3	0.16	0.16	0	
ALKALINITY	FLUME 672	1	59	60	1.7	
ALKALINITY	FLUME 7	3	130	120	3.0	
BA	FLUME 7	3	0.021	0.021	0	
BE	FLUME 7	3	0.00080	0.00079	1.3	
CA	FLUME 672	1	21	21	0	
CA	FLUME 7	3	27	27	0	
CL	FLUME 672	1	1.8	1.5	18	
CL	FLUME 7	3	1.0	1.0	0	
CR	FLUME 7	3	0.0079	0.0080	1.3	
FE	FLUME 672	1	0.068	0.075	9.8	
FE	FLUME 7	3	0.015	0.014	6.9	
MG	FLUME 672	1	5.0	5.0	0	
MG	FLUME 7	3	17	17	0	
MN	FLUME 672	1	0.012	0.012	0	
NA	FLUME 672	1	4.6	4.5	2.2	
NA	FLUME 7	3	0.55	0.61	10	
SI	FLUME 672	1	4.8	2.1	78	*
SI	FLUME 7	3	0.77	3.1	120	*
SO4	FLUME 672	1	23	26	12	
SR	FLUME 672	1	0.071	0.070	1.4	
TOTAL URANIUM	FLUME 672	1	0.0010	0.0010	0	
TOTAL URANIUM	FLUME 7	3	0.0010	0.0010	0	
V	FLUME 7	3	0.0070	0.0074	5.6	
ZN	FLUME 7	3	0.0084	0.012	35	*

Chain-of-custody was maintained on all samples. In addition, ORNL's Request of Analytical Services forms were completed for each sample to maintain accountability and traceability of the samples. Sample forms were filled out in the field in ink by each sampler.

EPA conducts a national quality assurance program in support of the NPDES program. QC samples are submitted annually for analysis. All results from ORNL for 1987 were determined to be acceptable. Results for 1988 have not been reported by the EPA.

The Control Laboratory Program is administered by the U.S. EPA Control Lab Program-Sample Management Office in Virginia in cooperation with the EMSL-LV Office and EPA regions. This program qualifies laboratories for the determination of organic and inorganic contaminants in aqueous and solid hazardous waste materials. The program enforces stringent QA protocol requirements for laboratory operation. Analysis of quarterly performance samples is mandatory for certification. At ORNL, the quarterly scores for the 1987 ranged from 86.5 to 96.6 (out of 100 total points) for the inorganic laboratories. It should be noted that the lowest score was during the fourth quarter of 1987 and that the EPA had changed the rating scale. The average scores of all participating laboratories (19 to 23) ranged from 78 to 84 for the inorganics. The organic scores were not available at the time this report was prepared.

C.2 GENERAL LABORATORY QA PRACTICES

This section describes the QA practices in place at the time the LLWDDD samples were being analyzed.

The analytical laboratories employ highly trained and well qualified staffs who are provided with excellent equipment and facilities. Approved and current analytical methodologies employing good laboratory and measurement practices are used routinely to ensure analytical reliability. The analytical laboratories conduct extensive internal quality control programs and participate in several external quality control programs.

C.2.1 Internal Quality Control

A key feature of analytical quality assurance is quality control. The analytical laboratories have quality assurance and quality control officers appointed to work with them. These individuals monitor the general quality of analytical data. The QA and QC officers administer a program generating QC samples of known composition and submit these to the laboratories on an established periodic basis. These samples are prepared utilizing EPA, National Bureau of Standards (NBS), or other reliable materials and are submitted as samples of unknown value to the analyst. All analytical activities are supported by the use of known composition which are used in calibration of instruments, methods standardization, spike additions for recovery tests, and other practices. Certified standards from the NBS, EPA, or from other DOE laboratories are used for such work. All of the laboratories operate under specific criteria for QA activities which are documented by each installation in their QA manuals.

For radiological analyses, uncertainties are reported at the 95% confidence level and represent counting statistics only. Many of the concentrations of radioactive materials in ambient environmental samples are at or near zero.

High purity germanium (HPGe) and lithium-drifted germanium [Ge (Li)] detectors utilizing standard counting configurations are used for identification of gamma emitting radionuclides in environmental samples. Water standards are prepared by dilution of an NBS-traceable mixed gamma primary standard and transfer of the dilution to the appropriate container.

Surface barrier alpha detectors are typically used to identify alpha emitting radionuclides in environmental samples. Typically, the detectors are energy calibrated with a secondary standard and background are taken on a monthly basis. Each procedure for alpha emitting radionuclides uses a known amount of tracer to determine yield and efficiency. Proportional counting systems are used to determine gross alpha and beta activities in environmental samples. Typically, the detectors are calibrated with NBS materials and a primary standard is counted each day to check instrument response. Backgrounds are determined by overnight counting on a weekly basis.

The total effort in these programs is at least 10% of the laboratory effort, in accord with EPA expectations, and probably reaches 20% in some activities. QC data are stored in a retrievable fashion so that they can be related to the analytical results which they support. Each installation generates quarterly and annual quality assurance reports which represent the results of their program and assist the laboratories in evaluating the adequacy of their programs and procedures.

C.2.2 External Quality Control

The sources of the external QC programs are laboratories in EPA, DOE, and the commercial sector. These programs generate data which permit participating laboratories performance review and comparison to other participating laboratories.

Presently, there are three national quality assurance programs in support of the NPDES program. QC samples are submitted annually for analysis. All results from ORNL for 1987 were determined to be acceptable. Results for 1988 have not been reported by the EPA.

The Control Laboratory Program is administered by the U.S. EPA Contract Lab Program-Sample Management Office in Virginia in cooperations with the EMSL-LV Office and EPA Regions. This program qualifies laboratories for the determination of organic and inorganic contaminants in aqueous and solid hazardous waste materials. The program enforces stringent QA protocol requirements for laboratory operation. Analysis of quarterly performance samples is mandatory for certification. At ORNL, the quarterly scores for 1987 ranged from 86.5 to 95.6 (out of 100 total points) for the inorganic laboratories. It should be noted that the lowest score was during the fourth quarter of 1987 and that the EPA has changed the rating scale. The average scores of all participating laboratories (19 to 23 of them) ranged from 78 to

84 for the inorganics. The organic scores were not available at the time this report was prepared.

C.3 SPECIFIC LABORATORY CONTROL

This section contains descriptions of QA and QC measures that were implemented specifically for the analysis of the LLWDDD samples.

Quality control samples have been submitted with the LLWDDD surface and groundwater samples for the last three quarters. Sample bottles were supplied by the Environmental Monitoring and Compliance Department. The samples were prepared by the Quality Control Officer of the Analytical Chemistry Division (Oak Ridge National Laboratory) and returned to the sampling team for submittal as blind controls with the quarterly field samples. The following sample types were prepared each quarter: ICP metals with total uranium, AA metals (selenium, mercury, and arsenic), anions and alkalinity, tritium, gross beta and strontium 90, and volatile organics. Tritium and volatile organics were not prepared the first quarter because of a lack of materials.

Water pollution quality control check sample concentrates obtained from the U.S. EPA Environmental Monitoring and Support Laboratory in Cincinnati were used to prepare the ICP metals, AA metals, and the anion and alkalinity samples. The tritium and strontium 90 (gross beta) samples were prepared from Amersham radioactive materials which meet NBS traceability requirements. The total uranium sample was prepared from a gravimetrically prepared solution of NBS Standard Reference Material 950b U_3O_8 in a 1.5 N nitric acid solution. Volatile organic samples were prepared from an EPA reference solution of GC/MS Purgeables II obtained from the Quality Assurance Materials Bank at Research Triangle Park, North Carolina. A known amount of reference solution was spiked into a sealed Tedlar sampling bag containing a predetermined volume of water. All samples were preserved according to Federal Register guidelines (40 CFR 136, 7/1/86).

Sample results are given in Table C.5. The percent recovery between the amount of spike added and measured value is calculated for each analyte and sample. Differences of more than 20 percent are noted in the table. Out of 95 measurements, only 19 had percent recoveries varying by more than 20 percent. Total uranium was not recovered appreciably in any of the samples. However, almost 100 percent recovery was obtained from blind external analytical control samples supplied by an outside vendor. The sample preparation for the last quarter's sample was repeated and resubmitted to the laboratory reexamination. Full recovery of the uranium was obtained. No calculation of dilution errors were evident in the analytical documentation. This analysis will be monitored closely in upcoming quarters. The calcium and cadmium spiking levels were about three times the instrument detection limit which may account for the variability between the measured and spiked results.

Table C.5. Spike recoveries for 1st - 3rd quarters

Type of analysis=Organics (μ/L)

Analyte	Sampling Period	Concentration	Spike	Percent Recovery	Differs by more than 20%
1,1,2,2-TETRACHLOROETHANE	2	48	63	76	*
1,1,2,2-TETRACHLOROETHANE	3	120	130	95	
1,1-DICHLOROETHENE	2	28	26	110	
1,1-DICHLOROETHENE	3	46	52	88	
1,2-DICHLOROETHANE	2	29	31	93	
1,2-DICHLOROETHANE	3	61	62	98	
1,2-DICHLOROETHENE (TOTAL)	2	69	69	100	
1,2-DICHLOROETHENE (TOTAL)	3	120	140	87	
1,2-DICHLOROPROPANE	2	46	50	92	
1,2-DICHLOROPROPANE	3	100	100	100	
CARBON TETRACHLORIDE	2	28	33	84	
CARBON TETRACHLORIDE	3	58	66	87	
CHLOROBENZENE	2	45	51	89	
CHLOROBENZENE	3	87	100	86	
METHYLENE CHLORIDE	2	53	50	110	
METHYLENE CHLORIDE	3	99	100	99	
TRICHLOROETHENE	2	57	62	92	
TRICHLOROETHENE	3	140	120	110	

Table C.5 (continued)

Type of analysis=Radionuclides (Bq/L)

Analyte	Sampling Period	Concentration	Spike	Percent Recovery	Differs by more than 20%
GROSS BETA	1	48	45	110	
GROSS BETA	2	800	940	85	
GROSS BETA	3	1200	1400	85	
TOTAL SR	1	24	22	110	
TOTAL SR	2	390	470	83	
TOTAL SR	3	630	710	89	
TRITIUM	2	450	440	100	
TRITIUM	3	640	670	96	

Table C.5 (continued)

Type of analysis=Inorganics (mg/L)

Analyte	Sampling Period	Concentration	Spike	Percent Recovery	Differs by more than 20%
AL	1	0.36	0.36	100	
AL	2	0.44	0.56	79	*
AL	3	0.39	0.40	98	
ALKALINITY	1	39	39	99	
ALKALINITY	2	28	29	94	
ALKALINITY	3	39	39	99	
AS	1	0.053	0.053	99	
AS	3	0.050	0.053	94	
BE	1	0.11	0.12	92	
BE	2	0.10	0.11	91	
BE	3	0.12	0.13	93	
CA	1	0.060	21	0.28	*
CA	2	0.12	22	0.56	*
CA	3	0.12	21	0.56	*
CD	1	0.013	0.020	65	*
CD	2	0.011	0.030	37	*
CD	3	0.020	0.021	93	
CL	1	51	45	110	
CL	2	53	56	94	
CL	3	47	45	100	
CO	1	0.13	0.13	100	
CO	2	0.096	0.11	87	
CO	3	0.13	0.14	91	
CR	1	0.13	0.13	100	
CR	2	0.12	0.11	110	
CR	3	0.13	0.14	91	
CU	1	0.18	0.17	110	
CU	2	0.13	0.11	120	
CU	3	0.17	0.19	91	
F	1	10	9.8	100	
F	2	15	17	90	
F	3	14	12	110	
FE	1	0.39	0.40	98	
FE	2	0.096	0.11	87	
FE	3	0.40	0.44	91	
HG	1	0.00090	0.0013	69	*
HG	3	0.0010	0.0013	77	*
MG	1	0.019	4.4	0.43	*
MG	2	0.0075	5.4	0.14	*
MG	3	0.0071	4.4	0.16	*
MN	1	0.17	0.17	100	
MN	2	0.11	0.11	100	
MN	3	0.17	0.19	89	
NA	1	0.30	25	1.2	*

Table C.5 (continued)

Type of analysis=Inorganics (mg/L)

Analyte	Sampling Period	Concen-tration	Spike	Percent Recovery	Differs by more than 20%
NA	2	0.12	22	0.56	*
NA	3	0.25	24	1.0	*
NI	1	0.11	0.10	110	
NI	2	0.11	0.11	100	
NI	3	0.11	0.11	96	
NO3	1	40	36	110	
NO3	2	26	22	120	
NO3	3	49	38	130	*
PB	1	0.23	0.22	100	
PB	2	0.11	0.11	100	
PB	3	0.23	0.24	96	
SE	1	0.019	0.022	87	
SE	3	0.019	0.022	87	
SO4	1	47	49	95	
SO4	2	22	22	100	
SO4	3	45	49	91	
TOTAL URANIUM	1	0.0010	13	0.0078	*
TOTAL URANIUM	2	0.25	29	0.87	*
TOTAL URANIUM	3	0.57	28	2.0	*
V	1	0.37	0.42	88	
V	2	0.23	0.28	82	
V	3	0.41	0.47	88	
ZN	1	0.20	0.21	95	
ZN	2	0.089	0.11	81	
ZN	3	0.22	0.23	96	

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