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**Pilot Uranium Lysimeter Studies  
at the Oak Ridge Y-12 Plant**

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C. W. Francis  
L. K. Hyder  
S. C. Howard  
J. E. Cline  
R. B. Clapp

Environmental Sciences Division  
Publication No. 3981



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Environmental Sciences Division

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C. W. Francis  
L. K. Hyder  
S. C. Howard<sup>a</sup>  
J. E. Cline<sup>b</sup>  
R. B. Clapp

Environmental Sciences Division Publication No. 3981

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<sup>a</sup>Central Waste Management  
<sup>b</sup>Y-12 Plant Development Division

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OAK RIDGE NATIONAL LABORATORY  
Oak Ridge, Tennessee 37831-6285  
managed by  
MARTIN MARIETTA ENERGY SYSTEMS, INC.  
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## LIST OF FIGURES

Figure	Page
1. Site plan for the Y-12 Plant Uranium Lysimeter Facility. . . . .	1
2. Cross section of a representative lysimeter and central core. . . . .	2
3. Placement of in situ collection devices in waste dumpster. . . . .	4
4. Leachate collection and flow-through water quality cell. . . . .	7
5. Water balance in the Oak Ridge Y-12 Plant pilot lysimeter. . . . .	9
6. Schematic of approximate locations of in situ collection devices in waste dumpster. . . . .	10
7. The pH of bottom leachate. . . . .	12
8. Dissolved oxygen content of bottom leachate. . . . .	12
9. Specific conductivity of bottom leachate. . . . .	13
10. Oxygen reduction potential of bottom leachate. . . . .	13
11. Relationship between leachate pH and quantity of leachate generated. . . . .	14
12. Relationship between conductivity and quantity of leachate generated. . . . .	15
13. Relationship between pH and conductivity of leachate. . . . .	16
14. Uranium concentrations in bottom leachate. . . . .	16
15. Comparison of uranium and iron concentrations in bottom leachate. . . . .	17
16. Comparison of uranium concentrations in bottom leachate sampled under oxic conditions (BOTTOM LEACHATE) to those sampled under anoxic conditions (IN LINE). . . . .	18
17. In situ sampling devices (BEAKER) and CANDLE) and bottom leachate sampling methods (BOTTOM LEACHATE under oxic conditions and IN LINE under anoxic conditions). . . . .	19
18. Comparison of uranium concentrations in in situ leachate sampled by suction candles and beakers. . . . .	20
19. General characteristic of bottom leachate in terms of alkalinity, biological oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC). . . . .	22
20. Anion concentrations in bottom leachate. . . . .	23
21. Quantity of uranium leached from the Y-12 Plant lysimeter pilot study. . . . .	24
22. Water balance from 1990 leaching study. . . . .	26
23. Leachate uranium concentrations sampled from various sampling devices. . . . .	27

24.	Uranium concentrations in leachate sampled from suction candles 1 and 3. . . . .	28
25.	Uranium concentrations in "in line" bottom leachate (sampled under anoxic conditions) and bottom leachate sampled from collection drums (sampled under oxic conditions). . . . .	30

Appendix A

A.1	Aluminum concentrations in leachate . . . . .	49
A.2	Boron concentrations in leachate. . . . .	49
A.3	Calcium concentrations in leachate. . . . .	50
A.4	Chromium concentrations in leachate. . . . .	50
A.5	Iron concentrations in leachate. . . . .	51
A.6	Magnesium concentrations in leachate. . . . .	51
A.7	Potassium concentrations in leachate. . . . .	52
A.8	Sodium concentration in leachate. . . . .	52
A.9	Uranium concentrations in leachate. . . . .	53
A.10	Zinc concentrations in leachate. . . . .	53

Appendix B

B.1	Changes in pH of bottom leachate (field measurements from a flow-through cell). . . . .	66
B.2	Changes in dissolved oxygen (DO) of bottom leachate (field measurements from a flow-through cell). . . . .	66
B.3	Changes in oxygen reduction potential of bottom leachate (field measurements from a flow-through cell). . . . .	67
B.4	Changes in conductivity of bottom leachate (field measurements from a flow-through cell). . . . .	67
B.5	Changes in temperature of bottom leachate (field measurements from a flow-through cell). . . . .	68
B.6	Comparison of total organic carbon (TOC) in leachate sampled from several leachate collection devices. . . . .	68
B.7	Chemical oxygen demand (COD) of bottom leachate over time. . . . .	69
B.8	Biological oxygen demand (BOD) of bottom leachate over time. . . . .	69
B.9	Comparison of alkalinity of bottom leachate sampled under anoxic (in line) and oxic (drum) conditions. . . . .	70
B.10	Sulfate concentrations in leachate sampled from several leachate collection devices. . . . .	70
B.11	Anion concentrations in leachate. . . . .	71
B.12	Concentrations of selected cations in bottom leachate. . . . .	71

B.13	Calcium concentrations in leachate sampled from several leachate collection devices. . . . .	72
B.14	Iron concentrations in leachate sampled from several leachate collection devices. . . . .	72
B.15	Potassium concentrations in leachate sampled from several leachate collection devices. . . . .	73
B.16	Magnesium concentrations in leachate sampled from several leachate collection devices. . . . .	73
B.17	Sodium concentrations in leachate sampled from several leachate collection devices. . . . .	74



## LIST OF TABLES

Table	Page
1. Summary of leachate collection in 1990 from in situ collection devices . . . . .	29
Appendix A	
A.1 Field measurements on bottom leachate from the Oak Ridge Y-12 Plant pilot lysimeter . . . . .	36
A.2 Concentrations observed in leachate from the Oak Ridge Y-12 Plant uranium pilot lysimeter . . . . .	40
A.3 General characteristics of bottom leachate from the Oak Ridge Y-12 plant pilot lysimeter . . . . .	47
A.4 Anion concentrations in bottom leachate from the Oak Ridge Y-12 plant pilot lysimeter . . . . .	48
Appendix B	
B.1 Summary of leachate analyses 1990 Y-12 pilot lysimeter . . . . .	55
B.2 Field measurements on bottom leachate . . . . .	63
B.3 Summary of Detection Limits for Toxic Metals in the Primary Drinking Water Standards (PDWS) . . . . .	64
B.4 Summary of Occasions the Leachate Quality Exceeded Primary Drinking Water Standards (PDWS) . . . . .	65



## ABSTRACT

Pilot Uranium Lysimeter Studies at the Oak Ridge Y-12 Plant 1992. C. W. Francis, L. K. Hyder, S. C. Howard, J. E. Cline, and R. B. Clapp. ORNL/TM-12217, Oak Ridge, National Laboratory, Oak Ridge, Tennessee.

A field lysimeter test facility has been constructed at the Oak Ridge Y-12 plant to evaluate land burial of wastes containing depleted uranium. The principal objective in the construction of such a facility is to provide a means for monitoring waste leachate characteristics over time, in particular uranium concentrations in leachate. The design of the field lysimeter test facility allows, via the portals along the side walls of the lysimeter, the collection of leachate as a function of depth in the lysimeter. The methodology to collect leachate from within the field lysimeter has not been clearly defined. Thus, before wastes were loaded into the field lysimeter facility, a pilot lysimeter study was initiated to test several design concepts for the collection of in situ leachate. The primary objective of this pilot study was to demonstrate the feasibility and quality assurance of proposed instrumentation used to monitor leachate generation and characteristics in the full-scale field lysimeter. Secondary objectives included gaining experience in the handling/packing of wastes, installation/operation of the leachate collection devices, and waste leachate characterization.

The pilot lysimeter study involved packing a waste dumpster (5.5 × 6.0 × 7 ft high) with two general types of Y-12 Plant wastes. One of the wastes, called production trash, contained depleted uranium. The total amount of depleted uranium measured in this waste was 2.07 kg (4.6 lb). The other waste, consisting of general office trash, was considered "clean" (i.e., contamination with depleted uranium was not suspected). Water was added to the top of the pilot lysimeter by pumping 55-gal aliquots over a specific time intervals to simulate a 2.7-in. rainfall. Water was added during the summer months of 1989 and 1990. Over the study period of 286 days (May 4 to November 14, 1989 and May 1 to August 1, 1990), 1705 gal of water was added, of which 909 gal was collected as bottom leachate, leaving approximately 800 gal of water remaining in the waste. An equilibrium in quantity of water added and quantity of leachate collected was never attained.

Three type of devices were tested to collect in situ leachate. These included standard "off-the-shelf" soil suction candles to collect unsaturated flow of leachate and two specially designed leachate collection devices to collect saturated flow (flow of leachate largely confined to macropor void volumes within the waste). Both of these devices operated on the principle of saturated flow of leachate into fine-grained sand. One design was a V-shaped tray made of stainless steel (4 ft long, 6 in. wide, and 3 in. deep), and the other was a 4-L stainless steel beaker.

Peak uranium levels (0.2 to 0.3 mg/L) in the bottom leachate were observed during the first month of leaching. After June 4, 1989, uranium concentrations in the bottom leachate averaged 0.021 mg/L during the summer (uranium concentration ranged from 0.005 to 0.066 mg/L). This mean concentration was below the uranium concentration measured in the demineralized water used for leaching. Uranium concentrations in the leachate collected by suction candles were > 10 times that observed in the bottom leachate; however, leachate could be routinely obtained from only one of the three suction candles installed. Vacuums on the

order of 75 centibar could be established and held for reasonable lengths of time (> 3 h and upto 3 days in some instances), indicating that none was broken when the wastes were loaded. A different method is suggested for installation of suction candles in the field lysimeters utilizing a quadrupod design to provide protection against breakage of the candle when more wastes are loaded and bagged silica flour around the candle's tip to ensure better contact with macropore water in coarser-textured wastes. The 4-L beakers were more effective in the collection of leachate moving within the waste macropores (saturated flow) than the trays. The preferred design for collection of macropore leachate in the field lysimeters would be similar to the 4-L beaker design, but larger (e.g., a 5-gal, Teflon-lined bucket loaded with acid-washed river rock).

The total quantity of uranium leached from the pilot lysimeter was ~ 150 mg, < 0.01% of the total 2.07 kg of uranium contained in the waste. Approximately one-third of the uranium was leached from the lysimeter during the first month, presumably as the U(VI) form before the conditions in the lysimeter became sufficiently anoxic to reduce the uranium to an immobile U(IV) form. The maximum uranium concentration in the leachate observed by in situ sampling with a suction candle was ~0.8 mg/L meaning that the leaching transfer coefficient in situ the waste was on the order of 0.001 kg/L.

## INTRODUCTION

A field lysimeter test facility has been constructed to evaluate land burial of wastes containing depleted uranium (Clapp et al. 1988). The facility includes two principal units (A and B). Unit A has nine standard 8-ft-diam by 10-ft-deep column lysimeters around its center core. Unit B has eight of the same type of lysimeters and three smaller 2-ft-diam by 10-ft-deep lysimeters (Figs. 1 and 2). The lysimeters are to be used to leach a variety of wastes under natural conditions at the Oak Ridge Y-12 Plant. Three of the lysimeters in unit B are equipped so that water may be added in an accelerated manner (i.e., at a rate equivalent to five times the annual rainfall). The principal objective in the design and operation of the field lysimeter test facility is to monitor leachate characteristics over time, in

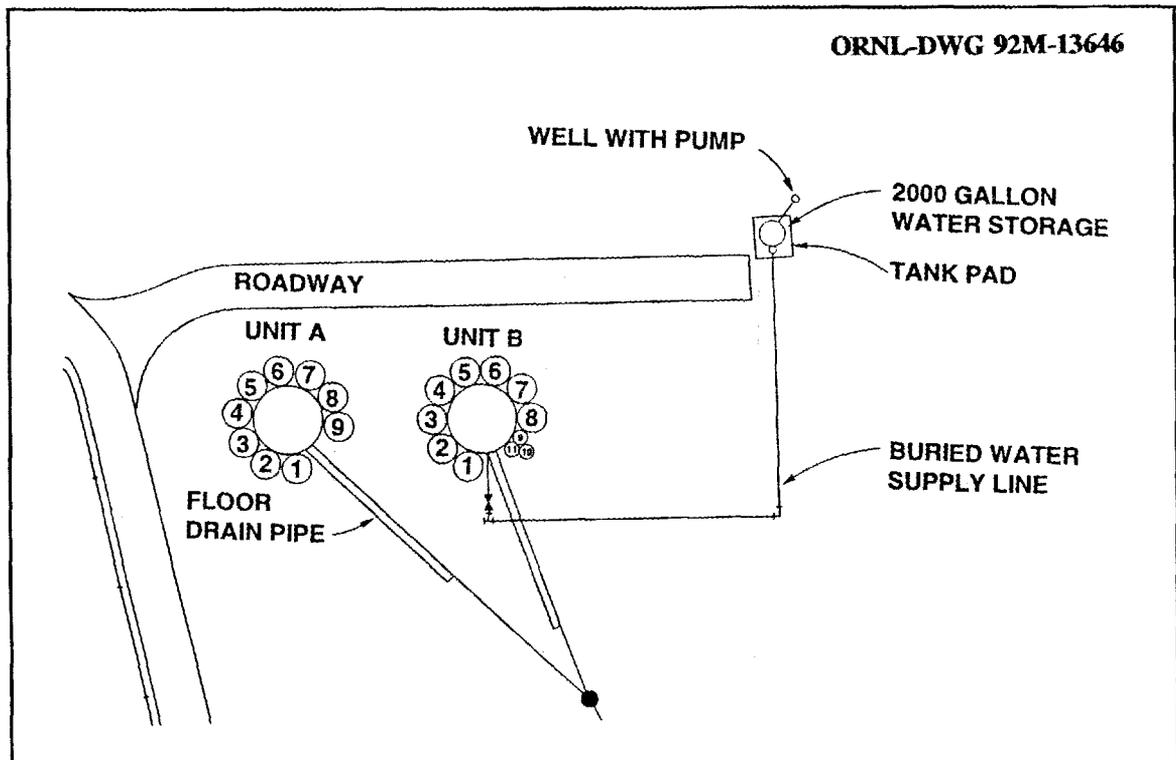


Fig. 1. Site plan for the Y-12 Plant Uranium Lysimeter Facility.

particular uranium concentrations in the bottom leachate. To understand more clearly the mechanisms responsible for the leaching of uranium from the various waste forms loaded into the lysimeters ( i.e., so that predictive models can be developed ), portals have been constructed along the walls of the lysimeters so that leachate can be sampled at varying waste depths (see Fig. 2).

A technical review of the Y-12 Plant Uranium Lysimeter Project was conducted during the third week of August 1988. The three technical reviewers were a senior staff member from Westinghouse Hanford Company, a senior staff member from Brookhaven National Laboratory, and a professor of civil and environmental engineering at the University of Wisconsin. One of the major concerns raised by these reviewers was the need to demonstrate

the feasibility and quality assurance of proposed instrumentation used to monitor leachate generation and characteristics, namely, the collection of leachate and gases within the waste. To address this concern, a pilot lysimeter study was initiated to test several design concepts for the collection of in situ leachate. The primary objective of this pilot study was to determine the feasibility and effectiveness of these proposed in situ leachate collection devices. Secondary objectives included gaining experience in handling/packing of wastes, installation/operation of the leachate collection devices, and waste leachate characterization. The purpose of this report is to present the results of this pilot study.

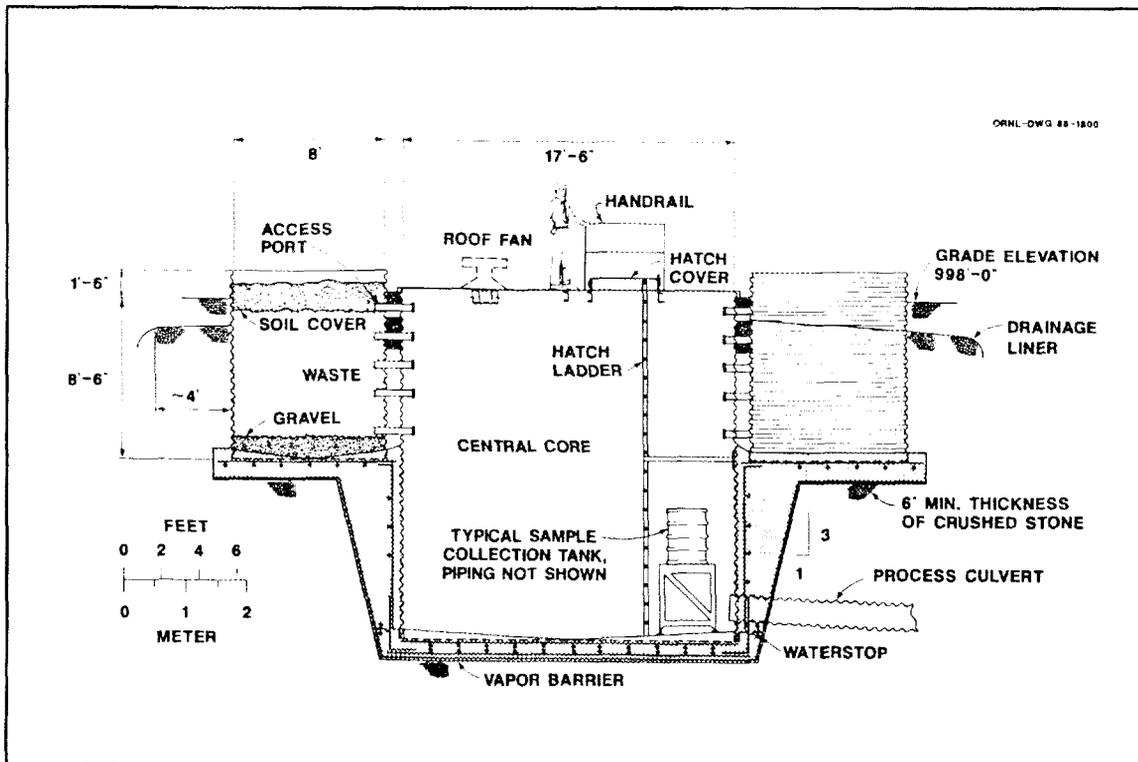


Fig. 2. Cross section of a representative lysimeter and central core.

## METHODS AND MATERIALS

### LEACHATE COLLECTION DEVICES

Three types of devices were tested to collect leachate. These included standard "off-the-shelf" soil suction candles and two specially designed leachate collection devices. Conventional soil suction candles operate best in matrixes that exhibit moisture tensions usually greater than 0.5 atm (50 centibars of mercury) and are designed to collect interstitial liquid contained in micropores of the soil/waste matrix. For wastes that exhibit low moisture tension levels (namely, noncompactable coarse textured, irregularly shaped waste forms), air rather than leachate will enter suction candles set at tension levels often encountered in soil. For this reason, suction candles are not expected to be effective collectors of leachate for some wastes and a specially designed leachate collection device may be required. For these lysimeter studies that contain coarse-textured wastes (relative to soils), the downward movement of leachate caused by intermittent fluxes of rainfall onto the lysimeter will be in the form of saturated flow driven by gravitational forces into the relatively large interstitial pores (macropores).

### UNSATURATED FLOW LEACHATE COLLECTION

Soil suction candles have been used extensively to estimate leachate quality at landfill sites; however, the candles are usually used in soil adjacent the landfill rather than in situ the wastes. Also, some question exists as to whether the leachate collected by these candles really reflects the chemical characteristics of the leachate. For example, in collecting soil water in sandy, coarse-textured soils or wastes, the suction candles are usually installed by packing the ceramic tip in 200-mesh silica sand. This procedure is necessary to develop the relatively high moisture tension and to bridge the movement of water from the macropores to the ceramic cup of the suction candles. Candles made of porous Teflon™ (brand name for a polytetrafluoroethylene formulation) are also available but usually cost considerably more. An important aspect to consider in using ceramic-tipped suction candles is the possible discrepancy in the chemical characteristics of the waste leachate collected by these units compared with the true chemical makeup of the waste leachate. For example, the potential for sorption of uranium on the silica sand packed around the candle and the ceramic cup of the candle needs to be evaluated. Also, in most cases the body of the candles is made of polyvinylchloride (PVC) that may adversely affect the true chemical characteristics of the organic compounds in the leachate via adsorption or deteriorative/dissolution mechanisms of the plastic material per se. Another major obstacle is the limited quantity of leachate collected from soil suction candles from a single sampling period. For example, if a large volume of leachate is required for characterization (i.e., on the order of 0.5 to 1 L, multiple sampling with compositing for the samples will be required.

Three suction candles (Model 1920 pressure-vacuum soil water sampler manufactured by Soilmoisture Equipment Company) were installed in the waste (Fig. 3). Leachate was sampled from each candle via two access tubes (3/16-in. ID Teflon tubing). One tube at the top of the 36-in. casing was used to induce a vacuum of ~75 centibars with a vacuum hand pump. The other tube at the bottom of the casing and inside the ceramic cup was used to

withdraw the lechate that had accumulated under the applied vacuum.

### Saturated Flow Lechate Collection

Two types of specially designed devices to collect saturated flow (flow largely confined to macropore void volumes within the waste) were installed in the dumpster packed with waste. Both operate on the principle of saturated flow of lechate into fine-grained sand. One design was a V-shaped tray made of stainless steel, 4 ft long, 6 in. wide, and 3 in. deep (constructed at the Y-12 Plant). Two of these, packed with fine-grained sand (~70% passing a No. 50 screen), were installed in the waste. Each were equipped with an outlet tube (3/16-in. ID Teflon tubing) at each end of the tray from which lechate could be collected from the back and front of the dumpster, respectively. Three sample portals (each 2.5 in. ID with a No. 13 rubber stopper) ~2.5 ft above the bottom of the dumpster were installed so that in situ lechate could be sampled from outside the dumpster.

The second design consisted of a 4-L stainless steel beaker (6.4 in. diam and 7.6 in. tall) filled with the same sand as used in the trays with a tube (3/16-in. ID Teflon) attached to the



**Fig. 3. Placement of in situ collection devices in waste dumpster.** bottom for collection of lechate. The major disadvantage of this design is the limited surface area available for lechate collection; namely, the surface area of the beaker design was ~10% of the surface area for the tray design. Three of these beakers were installed in the waste.

## LOADING WASTE

In February 1989, a waste dumpster ( $5.5 \times 6.0 \times 7$  ft high,  $\sim 240$  ft<sup>3</sup> in volume) was packed with two general types of the Y-12 Plant wastes. One of the wastes, called production trash, contained depleted uranium. The other waste, consisting of general office trash, was considered "clean" (i.e., no suspected contamination with depleted uranium). Production trash is a mixture of blotter paper and floor sweepings with smaller quantities of other materials including work gloves, metal turnings, and paper wipes from the 9212 A-Wing and 9205-5 West machine shops. Other wastes generated in the production areas of Buildings 9215 and 9204-4 were also included. Candidate dumpsters from these buildings containing wastes contaminated with depleted uranium were transported to Building 9720-28, where the contents of each dumpster were dumped onto the floor and covered with plastic to prevent contamination of the surrounding areas. All the bagged and boxed waste were monitored for uranium activity in a National Nuclear Corporation waste curie monitor, Model 55 (WCM-55). The total amount of depleted uranium measured in these wastes was 2.07 kg (4.6 lb). These wastes along with some of the "clean" office wastes were compacted into a bale ( $\sim 45$  ft<sup>3</sup>). The "clean" office trash was produced from office areas in the eastern end of the Y-12 Plant. The strappings on the bale were removed, and the waste was placed into the dumpster using a front-end loader.

Before any waste was added to the dumpster,  $\sim 8$  in. of pea gravel was added to the bottom of the dumpster. This gravel then was covered with a synthetic geotex fiber to prevent particulate movement into the gravel bed. Approximately one-half of the bale containing the 2.07 kg of depleted uranium was placed in the dumpster. At that time, the in situ leachate collection devices were positioned in the waste (see Fig. 3). The ceramic tips of the suction candles were inserted into the partially compacted waste form. Silica flour (200-mesh silica sand) was poured around the bottom portion of the candles to facilitate transport of leachate to the candles (the silica flour was not hand packed around the candles but rather loosely poured around the candles until the ceramic tips were covered). Workers wore shoe covers, gloves, coveralls, and face respirators during loading of the lysimeter. After placement of the collection devices, the remaining part of the bale containing the 2.07 kg of depleted uranium was placed on top of the previously loaded waste. The dumpster was then filled to within  $\sim 1$  ft of the top of the dumpster with a partial bale of "clean" office waste. An attempt was made to spread the waste evenly across the dumpster. However, because the waste bale was compacted (even after the strapping was removed), most of the waste remained in the center of the dumpster and the edges contained the less-compacted waste.

A layer of topsoil ( $\sim 1$  ft in depth) from Bear Creek Valley was added to the top of the waste. The dumpster was then taken to a parking area south of Building 9731. The intent was to place the dumpster in the bay area of building 9731 where the leaching with demineralized water could be conducted. However, because of space limitations this area could not be used. The dumpster was covered with two layers of plastic to prevent rain from accumulating in the dumpster. However; prior to covering, the dumpster received  $\sim 3$ -5 in. of rainfall. The last week of April, the dumpster was moved into a covered area at the sludge handling facility. During the time the dumpster was stored outside of Building 9731,

considerable rainwater accumulated on the plastic covering—some of which leaked into dumpster along the back side of the dumpster. This was apparent when the bottom drain of the dumpster was opened and 10 to 20 gal of leachate drained from the dumpster.

## LEACHING WASTES

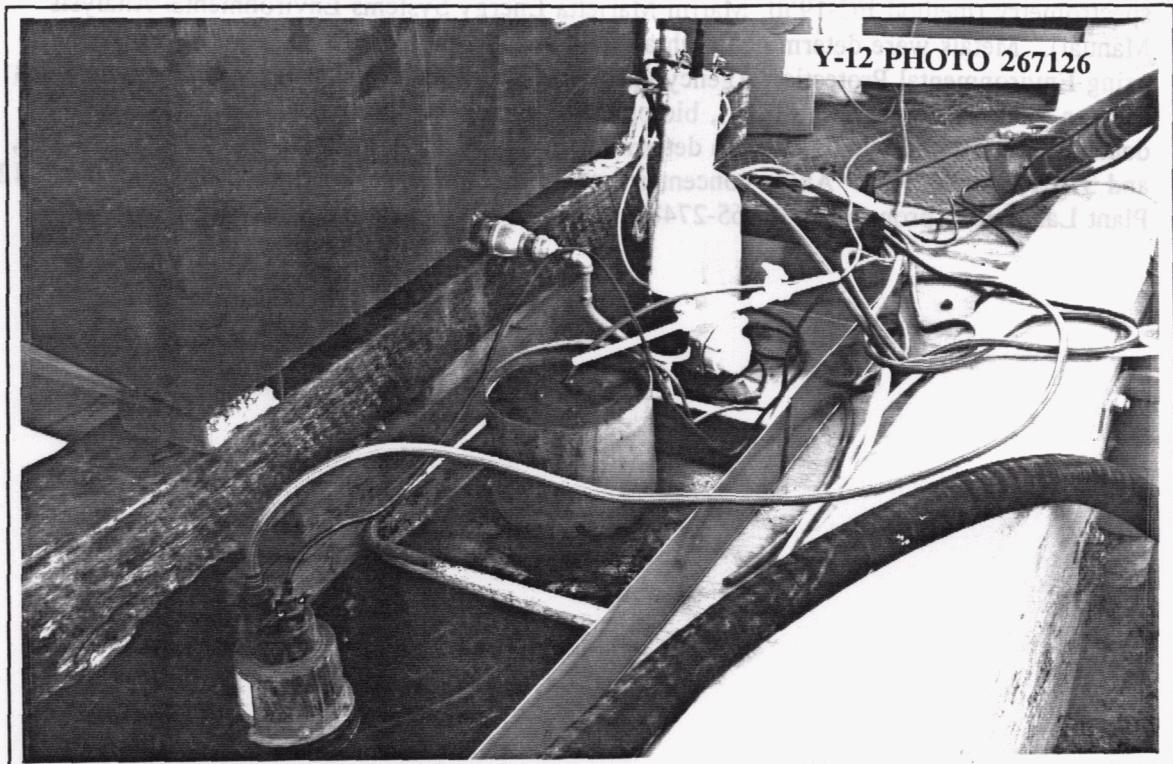
The first additions of demineralized water were made May 4, 1989. The water was added to the top of the pilot lysimeter by pumping 55-gal aliquots over specific time intervals to simulate rainfall. For example, most of the water was added as 55-gal aliquots over a 5.3-h time span simulating a 2.7 in. rainfall. Water was distributed over the soil surface with an ordinary 25-ft "sprinkling" garden hose. To induce a spraying effect, the real-time pumping rate had to be considerably higher than the rainfall rate; thus, 4.2-gal increments were added over 25-min intervals, giving an infiltration rate of  $3.5 \times 10^{-4}$  cm/s (approximately one-tenth of the infiltration capacity of the overlying soil layer). During March and April, the soil and waste in the lysimeter had settled considerable allowing ~2-ft of head space between the soil and the top of the lysimeter. The top of the lysimeter (dumpster) was covered with two layers of clear, heavy plastic. This prevented the loss of any sprinkler water and actually aided in distributing water added to the lysimeter across the soil surface. Visual observation indicated a uniform application of water to the soil surface; however, no measurements were taken of water over the soil surface to confirm such a distribution. On June 26, 1989, the clear plastic covering the lysimeter was covered with a double layer of black plastic to eliminate plant growth that had resulted from the watering efforts. The idea was to decrease potential transpiration/evaporation effects as much as possible.

## LEACHATE COLLECTION AND ANALYSES

### Collection Methods

Bottom leachate was monitored directly via a flow-through cell for pH, dissolved oxygen (DO), temperature, conductivity, and oxidation reduction potential (ORP) with a Surveyor II water quality meter manufactured by the Hydrolab Corporation, Austin, Texas. The meter was calibrated with standardized solutions in the laboratory before installation. On September 26 (145th day of leaching), unusual and erratic readings appeared and the meter was taken to the laboratory and recalibrated. No specific time intervals were used in recording these measurements. Generally speaking, measurements were recorded on days that water was added to the lysimeter and continued the next few days as leachate samples were taken to evaluate leachate characteristics. After moving through the flow-through cell, leachate was discharged to an open sump containing a sump pump that transferred the leachate to a 55-gal collection barrel. The quantity of leachate generated over time was determined by manually measuring the level of leachate collected in the 55-gal barrel and recorded in the technical notebook (ORNL Technical Notebook No. A-102940). A photo of the leachate collection system is presented in Fig. 4.

Leachate collected from the in situ sampling devices as well as bottom leachate were routinely analyzed for uranium and metals (all of these samples were acidified to pH < 2 with



**Fig. 4. Leachate collection and flow-through water quality cell.**

concentrated Ultrex nitric acid). Bottom leachate was collected under oxic conditions from the 55-gal barrel used to monitor the quantity of leachate generated (samples were collected from the barrel prior to disposal of the leachate to ensure that a material balance  $\times$  volume collected could be calculated). In-line aliquots sampled under anoxic conditions were taken for analysis starting June 19, 1989. This was accomplished by withdrawing a bottom leachate sample from an enclosed 2-L sump (located upstream to the flow-through cell) directly into a container containing concentrated Ultrex nitric acid. The objective was to compare uranium concentrations in leachate collected under oxic conditions (where apparent precipitation of iron had occurred) with those collected under anoxic conditions (leachate containing reduced forms of iron) to determine the influence of iron precipitation and the accompanying potential for entrainment or coprecipitation of uranium.

Attempts were made to collect leachate from in situ sampling devices the day or so following water additions to the lysimeter and prior to adding more water to the lysimeter. Vacuums between 50 and 75 centibars were made with a hand vacuum pump on all suction candles before the water additions. In addition, efforts were made to withdraw leachate from the stainless steel trays and breakers by applying 50 to 75 centibars of vacuum on their respective leachate collection lines.

#### **Methods of Analyses**

Concentrations of total uranium in leachate sample were determined by mass

spectrometry (method EC-1950, Martin Marietta Energy Systems Environmental Analysis Manual). Metals were determined with an inductively coupled (ICP) plasma spectrometer using Environmental Protection Agency (EPA) method 200.7. Other leachate characteristics such as total organic carbon (TOC), biological oxygen demand (BOD), chemical oxygen demand (COD), and alkalinity were determined by using EPA methods 415.1, 405.1, 410.2, and 310.1, respectively. Anion concentrations in leachate were determined by using the Y-12 Plant Laboratory procedure (Y/P65-2748).

## RESULTS AND DISCUSSION-1989 LEACHING STUDIES

### WATER APPLICATIONS AND LEACHATE COLLECTIONS

#### Bottom Leachate Collections

As water was added to the lysimeter, water slowly accumulated in the waste. For example, after one month of adding ~400 gal of water, nearly one-half had been collected as bottom leachate, leaving ~200 gal in the waste (see Fig. 5). Over the study period of 194 days (May 4 to November 14, 1989), 1155 gal of water were added and 629 gal were

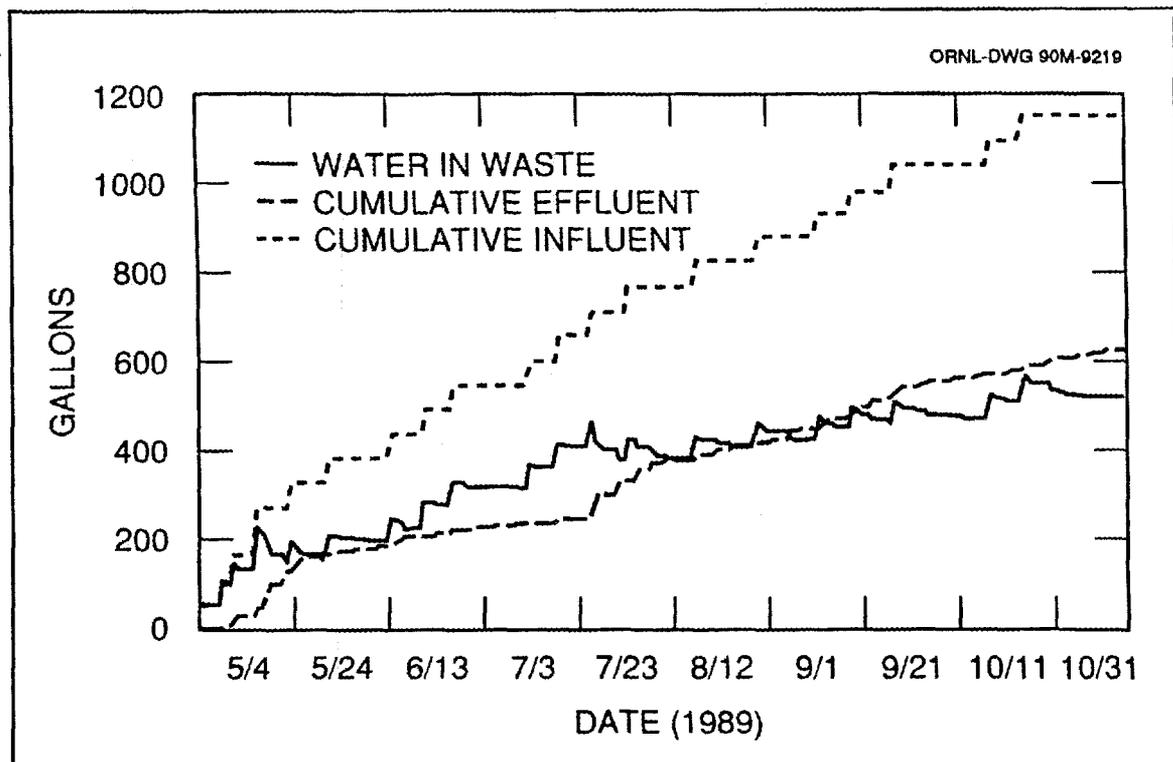


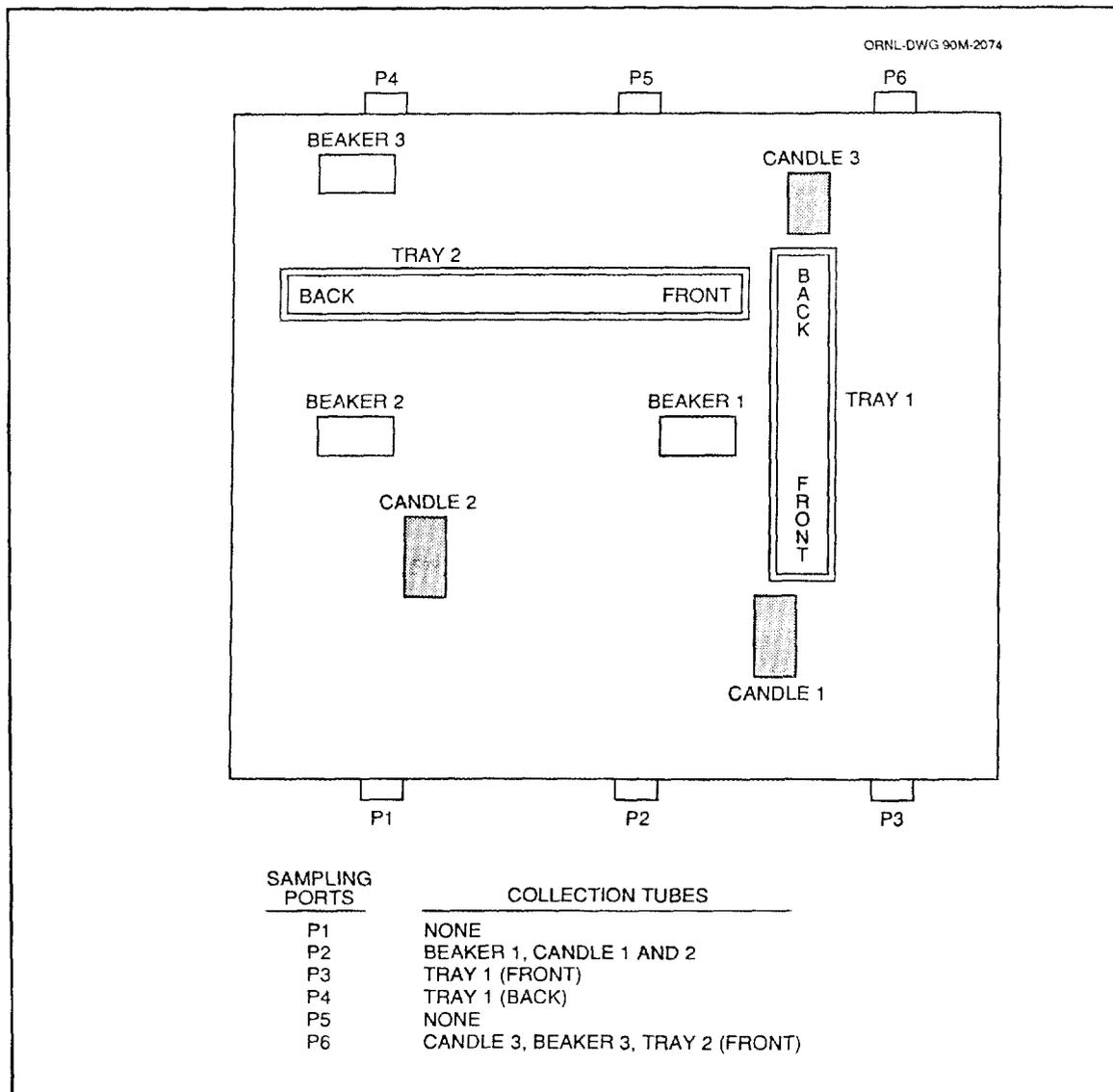
Fig. 5. Water balance in the Oak Ridge Y-12 Plant pilot lysimeter.

collected as bottom leachate, leaving 528 gal in the waste. The rate at which water was retained by the waste slowed significantly after August, but there was no evidence that equilibrium conditions, with respect to the total amount of water that might be contained by the waste, had been reached. These data imply considerable short circuiting of water around waste forms as well as a general hydrophobic character of the waste. The waste contained considerable amounts of paper, which after being compacted, would tend to be slow in taking up water. The only exception may be noted in mid-July where little leachate was collected. It appeared that the bottom leachate line was plugged, and the leachate line was disconnected from the dumpster to verify if plugging had occurred. No suspended particulate was observed in the line; however, after reassembling the line considerable leachate was collected, implying

that the leachate line was plugged (note the increased flow of leachate during the last of July and early part of August). Generally speaking, the bottom leachate, in an anoxic state, was quite clear. Only when the leachate was exposed to air was there evidence of particulate (presumably as a result of oxidation and precipitation of ferric iron).

**In Situ Leachate Collection**

Collection of in situ leachate was disappointing in that usable amounts of leachate (> 300 mL) could be obtained on a routine basis from only one of the suction candles and one of the beakers. Both of these collection devices (candle 3 and beaker 3) were positioned near the back side of the lysimeter (see Fig. 6). Small amounts of leachate (between 100 and



**Fig. 6. Schematic of approximate locations of in situ collection devices in waste dumpster.**

300 mL) were obtained from tray 1 (back tubing, on July 12, September 9, and October 25) and tray 2 (back tubing, on July 17). Also, a small amount of leachate was collected from beaker 1 on August 2 and 16.

These results were somewhat surprising. All of the suction candles appeared to be operative, in that 75 centibars of vacuum could be applied and retained (usually >3 h and in certain cases up to a couple of days), indicating that they were intact when the remaining waste was placed in the dumpster. No doubt some shifting occurred as the new waste was applied, which would likely cause loss of silica flour from around the ceramic tip and might have been the reason some of them could not collect leachate. A better design is needed for placement of the suction candles in the field lysimeters.

The fact that little or no leachate could be collected from the trays or beakers (except beaker 3) might indicate that these devices were in unsaturated zones or simply surrounded by dry wastes. In most cases only dry sand was collected when vacuums of 50 to 75 centibars were applied (indicating that if such devices are to be used in the field lysimeters, coarser sand particles or pebbles should be placed in the devices). Because leachate could only be collected from one of the suction candles (candle 3 which was located close to the back side of the lysimeter), it was speculated that certain parts of the waste were dry. The water balance indicated that the waste had not reached saturation (Fig. 5). Added water may be short-circuiting along the back side of the dumpster where wastes were not compacted to the same extent as along the middle and front of the dumpster where the bulk of the compacted bale was placed. Such a hypothesis is difficult to prove without removing the wastes and inspecting for certain dry zones within the waste. These data (or lack of data) strongly demonstrate that more attention needs to be directed to the methods or procedures used in loading the field lysimeters.

### **FIELD MEASUREMENTS (BOTTOM LEACHATE CHARACTERISTICS)**

The pH, dissolved oxygen content (DO), conductivity, and oxygen reduction potential (ORP) of the bottom leachate were monitored in the field with a flow-through cell and a water quality meter. The meter was calibrated with standard solutions in the laboratory prior to installation in the field. Routine calibrations were not practical since the intent was to monitor anoxic leachate flowing from the lysimeter; thus, the data should be taken as a guide to changes occurring in the leachate characteristics rather than precise measurements of the characteristics per se. The data for pH, DO, conductivity, and ORP are illustrated in Figs. 7, 8, 9, and 10, respectively. Tabular data are presented in Appendix A in Table A.1.

Initial pH measurements (through the first month of leaching) revealed the leachate to be alkaline to neutral. An acid front appeared to break through abruptly about June 1, bringing the pH to quite low values (on the order of 4.0 to 4.5, see Table A.1). During June and July the pH of the bottom leachate increased gradually to values near 6, then suddenly decreased to 3.8 about August 1. The reason for this sudden drop is not clear (conductivity also declined over the same time scale, as discussed in the following).

The pH drop in bottom leachate may have been caused by instrument malfunction; however, the readings for DO and ORP did not show a similar response but were instead

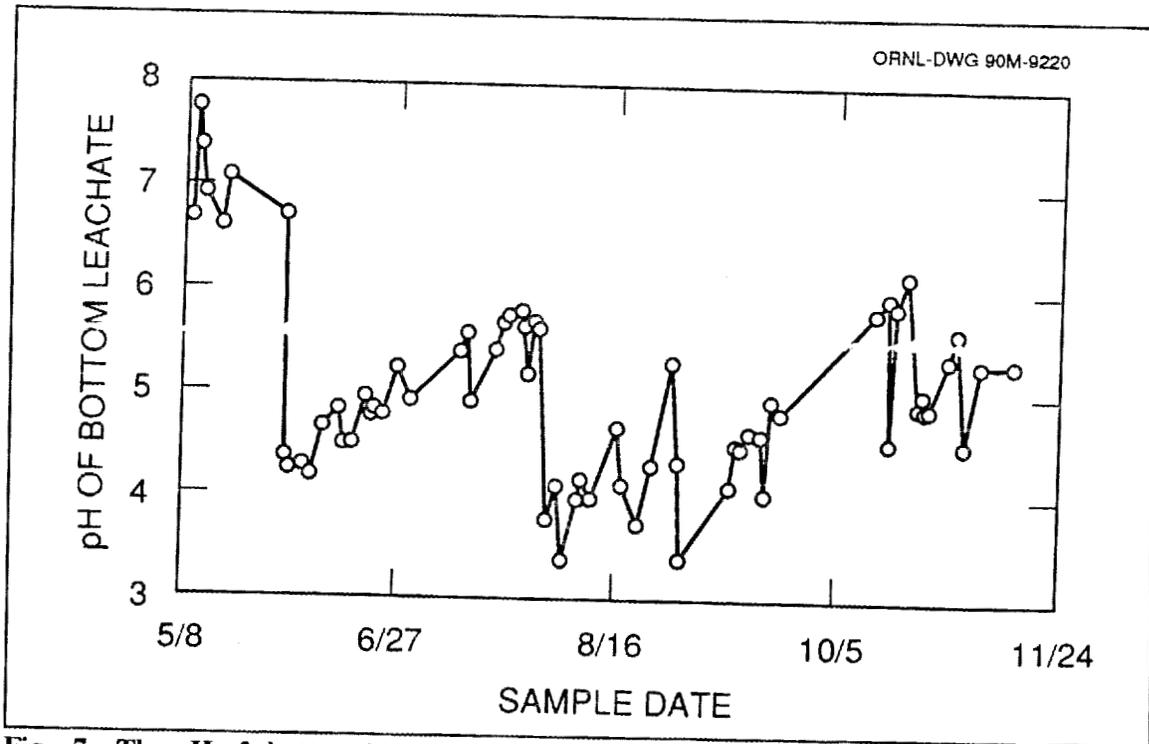


Fig. 7. The pH of bottom leachate.

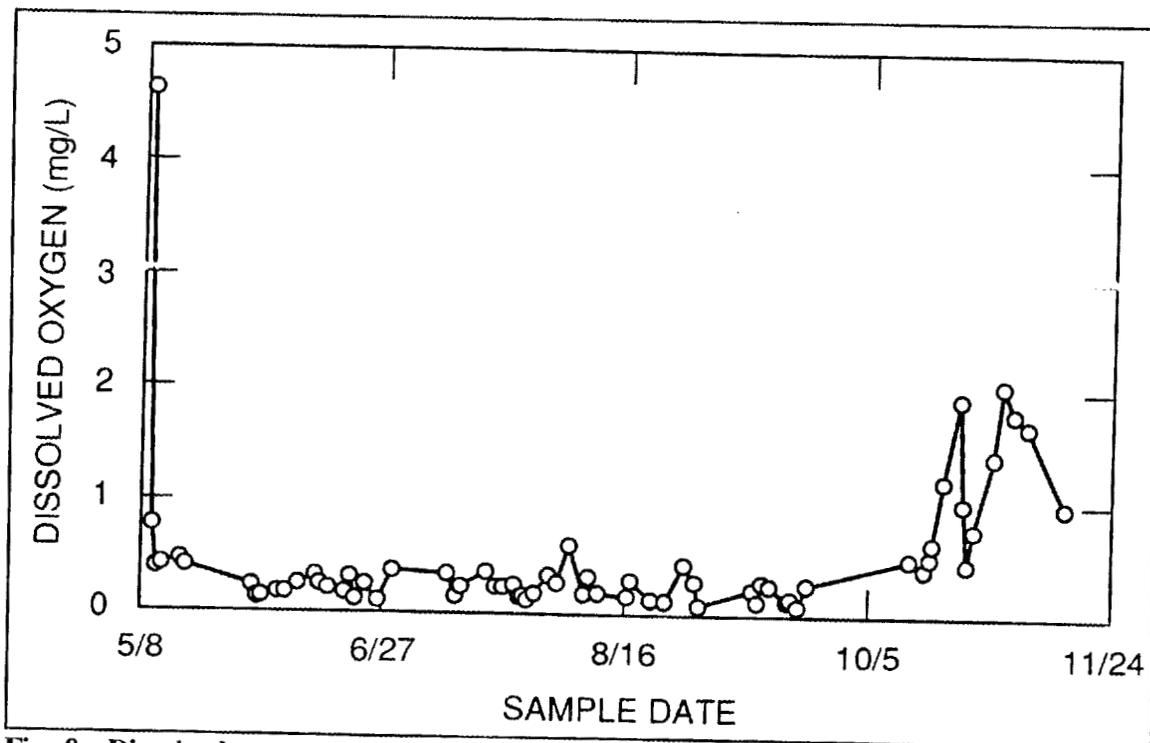


Fig. 8. Dissolved oxygen content of bottom leachate.

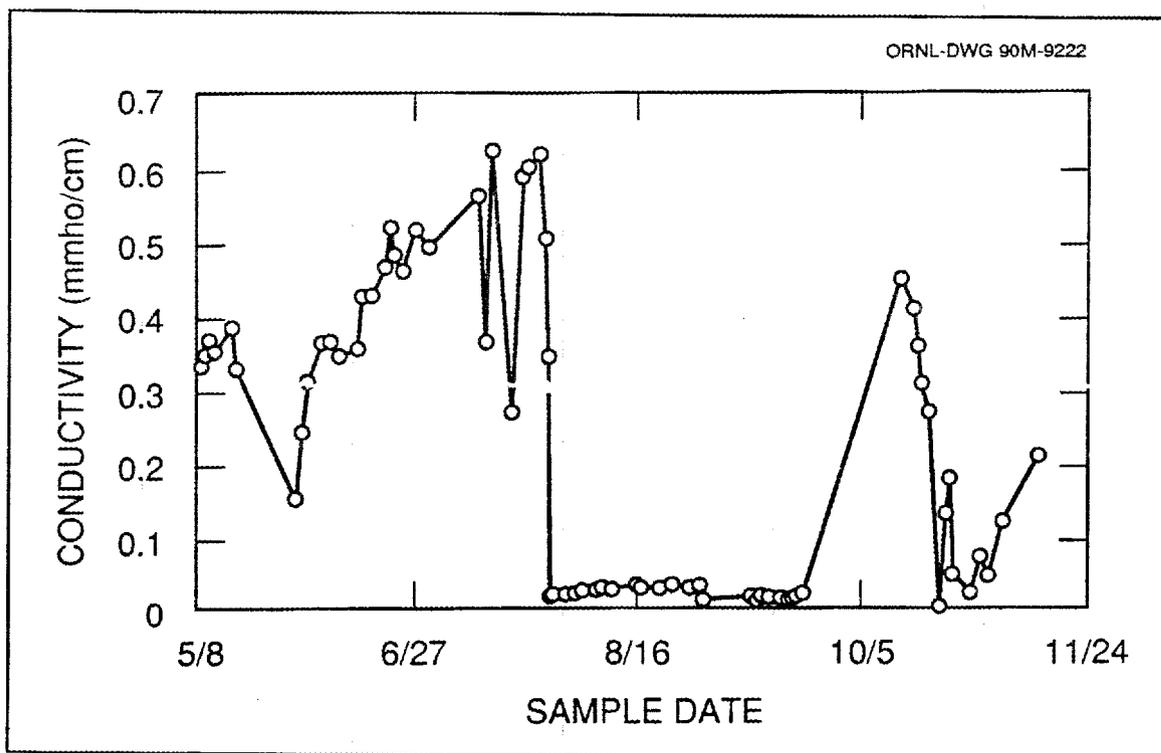


Fig. 9. Specific conductivity of bottom leachate.

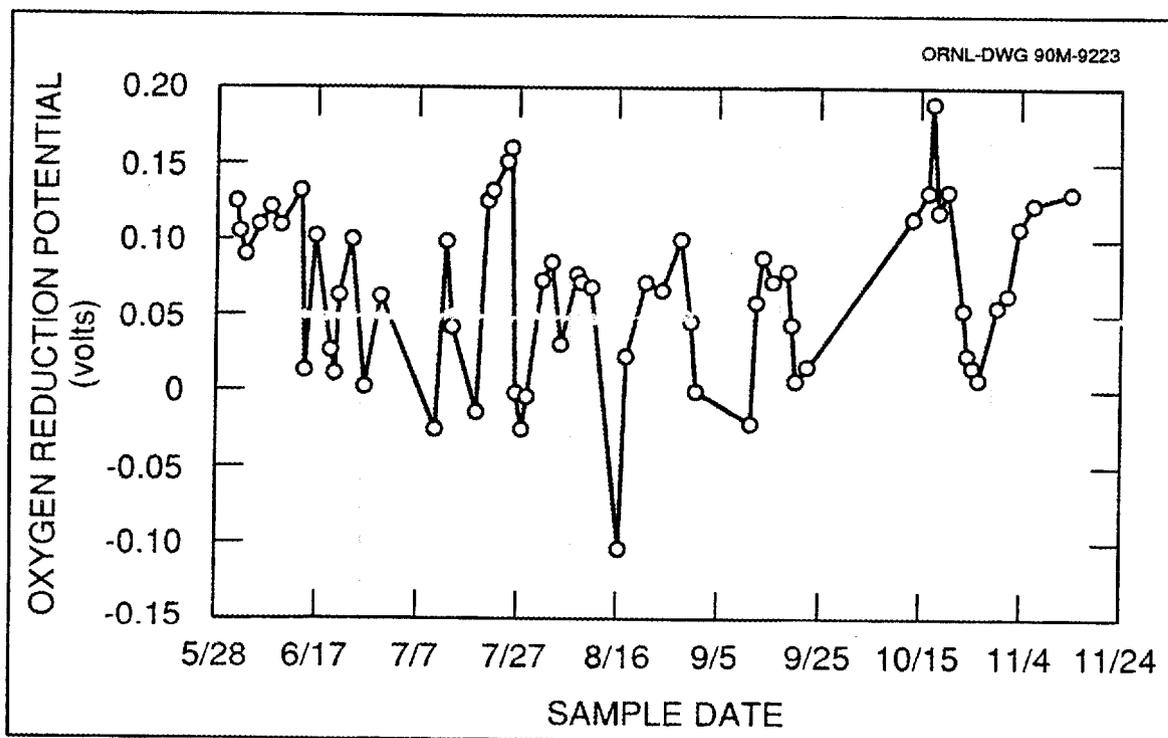


Fig. 10. Oxygen reduction potential of bottom leachate.

rather consistent (see Figs. 8 and 10). A relatively good series of measurements, in terms of spacing, over the period of interest (July 21 to mid-August) indicates a definite change in leachate character. One factor contributing to the change may be the rate at which leachate was generated. During June and up to the latter part of July, little leachate was generated (see Fig. 5). A closer look at the relationship between pH and quantity of leachate collected (Fig. 11) indicates a possible cause-and-effect relationship. From June 1 to July 25, the average rate of leachate generated was 1.4 gal/day, whereas from July 25 to August 31 the rate generated was 4.9 gal/day, nearly 3.5 times more. Conductivity showed a similar response with the quantity of leachate generated (see Fig. 12, i.e., conductivity on July 25 dropped from 0.331 to 0.019 mmho/cm the next day, July 26). Note that the drop in conductivity preceded the drop in pH (compare Figs. 11 and 12 and the data in Table A.1).

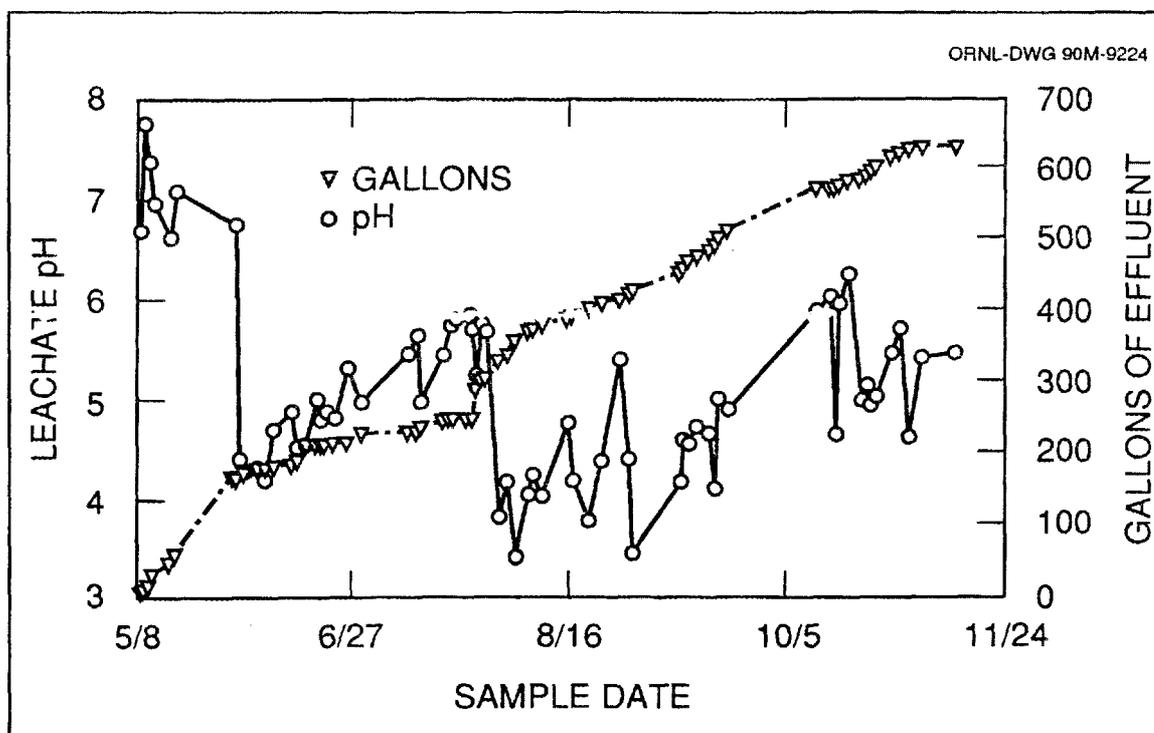


Fig. 11. Relationship between pH and quantity of leachate generated.

This observation between increased leachate generation and corresponding changes in conductivity and pH measurements indicates that the observed measurements for pH and conductivity are probably real and not a malfunction of the water quality meter. A relatively strong positive correlation seems to exist between pH and conductivity (Fig. 13). On September 26, the water quality meter did reveal abnormal and erratic observations. The unit was taken to the laboratory and recalibrated before being reinstalled on October 13, 1989.

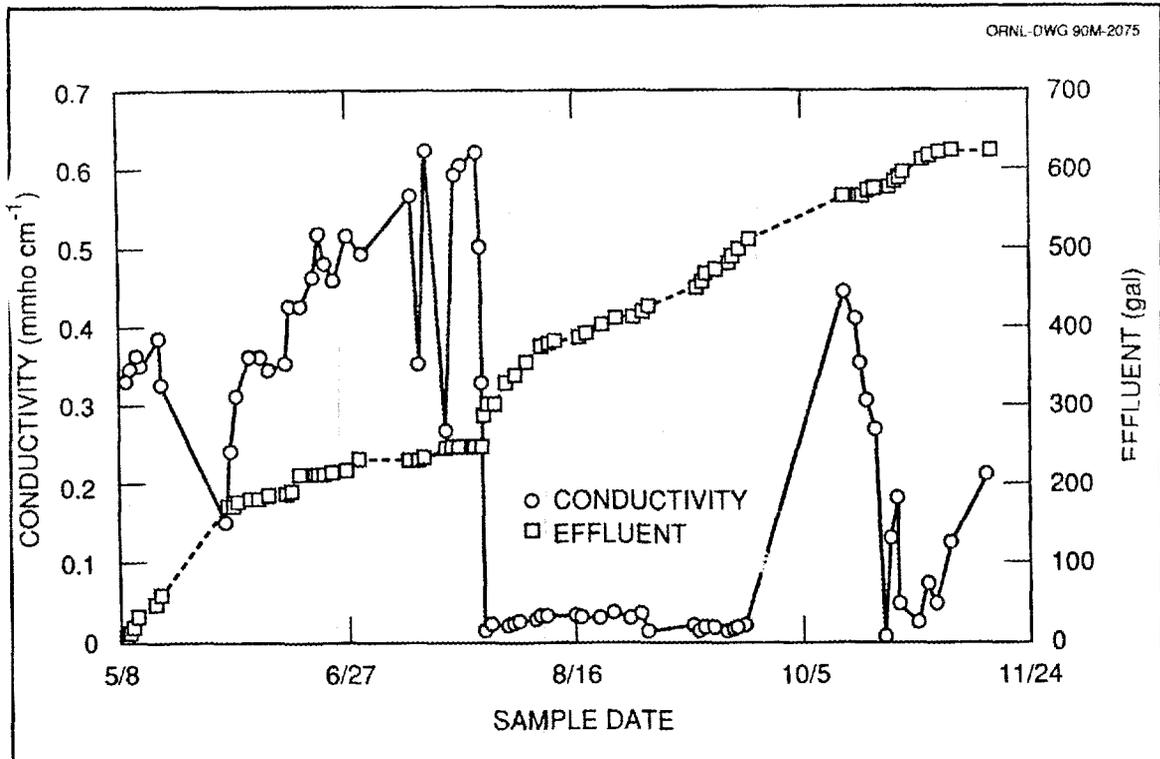


Fig. 12. Relationship between conductivity and quantity of leachate generated.

## URANIUM CONCENTRATIONS IN LEACHATE

### Bottom Leachate

Peak uranium levels (0.2 to 0.3 mg/L) in bottom leachate were observed during the first month of leaching (Fig. 14). After June 4, uranium concentrations averaged 0.021 mg/L (range from 0.005 to 0.066 mg/L). This mean concentration was below the uranium concentration in the demineralized water used for leaching (0.049 mg/L). The relatively high uranium concentrations in the initial leaching likely represented oxalic leaching of the U(VI) oxidation state ( $\text{UO}_2^{+2}$ ). As the waste became anoxic as a consequence of the biodecomposition of available carbon in the waste, appreciable levels of iron [presumably Fe(II)] appeared and the leaching of uranium was sharply inhibited, probably because of the reduction of U(VI) forms to U(IV) forms (Fig. 15). Such a mechanism is based on known associations of iron and uranium; however, no analyses were undertaken to determine the chemical speciation of iron or uranium in the leachate.

To investigate the influence of iron oxidation and subsequent precipitation of the Fe(III) form (evidenced by the reddish precipitate in the bottom of the sump and collection barrel), an in-line collection procedure was developed so that anoxic bottom leachate could be collected directly into nitric acid thus avoiding the precipitation of iron that occurred in the collection of bottom leachate samples. The objective here was to compare uranium concentrations in leachate collected under oxalic conditions (where apparent precipitation of iron

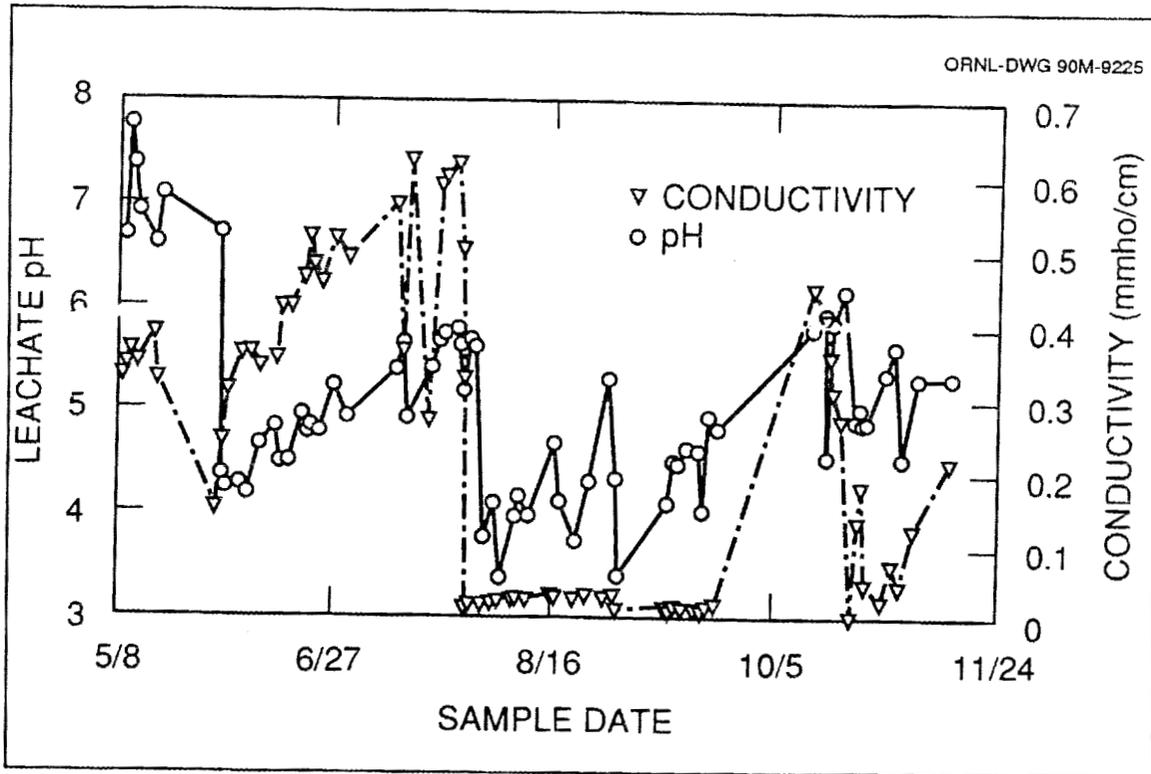


Fig. 13. Relationship between pH and conductivity of leachate.

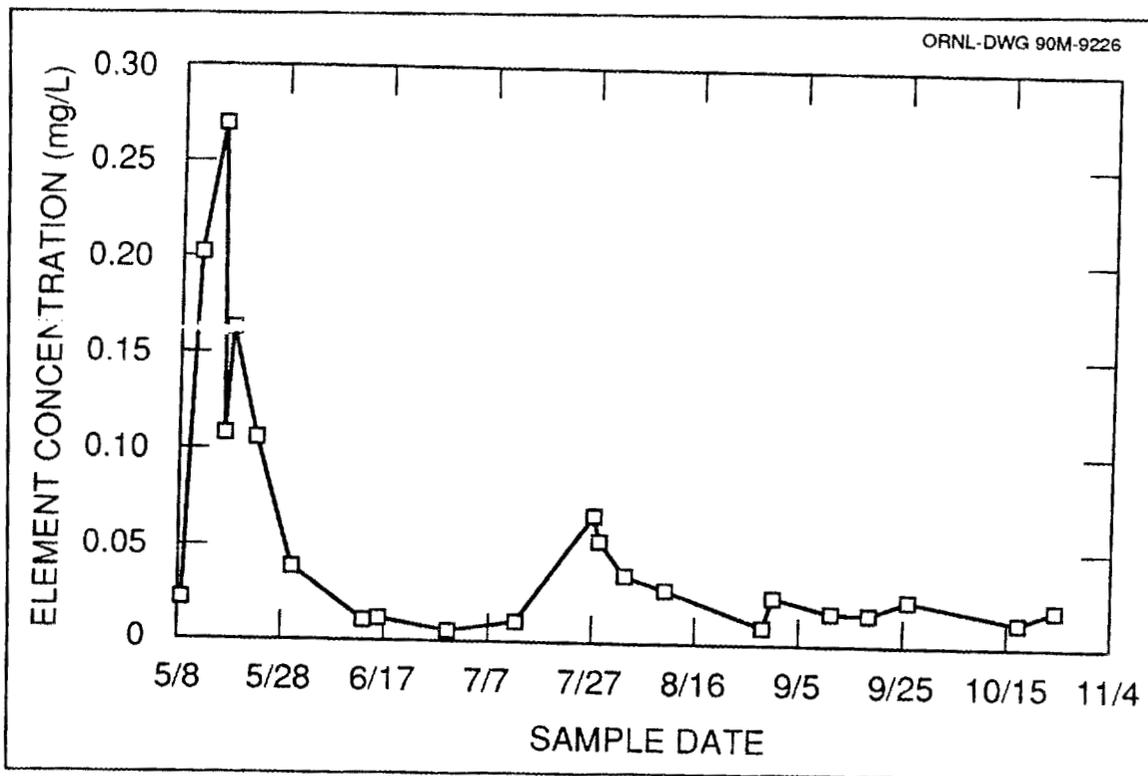


Fig. 14. Uranium concentrations in bottom leachate.

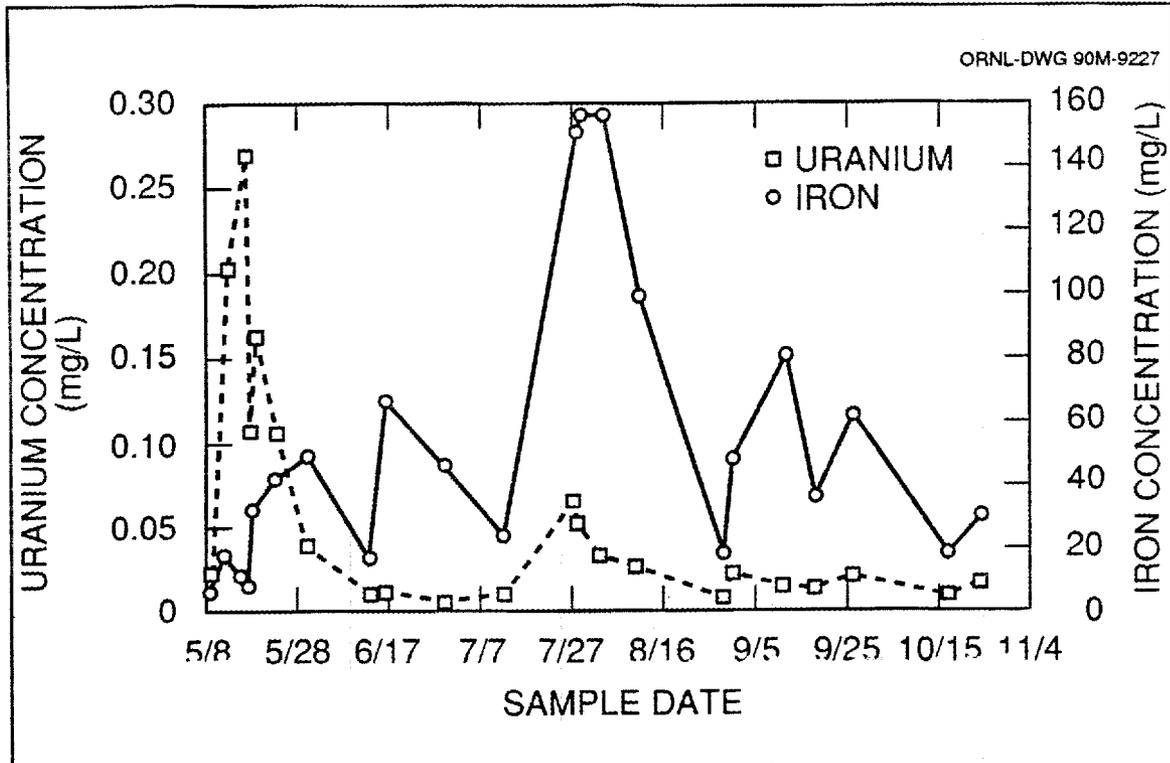


Fig. 15. Comparison of uranium and iron concentrations in bottom leachate.

had occurred) to those collected under anoxic conditions (leachate containing reduced forms of iron) to determine the influence of iron precipitation and the accompanying potential for entrapment or coprecipitation of uranium.

Uranium concentrations measured by the in-line collection method (representative of anoxic conditions) averaged 0.033 mg/L compared with an average uranium concentration of 0.021 mg/L in the bottom leachate (collected under oxic conditions after June 4). Figure 16 illustrates the uranium concentrations by the different sampling techniques. These mean concentrations (0.033 and 0.021 mg/L) were not statistically different ( $P < 0.05$ ) by the Duncan's Multiple Range Test (SAS User's Guide 1985). On the other hand, mean iron concentrations were 154 and 67 mg/L by the in-line and oxic sampling methods, respectively. These data imply that uranium in the bottom leachate is not significantly coprecipitated or entrained by iron oxidation/precipitation processes.

#### Comparisons between Bottom Leachate and In Situ Leachate

The principal objective in conducting the pilot study was to determine how successfully in situ leachate could be collected and to examine its characteristics in relation to bottom leachate. Uranium concentrations in the leachate collected by suction candles were ~ ten times greater than that observed in the bottom leachate (a mean value of 0.359 mg/L compared with ~0.030 mg/L in bottom leachate sampled after June 4). Figure 17 illustrates the comparison of uranium concentrations in leachate sampled by suction candles compared

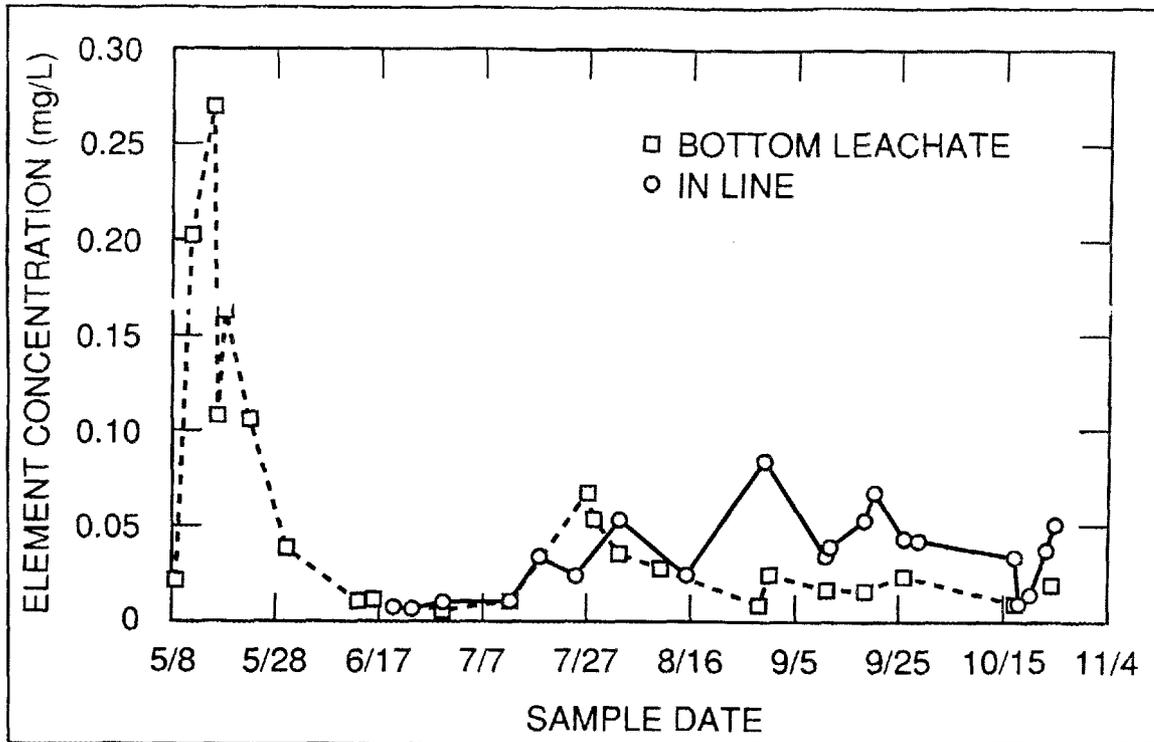


Fig. 16. Comparison of uranium concentrations in bottom leachate sampled under oxic conditions (BOTTOM LEACHATE) to those sampled under anoxic conditions (IN LINE).

with leachate sampled by other methods.

### Comparisons Between In Situ Leachate Sampling Devices

Leachate was routinely obtained from only one suction candle and one beaker throughout the experiment. Both of these sampling devices (beaker 3 and candle 3) were located toward the back of the dumpster. Two samples of leachate were collected from beaker 1. For the purpose of comparison between in situ leachate collection devices, chemical analyses of leachate collected from beaker 1 are included with the leachate analyses from beaker 3 and are collectively called "beaker" (total sample number = 14). Sixteen leachate samples were collected from candle 3, 14 of which were taken after June 4. The chemical analyses from the four leachate samples collected from the trays are not included in the comparison because of the limited number of samples. Uranium concentrations in leachate sampled from the candles and beakers are illustrated in Fig. 18. Mean uranium concentrations over the entire leaching period were 0.359 and 0.033 mg/L, respectively, for leachate collected from the candles and beakers, respectively. The much lower uranium concentration in the beaker leachate (mean conc. of 0.033 mg/L) is quite similar to the uranium concentration (0.049 mg/L) measured in the demineralized water used for leaching and probably represents macropore leachate that has had little contact with uranium-contaminated waste.

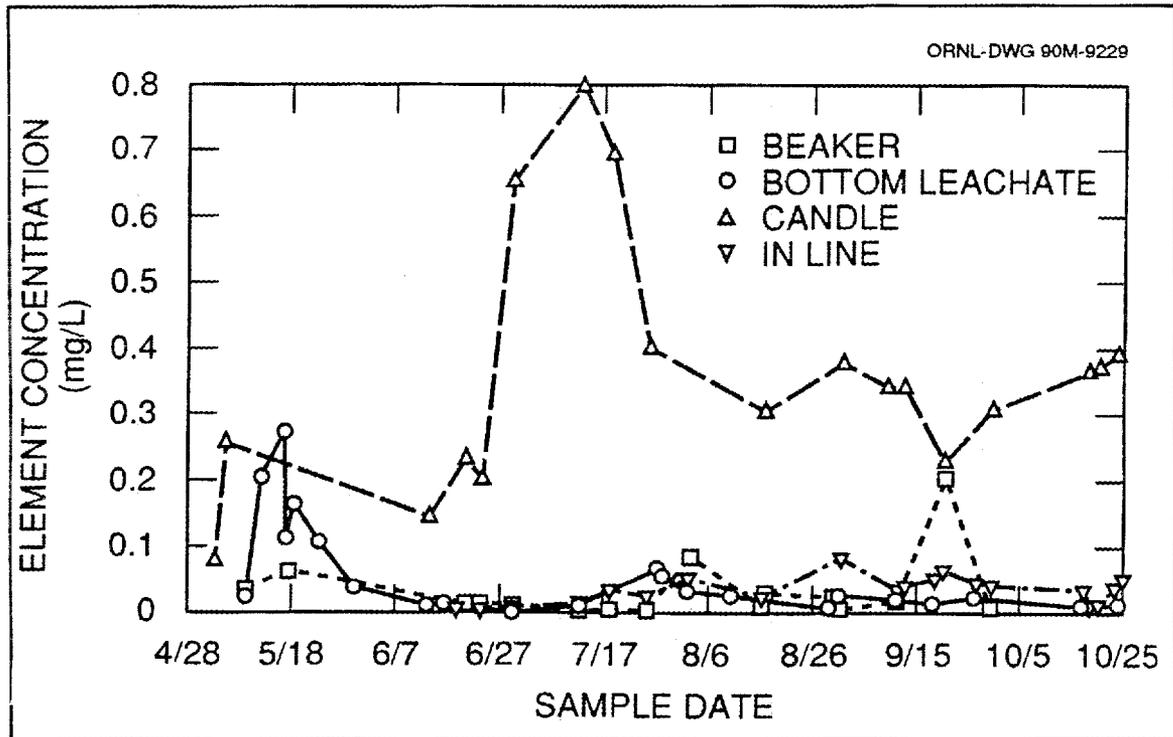


Fig. 17. In situ sampling devices (BEAKER) and CANDLE) and bottom leachate sampling methods (BOTTOM LEACHATE under oxic conditions and IN LINE under anoxic conditions).

#### OTHER METAL CONCENTRATIONS IN LEACHATES

Concentrations of metals other than uranium in the sampled leachate were determined by ICP spectroscopy. The concentrations of selected metals (Al, B, Ca, Cr, Fe, K, Mg, Na, and Zn) in leachate collected from the various sampling devices and methods over the leaching period are compared in Appendix A. The mean, maximum, and minimum values for all metals measured in the leachates by ICP are presented in Table A.2.

Some general conclusions can be made regarding the concentrations of the various metals measured in leachate by using the several different sampling devices and methods.

1. The highest concentrations of Al and B were found in leachate sampled by the suction candles.
2. Small differences in the concentration of alkaline metals and alkaline earths (Na, K, Ca, Mg, etc.) were observed between leachates sampled by suction candles and in bottom leachate sampled by oxic or under anoxic conditions.
3. The concentrations of alkaline metals and alkaline earths in the in situ leachate sampled by the beakers were lower than in the leachate collected by suction candles or in the bottom leachate sampled under oxic or anoxic conditions.

4. High concentrations of Fe and Zn were observed in bottom leachate sampled under anoxic conditions.

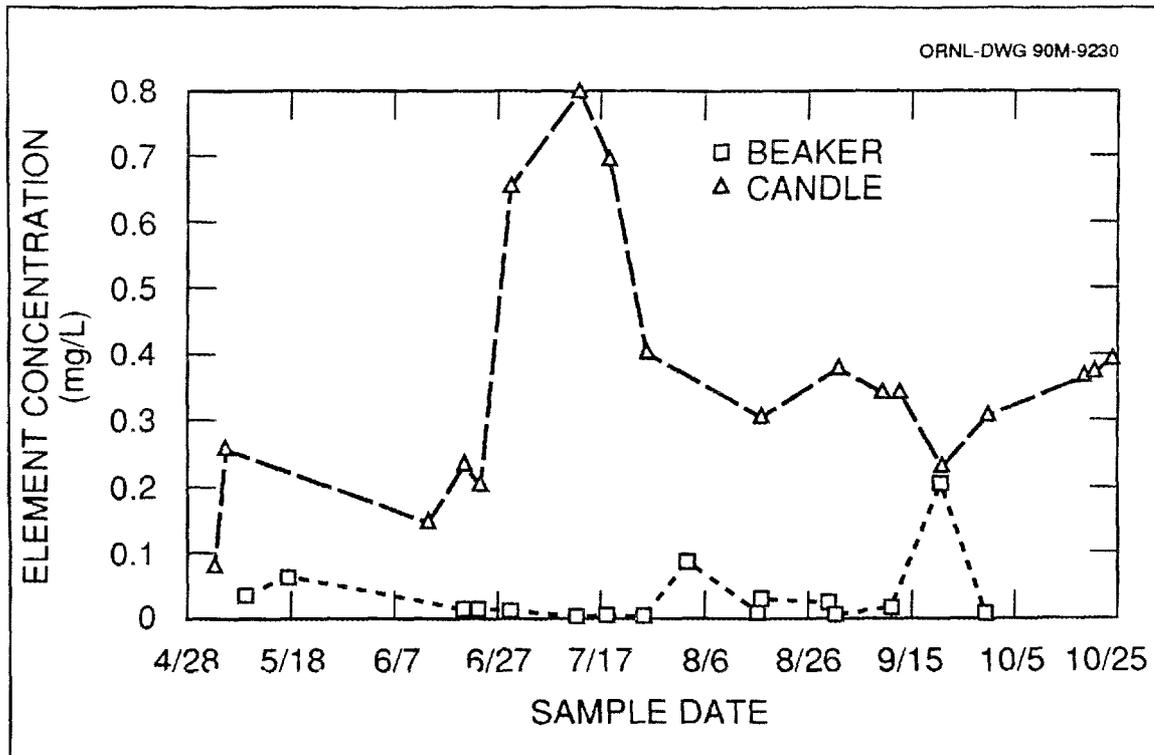


Fig. 18. Comparison of uranium concentrations in in situ leachate sampled by suction candles and beakers.

The high concentrations of aluminum observed in the leachate collected by the candles were not surprising considering the highly anoxic and low pH environment; however, the high boron concentrations were unexpected. The boron concentrations may have resulted from the inherent characteristics of the candles (potential source of boron) as concentrations fell from near 40 mg/L to less than 10 mg/L during the fourth month of leaching (see Appendix A). The small differences between concentrations of alkaline metals and alkaline earths in leachates sampled by the candles and concentrations in bottom leachate indicate little retention of these metals by the waste. As one would expect, few differences were noted in concentrations of these metals in bottom leachate whether sampled under oxic or anoxic conditions. On the other hand, iron and zinc concentrations in bottom leachate were significantly higher if sampled under anoxic conditions compared to oxic conditions, implying considerable precipitation of these metals as the leachate was exposed to the atmosphere.

Mean concentrations of metals in leachate sampled by the various devices and methods were statistically compared and ranked by Duncan's Multiple Range Test (SAS 1985). Some of the results are presented below.

1. The highest mean concentrations of Ag, As, Be, Ce, Cu, Ga, Mo, Ni, Th, and Ti were observed in leachate sampled from beakers. However, only in

the case of nickel was the difference higher ( $P < 0.05$ ) than the mean concentrations of nickel measured in bottom leachate sampled under oxic and anoxic conditions. The higher concentrations of nickel in leachates sampled by beakers probably represent contamination from the stainless steel beakers.

2. The highest mean concentrations of Al, B, Cr, Co, K, La, Mn, Na, Pb, Sc, Sr, U, V, and Zr were observed in leachate sampled from the candles. Only the mean concentrations for Al, B, Cr, K, Na, and U were statistically higher ( $P < 0.05$ ) than mean concentrations from other methods of sampling leachate.
3. The highest mean concentrations of Ca, Li, Mg, and Nb were observed in bottom leachate sampled under oxic conditions. Only in the case of lithium was the mean concentration significantly higher ( $P < 0.05$ ) than the other methods of sampling leachate.
4. The highest mean concentrations of Ba, Fe, and Zn were observed in the bottom leachate sampled under anoxic conditions. Only the mean concentrations for iron and zinc were statistically higher than other methods of sampling leachate.

## GENERAL CHARACTERISTICS OF LEACHATE

Some other leachate characteristics were measured [i.e., total organic carbon (TOC), biological oxygen demand (BOD), chemical oxygen demand (COD), alkalinity, and anion concentration]. The purpose of this was twofold: (1) to compare its characteristics to municipal waste leachate and (2) to assess its general characteristics in relation to treatability.

General trends in the characteristics of bottom leachate in relation to alkalinity, BOD, COD, and TOC over the leaching period are illustrated in Fig. 19 (tabular data are presented in Table A.3). Peak TOC concentration was  $\sim 1000$  mg/L which is about one-third of the mean TOC concentration reported by an EPA study surveying leachate characteristics of municipal waste landfills (Lu et al. 1985). Leachate from candle 3, sampled August 30, 1989, contained much higher levels of TOC and BOD (2300 and 7000 mg/L, respectively) than bottom leachate. These data imply that large amounts of soluble organic carbon are either sorbed, oxidized, or diluted as leachate moves downward in the lysimeter. The high concentrations of soluble organic matter may have a profound influence on solubilization of uranium within the lysimeter. Note that levels of TOC and uranium in bottom leachate were considerably lower than the levels measured in leachates sampled from suction candles.

Acetate was the dominant anion in bottom leachate (see Fig. 20 and Table A.4). Peak concentrations of acetate ( $\sim 1200$  mg/L) appeared in late July and decreased to  $\sim 500$  mg/L for the remainder of the leaching. After the last of July, the acetate appears to account for  $\sim 40\%$  of the total organic carbon measured in the leachate. Chloride concentrations in the bottom leachate remained relatively constant throughout the leaching. On the other hand, sulfate concentrations were highly variable. Analyses for nitrate and phosphate revealed concentrations below detection ( $< 1$  mg/L). Sulfite concentrations ( $\sim 3$  mg/L) were detected

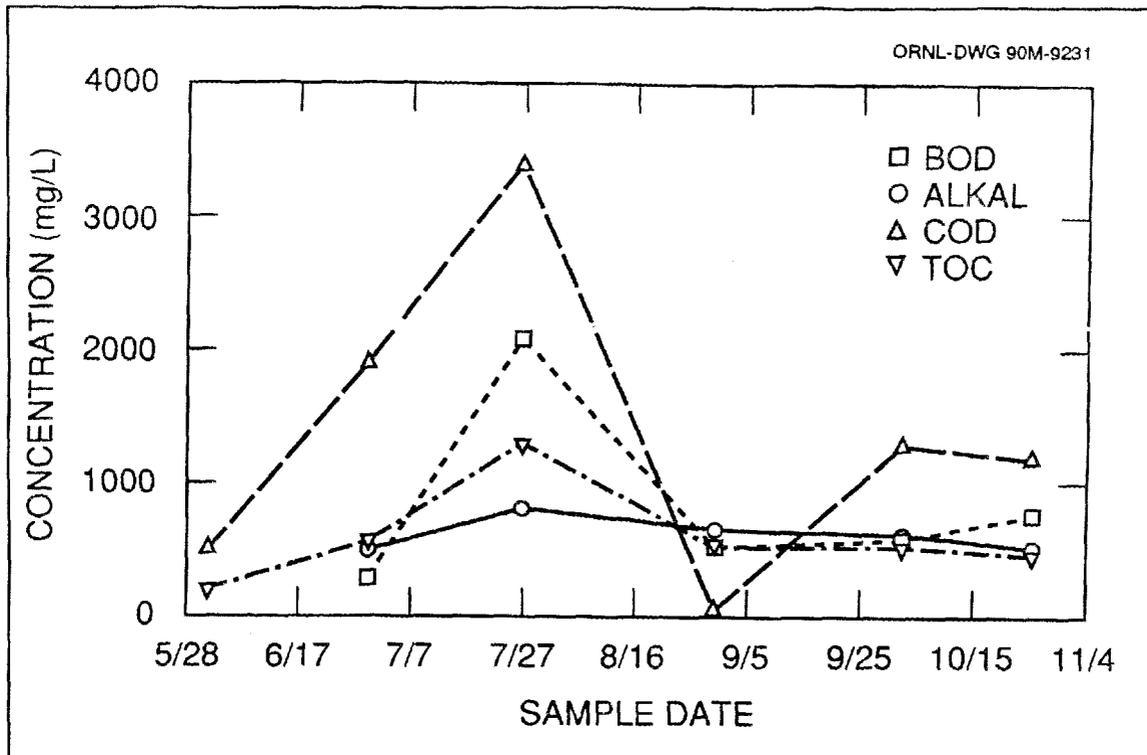


Fig. 19. General characteristic of bottom leachate in terms of alkalinity, biological oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC).

in bottom leachate July 26 and August 30.

### URANIUM LEACHING

The total quantity of uranium leached from the pilot lysimeter was  $\sim 120$  mg, less than 0.01% of the total 2.07 kg contained in the waste. On the order of one-third of the uranium was leached the first month (Fig. 21), presumably as the U(VI) form before the conditions in the lysimeter became anoxic. After this initial flushing in the presence of oxygen (maximum U concentration of 0.202 mg/L), concentrations of uranium in the bottom leachate were very low. Mean concentration of uranium in the bottom leachate after the initial leaching (viz, after one month) was 0.021 mg/L, in the same range as the uranium concentration in the demineralized water added to the waste for leaching.

The concentration of the uranium in the waste is unknown because the weights of the dumpster before and after loading were not determined. Significant confounding also exists in that only the lower part of the lysimeter contained uranium-contaminated wastes. If one assumes that only one-third of the bottom portion of the lysimeter contained contaminated wastes after settling and that the bulk density was on the order of  $1.2 \text{ g/cm}^3$ , the uranium concentration would then be on the order of 770 mg/kg. The maximum uranium concentration in the leachate observed by in situ sampling with the suction candle was  $\sim 0.8$  mg/L, meaning that leaching transfer coefficient in situ the waste was on the order of

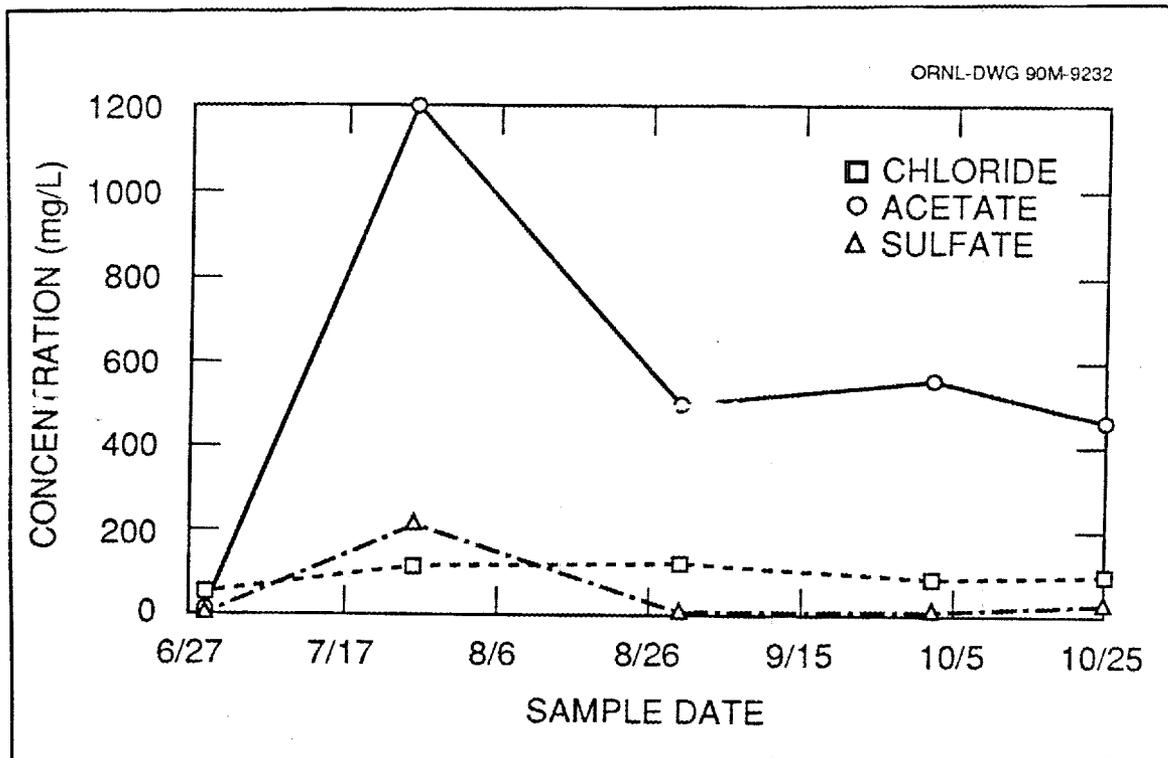


Fig. 20. Anion concentrations in bottom leachate.

0.001. Such a value (0.001) from these preliminary experiments would appear to be a useful (conservative but yet realistic) coefficient for use in subsequent transport models and pathway analyses.

These data imply that the leaching of uranium from this waste form would not constitute a significant environmental concern. Assuming a specific activity of  $^{238}\text{U}$  of  $0.36 \mu\text{Ci/g}$ , the activity of bottom leachate is  $< 10 \text{ pCi/L}$  ( $7.2 \text{ pCi/L}$ ). Of greater concern is the uranium concentration observed in the in situ leachate (maximum concentration of  $0.798 \text{ mg/L}$  or  $287 \text{ pCi/L}$ ). Earlier laboratory leaching results indicated that concentrations of uranium were lowered significantly when potential reductants such as iron chips were introduced into the leaching environment (Collins et al. 1990); the proposed mechanism being that  $\text{U(VI)}$  is reduced to the  $\text{U(IV)}$  state, which is much less soluble and thus relatively immobile in the environment. The limits of solubility for  $\text{U(IV)}$  are probably controlled by the redox potential (and the degree to which the system is poised, namely, the quantity of reductants), available sorption sites, and the quantity and character of water-soluble ligands (i.e., certain organic decomposition products resulting from the biodegradation of the organic waste) capable of complexing uranium.

Recent work investigating the microbial transformations of uranium in wastes (Francis et al. 1989) indicated that substantial amounts of uranium associated with the exchangeable, carbonate, and iron-oxide fractions of the Y-12 Plant New Hope pond sediment and sludge from the Y-12 Plant West End Treatment Facility were released into the medium culture used to conduct the experiments, but little uranium was detected in the solution phase.

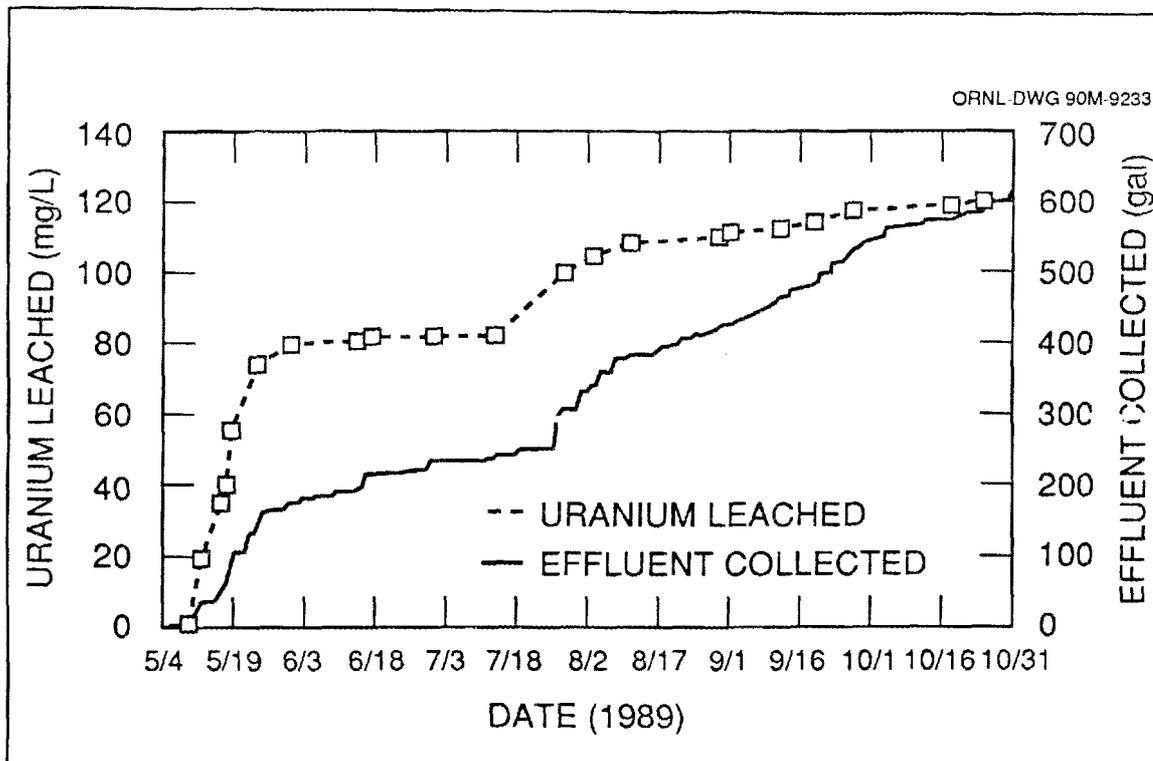


Fig. 21. Quantity of uranium leached from the Y-12 Plant lysimeter pilot study.

Immobilization of uranium was thought to be the result of biosorption of uranium on biomass and reduction and precipitation of uranium under the reducing conditions of the microbial activity. The uranium concentrations observed in leachate collected from the suction candles (though low compared with uranium concentrations observed in laboratory extraction studies) support the thesis that a certain uranium fraction is soluble under landfill conditions. Peak uranium concentrations in the leachate from the suction candles also occurred in the same time frame (mid-July) as peak TOC, COD, and BOD concentrations in the bottom leachate, indicating a potential relationship between soluble uranium and organic matter. Also, much higher levels of TOC and BOD were observed in leachates from suction candles than in the bottom leachate. However, this "soluble" uranium fraction is apparently immobilized as the leachate moves to further depths in the lysimeter. The following mechanisms may be responsible.

1. Leachate within the waste may be deficient in iron relative to the iron concentrations the leachate encounters as it travels through the pea gravel (which also contained a red-colored clay fraction) and along the bottom of the steel dumpster. Iron concentrations in the anoxic bottom leachate ranged between 100 and 200 mg/L compared to ~50 mg/L in suction candle leachate. Sorption of uranium on reduced coatings of iron sesquioxides is one proposed mechanism; however, no statistically significant difference was noted in the quantity of uranium measured in bottom leachate sampled under anoxic and oxic conditions. This observation indicated that oxidation and precipitation of iron did not in itself affect that fraction of uranium in the bottom leachate.

2. A second possible mechanism is sorption of a soluble organo-uranium complex on the synthetic fabric used as a barrier to prevent particulate transport into the bottom leachate.

## RESULTS AND DISCUSSION-1990 LEACHING STUDIES

### WATER BALANCE

Leaching was resumed May 1, 1990, by pumping 55-gal increments of demineralized water into the lysimeter (in the same manner as that conducted in 1989). By August 1, 1990, 280 gal of bottom leachate had been collected from adding 550 gal of water (Fig. 22). The water balance data are similar to that generated in 1989; (i.e.; waste within the lysimeter was

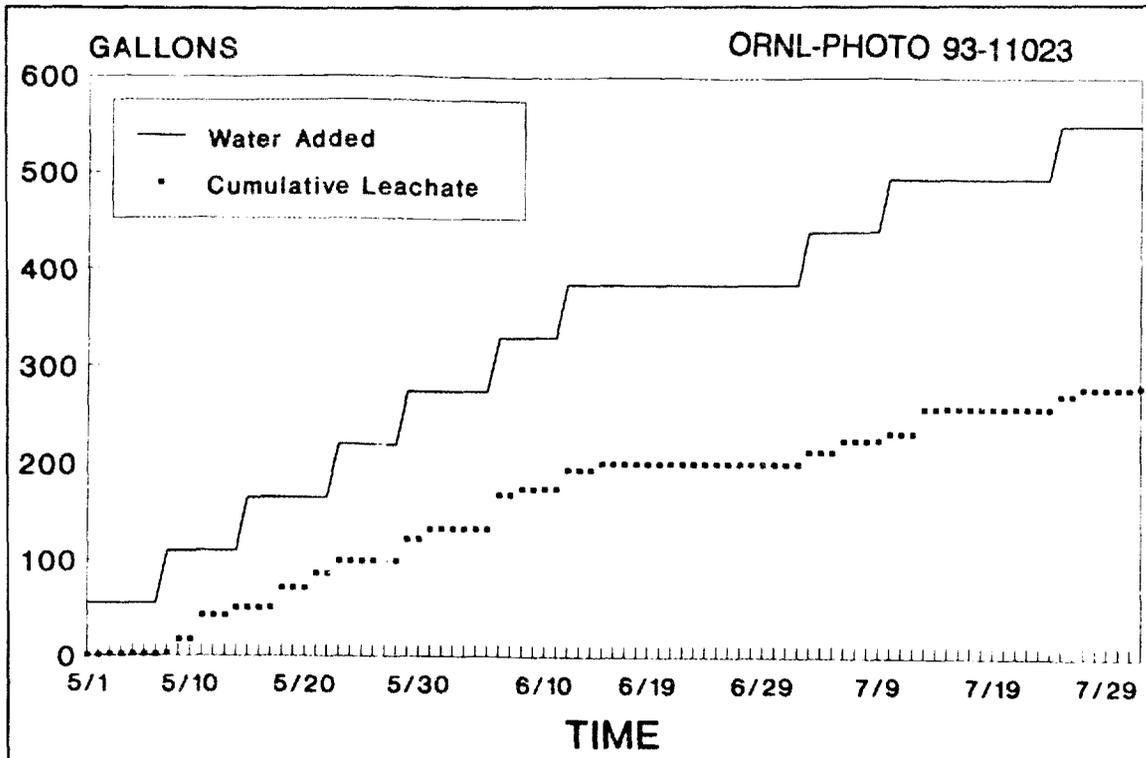


Fig. 22. Water balance from 1990 leaching study.

still taking-up water during the 1990 leaching, note the slope of the two curves in Fig. 22), implying an unsaturated condition within the waste form.

### URANIUM CONCENTRATIONS IN LEACHATE

Uranium concentrations in leachate never exceeded 1 mg/kg. The highest concentrations were measured in leachate sampled from suction candles (mean of 0.26 mg/L with a range from 0.08 to 0.99 mg/L, see Fig. 23). The mean value was  $\sim 0.10$  mg/L less than the mean uranium concentration observed in leachate sampled from suction candles in 1989. However, there is an important difference: in 1989, leachate could only be collected from candle 3. This year, a small amount of leachate could also be collected from candle 1, and the uranium concentration in leachate from candle 1 was on the order five times higher

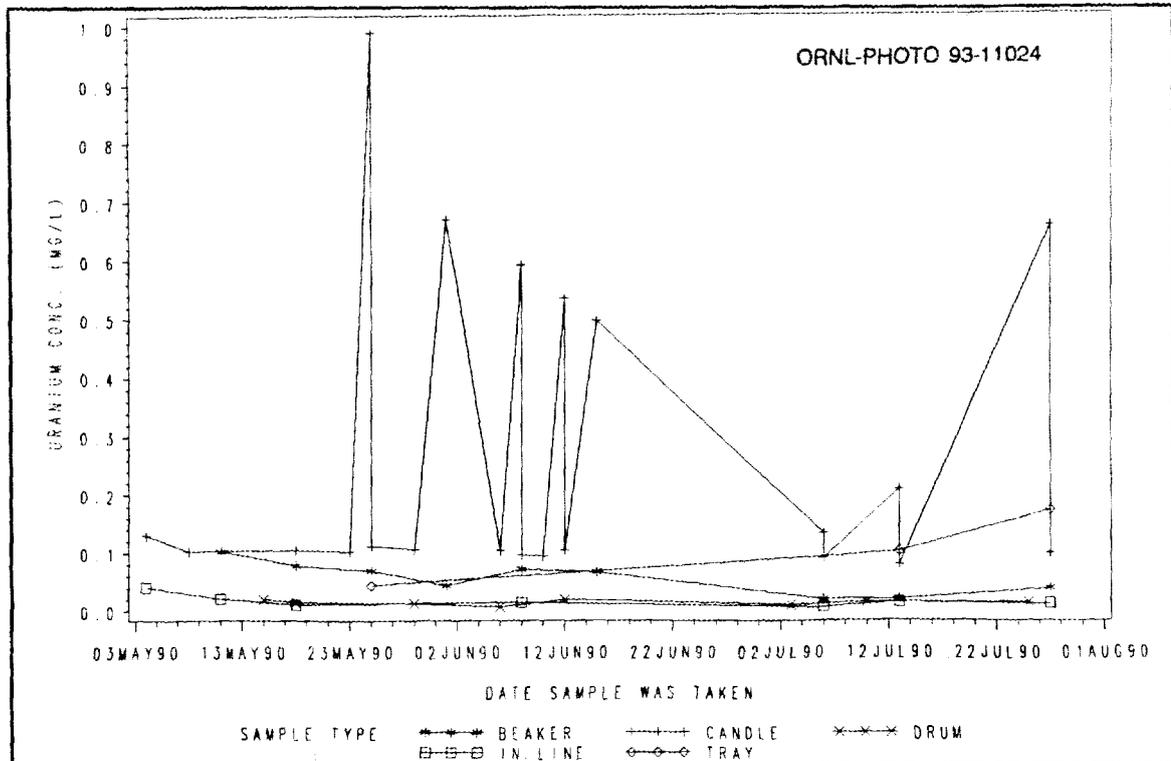


Fig. 23. Leachate uranium concentrations sampled from various sampling devices.

than the uranium concentration measured in leachate sampled from candle 3 (see Fig. 24). However, keep in mind, the quantity of leachate collected from candle 1 was very small (often times < 25 mL, see Table 1). These data further support the hypothesis that the wastes are gradually wetting with time; that is, leachate could only be collected from one of the three suction candles in 1989 where as in 1990, leachate could be collected from two candles and the quantity collected from candle 1 appeared to increase with respect to time (Table 1).

Uranium concentrations in leachate sampled from the beakers and trays (means 0.06 and 0.11 mg/L, respectively) were higher than the mean concentrations measured in bottom leachate [that collected from the collection drum (0.01 mg/L) and that collected "in line" under anoxic conditions directly from the bottom of the lysimeter (0.02 mg/L), see Table B.1 of Appendix B]. However, concentrations of uranium in leachate from both bottom leachate sampling points (in line and from the collection drum) did not differ (see Fig. 25) and were similar to the uranium concentration in the demineralized water used for leaching (0.01 mg/L).

### FIELD MEASUREMENTS OF LEACHATE CHARACTERISTICS

Bottom leachate was monitored directly via a flow-through cell for pH, dissolved oxygen (DO), temperature, conductivity, and oxidation reduction potential (ORP) with a Surveyor II water quality meter manufactured by the Hydrolab corporation, Austin, Texas. Values for pH ranged from a high of 6.62 to a low of 3.47 (mean of 4.91 over 28 sampling

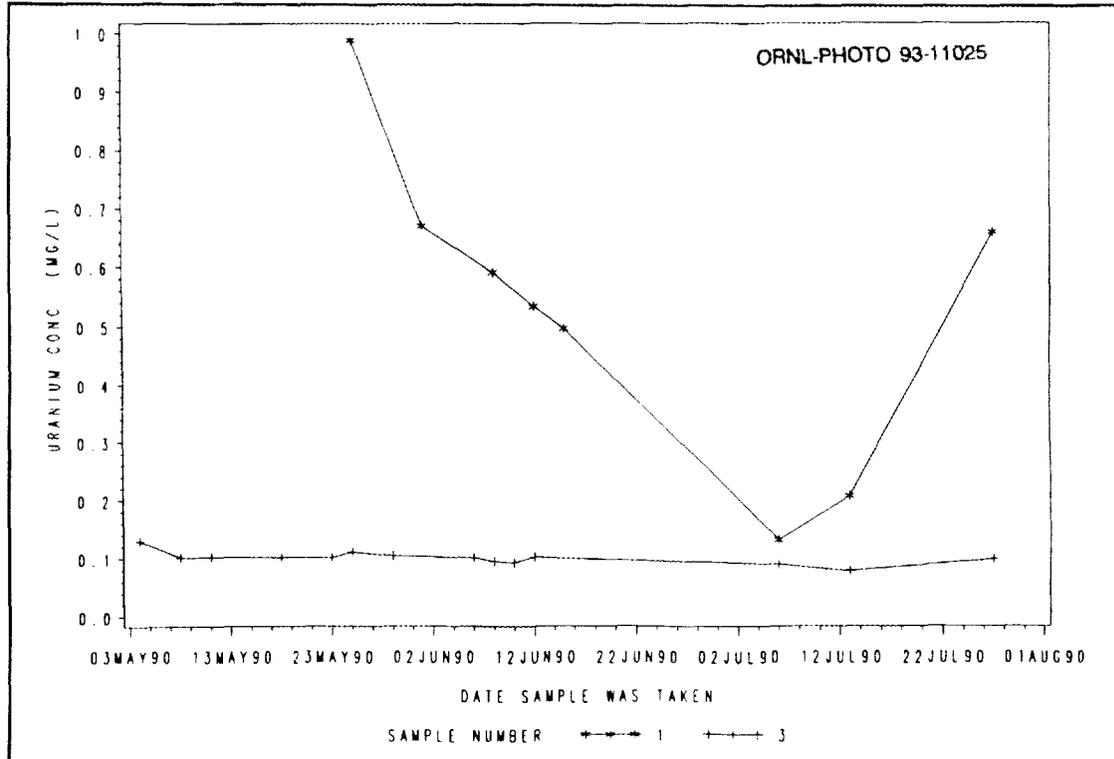


Fig. 24. Uranium concentrations in leachate sampled from suction candles 1 and 3.

dates). These data are summarized and illustrated in a variety of figures contained in Appendix B.

### LEACHATE TREATABILITY CHARACTERISTICS

A limited number of analyses were conducted to assess leachate treatability characteristics (i.e., TOC, COD, BOD, and alkalinity). Leachate sampled from the suction candles contained considerably more TOC than bottom leachate sampled from the collection drum or "in line" under anoxic conditions (see Appendix B). Bottom leachate sampled "in line" had CODs ranging from 660 to 930 mg/L. BODs from the same samples ranged from 360 to 490 mg/L. Alkalinity of bottom leachate ranged from 360 to 540 mg/L.

### ANION CONCENTRATIONS IN LEACHATE

Concentrations of selected anions were also determined, namely, Br, Cl, F, NO<sub>2</sub>, NO<sub>3</sub>, PO<sub>4</sub>, and SO<sub>4</sub>. Sulfate concentrations were the highest, bottom leachate (in line and drum) averaging well in excess of 1000 mg/L (see Table B1). The next highest anion concentration measured was chloride, initially observed in bottom leachate during the first week of leaching at 150 mg/L and leveling off to concentrations ranging from 10 to 50 mg/L. Concentrations of Br, F, NO<sub>2</sub>, NO<sub>3</sub>, and PO<sub>4</sub> were generally < 10 mg/L and often below detection.

Table 1. Summary of leachate collection in 1990 from in situ collection devices

Date	Beaker <sup>a</sup>			Tray		Candle		
	1	2	3	1	2	1	2	3
04-May-90	Dry	Dry	Dry	Dry	Tr	Dry	Dry	150
08-May-90	Ns	Ns	Ns	Ns	Ns	Dry	Ns	250
11-May-90	Tr	Dry	250	Dry	Dry	Dry	Dry	250
18-May-90	Ns	Ns	350	Ns	Ns	Ns	Ns	300
25-May-90	Tr	Dry	275	50	Dry	15	Dry	150
01-Jun-90	Tr	Dry	40	Dry	Dry	10	Dry	200
08-Jun-90	Tr	Dry	35	Dry	Dry	10	Dry	150
12-Jun-90	Ns	Ns	Ns	Ns	Ns	10	Dry	300
15-Jun-90	Dry	Dry	25	Dry	Dry	15	Dry	250
03-Jul-90	Ns	Ns	Ns	Ns	Ns	20	Dry	400
06-Jul-90	Dry	Dry	20	Dry	Dry	35	Dry	20
10-Jul-90	Ns	Ns	Ns	Ns	Ns	50	Dry	250
13-Jul-90	Dry	Dry	Tr	100	Dr	125	Dry	150
25-Jul-90	Ns	Ns	Ns	Ns	Ns	50	Dry	500
27-Jul-90	Dry	Dry	15	50	Dry	225	Dry	150

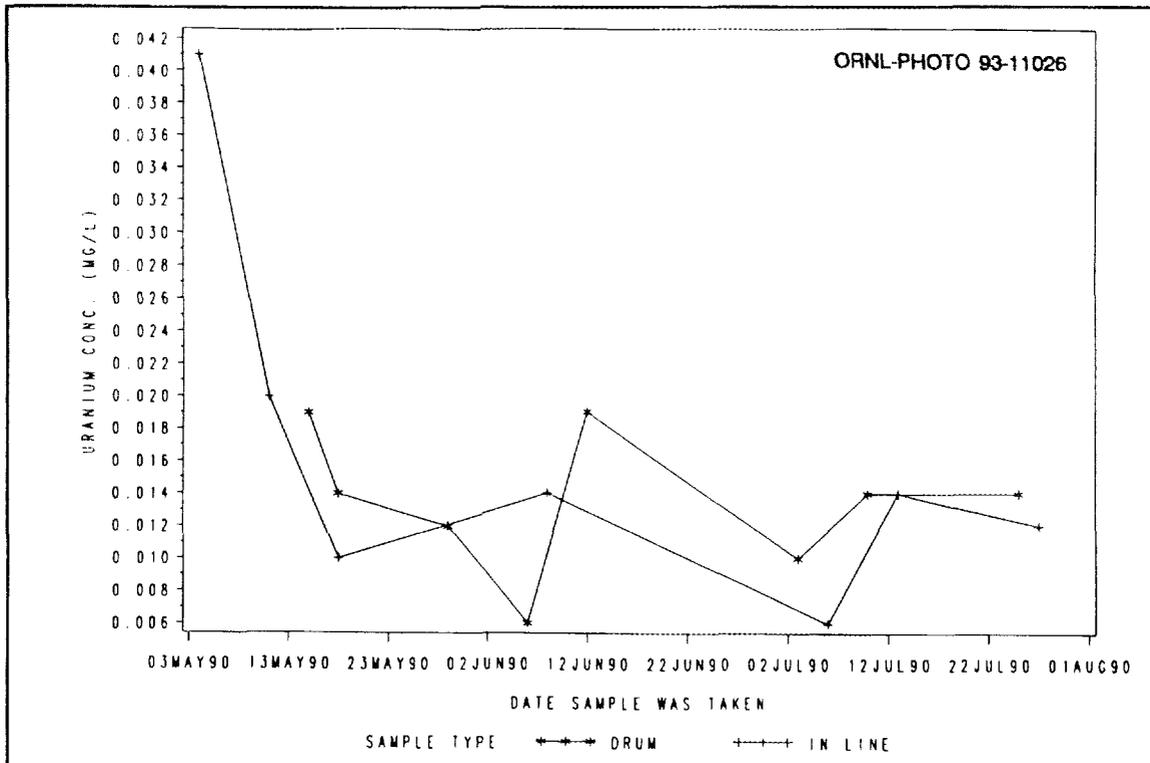
<sup>a</sup>Dry = no leachate, Tr = trace (<10 mL), Ns = not sampled, and mL of leachate collected.

#### CATION CONCENTRATIONS IN LEACHATE

Alkali metals, and alkaline earths, along with iron, characteristically make up the bulk of the cationic charge in waste leachates. Analysis determined by ICP spectroscopy revealed that Ca was the most dominant cation in the leachate (ranging between 100 and 250 mg/L), followed closely by Fe (ranging between 100 and 150 mg/L). Sodium concentrations generally ranged between 50 and 75 mg/L and K and Mg ranged between 10 and 40 mg/L, see Appendix B). In contrast to uranium, these cations were generally observed in bottom leachate (leachate collected in line and from the collection drum) at higher concentrations than that observed in leachate collected from the suction candles (Figs. B.13 to B.17). Thus, these observations imply that uranium was sorbed on waste in transit to the bottom of the lysimeter while the alkali metals, alkaline earths, and iron continue to be leached though out the depth of waste.

## TOXIC METALS IN LEACHATE

Concentrations of some toxic metals listed in the Primary Drinking Water Standard (PDWS) can be determined by ICP analyses; namely, Ag, As, Cd, Cr, and Pb. However, for the leachate sampled in this work, many of the levels were below detection (see Table B.3). For example, all 35 analyses for arsenic were below the detection limits, which varied from 0.04 to 0.2 depending on the dilution of the sample, etc. In the case of cadmium and silver, 34 of the 35 analyses were below detection. For lead, 32 of the 35 analyses were below detection. In only a few instances did the detectable concentration of any of these toxic metals exceed PDWS (see Table B.4). Most of the instances involved chromium, which was



**Fig. 25.** Uranium concentrations in "in line" bottom leachate (sampled under anoxic conditions) and bottom leachate sampled from collection drums (sampled under oxic conditions).

observed to be at higher levels in leachate sampled from beakers and candles than in bottom leachate (in line or from the collection drum) indicating that the beakers and suction candles might be sources of chromium contamination. Excessive barium concentrations observed in leachate sampled from suction candles may also be an indication that the suction candles were a source of barium for those leachate samples. Lead concentrations in leachate sampled from beakers were significantly higher than lead concentrations in leachate sampled from bottom leachate or candles. Along the same line, nickel concentrations in leachate sampled from the beakers and suction candles were three times higher than those concentrations measured in bottom leachate. Regardless the source, concentrations of the PDWS toxic metals were very low in all leachate sampled. In cases where concentrations exceeded PDWS, the

concentrations were less than a tenfold excess, indicating that a 1 to 10 dilution/attenuation factor would be more than adequate to protect groundwater quality.

## SUMMARY AND CONCLUSIONS

A pilot lysimeter study was conducted to determine the feasibility and effectiveness of several design concepts for collecting in situ leachate in the field lysimeters being constructed in Bear Creek Valley. To do this, Y-12 Plant production wastes containing 2.07 kg of depleted uranium were loaded into a waste dumpster and leached with demineralized water for during the summer months of 1989 and 1990. Three devices were tested to collect leachate from these wastes. These included (1) conventional ceramic-tipped suction candles to collect unsaturated flow and two devices filled with fine-grained sand to collect saturated flow; namely, (2) V-shaped trays constructed of stainless steel, and (3) 4-L stainless beakers. The primary objective of this pilot study was to determine the feasibility and effectiveness of these proposed in situ leachate collection devices. Secondary objectives included gaining experience in hand and packing of wastes, installation and operation of leachate collection devices, and waste leachate characterization.

The study identified the most suitable devices to collect in situ leachate and revealed that certain design changes and modifications of installation procedures need to be adopted. The study also recognized the need to carefully plan how the wastes should be loaded in the field lysimeters to avoid artifacts in the effectiveness of the collection devices. The study also provided some valuable information on the leaching characteristics of uranium from the Y-12 Plant production wastes. Presented below are comments and recommendations relevant to (1) design selection of in situ leachate collection devices, (2) loading of wastes in field lysimeters, and (3) leachate characterization.

### DESIGN SELECTION OF IN SITU LEACHATE COLLECTION DEVICES

Suction candles proved to be the most effective leachate collection devices even though leachate could be sampled from only one of the three candles installed. Vacuums on the order of 75 centibars could be established and held for reasonable lengths of time on all candles, indicating that none was broken when wastes were loaded. A different method is needed for installation of suction candles in the wastes scheduled for the field lysimeters. One suggestion is to mount the candle in a quadrupod and wrap a bag filled with silica flour around the ceramic tip of the candle. The quadrupod would provide protection against breakage of the candle when more wastes are loaded into the lysimeter, and the bagged silica flour would ensure better contact with macropore water in coarser-textured wastes.

The 4-L beakers were more effective in the collection of leachate moving within waste macropores (saturated flow) than were the trays. The lower concentrations of alkali metals and alkaline earths in leachate collected from the beakers compared with leachate collected from suction candles suggest that the beakers were probably collecting leachate from waste macropores. The tray design should be discarded because of its instability (i.e., susceptible to tipping as wastes are loaded in the lysimeter). The preferred design for collection of macropore would be a 4-L beaker design, but larger (e.g., a 5-gal, Teflon-lined bucket loaded with acid-washed river rock).

## LOADING OF WASTES IN FIELD LYSIMETERS

Much attention needs to be directed to procedures for loading wastes in the field lysimeters. Indirect evidence in the pilot study indicated considerable short circuiting around compacted waste forms, possibly leaving dry zones within the waste; thus, procedures need to be developed to ensure uniform packing of wastes within the lysimeter. Other recommendations include using "clean" river rock in the bottom of the lysimeter and eliminating the synthetic geofiber membrane between the waste and river rock.

## LEACHATE CHARACTERIZATION

The highest uranium concentration ( $\sim 0.2$  mg/L) observed in the bottom leachate from the lysimeter occurred during the first month of leaching prior to waste biodecomposition, which makes the lysimeter conditions anoxic. Uranium concentrations in the bottom leachate after this initial flushing in the presence of oxygen become very low, averaging 0.021 mg/L and in the same range as the uranium concentration (0.049 mg/L) in the demineralized water used for leaching. In situ leachate collected by suction candles averaged 0.359 mg/L over the same period. Peak uranium concentrations in leachate collected by the suction candles were  $\sim 0.8$  mg/L. Mean uranium concentration observed in leachate collected from the beakers was 0.033 mg/L, indicating the sampling of leachate that had little contact with uranium-contaminated waste. Experimental leaching data obtained from this study revealed transfer coefficients of uranium from the solid phase of uranium-contaminated waste to the solution phase to range between 0.001 and 0.0001. Data of this type should be of considerable value in the development of leaching and transport models and pathways analyses of uranium moving off-site.

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**APPENDIX A-1989 LEACHING STUDIES**

Table A.1  
 FIELD MEASUREMENTS ON BOTTOM LEACHATE  
 FROM THE OAK RIDGE Y-12 PLANT PILOT LYSIMETER

SAMPLE DATE	TEMPERATURE (CELSIUS)	pH	CONDUCTANCE (MMHO/CM)	DISSOLVED OXYGEN (MG/L)	OXYGEN REDUCTION POTENTIAL (VOLTS)
09MAY89	13.9	6.69	0.331	4.63	.
10MAY89	12.3	7.77	0.346	0.76	.
11MAY89	11.2	7.39	0.365	0.38	.
12MAY89	10.1	6.95	0.350	0.40	.
16MAY89	12.7	6.62	0.387	0.46	.
17MAY89	13.9	7.10	0.327	0.40	.
31MAY89	22.5	6.74	0.151	0.24	0.126
01JUN89	25.1	4.42	0.242	0.13	0.105
02JUN89	25.9	4.26	0.313	0.14	0.089
05JUN89	22.4	4.30	0.362	0.17	0.110
07JUN89	16.5	4.20	0.363	0.18	0.121
09JUN89	23.5	4.68	0.346	0.24	0.109
13JUN89	19.3	4.87	0.358	0.32	0.133
14JUN89	21.0	4.51	0.426	0.24	0.014
16JUN89	21.3	4.52	0.427	0.21	0.103
19JUN89	26.8	4.99	0.466	0.15	0.027
20JUN89	18.5	4.79	0.521	0.30	0.011
21JUN89	26.5	4.86	0.482	0.10	0.062
23JUN89	27.3	4.80	0.460	0.25	0.102
26JUN89	27.2	5.29	0.518	0.07	0.002

Table A.1 (continued)  
 FIELD MEASUREMENTS ON BOTTOM LEACHATE  
 FROM THE OAK RIDGE Y-12 PLANT PILOT LYSIMETER

SAMPLE DATE	TEMPERATURE (CELSIUS)	pH	CONDUCTANCE (MMHO/CM)	DISSOLVED OXYGEN (MG/L)	OXYGEN REDUCTION POTENTIAL (VOLTS)
29JUN89	22.9	4.95	0.492	0.38	0.064
10JUL89	26.1	5.42	0.566	0.35	-0.026
12JUL89	25.2	5.62	0.354	0.16	0.097
13JUL89	26.8	4.94	0.625	0.23	0.042
18JUL89	22.4	5.44	0.272	0.37	-0.015
20JUL89	22.4	5.71	0.593	0.22	0.126
21JUL89	23.4	5.79	0.604	0.23	0.132
24JUL89	23.0	5.84	0.621	0.24	0.151
25JUL89	23.8	5.68	0.505	0.13	0.159
26JUL89	27.5	5.22	0.331	0.15	-0.003
27JUL89	30.9	5.74	0.019	0.11	-0.027
28JUL89	25.0	5.66	0.025	0.17	-0.006
31JUL89	23.6	3.81	0.024	0.32	0.072
02AUG89	22.9	4.14	0.026	0.26	0.086
04AUG89	24.0	3.40	0.029	0.60	0.030
07AUG89	22.1	4.01	0.032	0.17	0.078
08AUG89	14.9	4.21	0.033	0.33	0.071
10AUG89	21.8	4.00	0.032	0.18	0.067
16AUG89	22.0	4.74	0.038	0.15	-0.104
17AUG89	23.5	4.16	0.037	0.30	0.023

Table A.1 (continued)  
 FIELD MEASUREMENTS ON BOTTOM LEACHATE  
 FROM THE OAK RIDGE Y-12 PLANT PILOT LYSIMETER

SAMPLE DATE	TEMPERATURE (CELSIUS)	pH	CONDUCTANCE (MMHO/CM)	DISSOLVED OXYGEN (MG/L)	OXYGEN REDUCTION POTENTIAL (VOLTS)
21AUG89	25.0	3.76	0.033	0.13	0.073
24AUG89	26.1	4.35	0.038	0.12	0.066
28AUG89	23.8	5.37	0.035	0.44	0.100
30AUG89	24.8	4.37	0.038	0.28	0.046
31AUG89	24.3	3.43	0.018	0.06	0.000
11SEP89	22.4	4.15	0.022	0.22	-0.023
12SEP89	27.5	4.55	0.017	0.11	0.059
13SEP89	23.6	4.51	0.021	0.28	0.088
15SEP89	22.1	4.69	0.021	0.27	0.072
18SEP89	17.3	4.65	0.018	0.13	0.078
19SEP89	17.4	4.08	0.019	0.16	0.044
20SEP89	24.6	4.99	0.021	0.08	0.007
22SEP89	20.3	4.86	0.025	0.27	0.013
13OCT89	13.3	5.85	0.453	0.49	0.113
16OCT89	18.0	5.99	0.414	0.41	0.131
17OCT89	20.3	4.61	0.360	0.51	0.190
18OCT89	12.8	5.91	0.313	0.64	0.117
20OCT89	4.9	6.21	0.275	1.18	0.133
23OCT89	10.6	4.94	0.009	1.92	0.053
24OCT89	12.0	5.08	0.136	1.00	0.024

Table A.1 (continued)  
 FIELD MEASUREMENTS ON BOTTOM LEACHATE  
 FROM THE OAK RIDGE Y-12 PLANT PILOT LYSIMETER

SAMPLE DATE	TEMPERATURE (CELSIUS)	pH	CONDUCTANCE (MMHO/CM)	DISSOLVED OXYGEN (MG/L)	OXYGEN REDUCTION POTENTIAL (VOLTS)
25OCT89	17.4	4.91	0.184	0.46	0.015
26OCT89	17.3	4.93	0.054	0.74	0.008
30OCT89	14.0	5.42	0.028	1.41	0.057
01NOV89	6.2	5.68	0.079	2.04	0.064
03NOV89	11.4	4.59	0.052	1.79	0.108
06NOV89	13.4	5.36	0.127	1.68	0.124
14NOV89	14.4	5.39	0.219	0.96	0.131

Table A.2  
 CONCENTRATIONS OBSERVED IN LEACHATE  
 FROM THE OAK RIDGE Y-12 PLANT URANIUM PILOT LYSIMETER  
 (MEAN CONCENTRATIONS UP TO OCT 30, 1989)

ELEMENT	SAMPLE TYPE	mg/L			
		MEAN	MIN	MAX	N
AG	BEAKER	0.048	0.004	0.520	16
	BOTLEACH	0.018	0.004	0.020	22
	CANDLE	0.016	0.004	0.020	18
	IN LINE	0.018	0.004	0.020	20
AL	BEAKER	1.821	0.080	21.500	16
	BOTLEACH	0.615	0.040	2.810	22
	CANDLE	14.611	0.100	32.400	18
	IN LINE	2.767	0.080	7.620	20
AS	BEAKER	0.258	0.040	1.600	16
	BOTLEACH	0.178	0.040	0.200	22
	CANDLE	0.164	0.040	0.200	18
	IN LINE	0.181	0.040	0.300	20
B	BEAKER	0.508	0.047	2.230	16
	BOTLEACH	2.987	0.300	7.090	22
	CANDLE	13.978	0.810	41.600	18
	IN LINE	3.682	1.890	6.790	20
BA	BEAKER	0.135	0.036	0.465	16
	BOTLEACH	0.393	0.137	0.991	22
	CANDLE	0.386	0.183	0.628	18
	IN LINE	0.431	0.225	0.758	20

Table A.2 (continued)  
 CONCENTRATIONS OBSERVED IN LEACHATE  
 FROM THE OAK RIDGE Y-12 PLANT URANIUM PILOT LYSIMETER  
 (MEAN CONCENTRATIONS UP TO OCT 30, 1989)

ELEMENT	SAMPLE TYPE	mg/L			
		MEAN	MIN	MAX	N
BE	BEAKER	0.002	0.000	0.018	16
	BOTLEACH	0.000	0.000	0.001	22
	CANDLE	0.001	0.000	0.001	18
	IN LINE	0.000	0.000	0.001	20
CA	BEAKER	64.262	25.600	172.000	16
	BOTLEACH	186.273	117.000	352.000	22
	CANDLE	167.667	111.000	229.000	18
	IN LINE	180.000	129.000	305.000	20
CD	BEAKER	0.019	0.006	0.030	16
	BOTLEACH	0.019	0.006	0.030	22
	CANDLE	0.018	0.001	0.030	18
	IN LINE	0.019	0.006	0.030	20
CE	BEAKER	0.074	0.020	0.170	16
	BOTLEACH	0.071	0.020	0.080	22
	CANDLE	0.073	0.020	0.170	18
	IN LINE	0.071	0.020	0.080	20
CO	BEAKER	0.039	0.002	0.260	16
	BOTLEACH	0.031	0.010	0.090	22
	CANDLE	0.041	0.010	0.080	18
	IN LINE	0.030	0.010	0.060	20

Table A.2 (continued)  
 CONCENTRATIONS OBSERVED IN LEACHATE  
 FROM THE OAK RIDGE Y-12 PLANT URANIUM PILOT LYSIMETER  
 (MEAN CONCENTRATIONS UP TO OCT 30, 1989)

ELEMENT	SAMPLE TYPE	mg/L			
		MEAN	MIN	MAX	N
CR	BEAKER	0.079	0.006	0.330	16
	BOTLEACH	0.033	0.006	0.070	22
	CANDLE	0.139	0.030	0.300	18
	IN LINE	0.051	0.015	0.100	20
CU	BEAKER	0.052	0.003	0.500	16
	BOTLEACH	0.023	0.002	0.260	22
	CANDLE	0.008	0.002	0.010	18
	IN LINE	0.010	0.002	0.030	20
FE	BEAKER	26.939	0.005	111.000	16
	BOTLEACH	53.723	6.200	157.000	22
	CANDLE	42.872	18.100	58.900	18
	IN LINE	154.580	94.600	216.000	20
GA	BEAKER	0.175	0.050	0.800	6
	BOTLEACH	0.048	0.020	0.050	14
	CANDLE	0.050	0.050	0.050	6
	IN LINE	0.050	0.050	0.050	7
K	BEAKER	11.600	3.000	39.000	16
	BOTLEACH	29.182	6.000	52.000	22
	CANDLE	44.261	11.000	67.000	18
	IN LINE	32.655	22.000	49.000	20

Table A.2 (continued)  
 CONCENTRATIONS OBSERVED IN LEACHATE  
 FROM THE OAK RIDGE Y-12 PLANT URANIUM PILOT LYSIMETER  
 (MEAN CONCENTRATIONS UP TO OCT 30, 1989)

		mg/L			
		MEAN	MIN	MAX	N
ELEMENT	SAMPLE TYPE				
LA	BEAKER	0.287	0.003	4.320	16
	BOTLEACH	0.009	0.003	0.010	22
	CANDLE	1.299	0.008	23.200	18
	IN LINE	0.009	0.003	0.010	20
LI	BEAKER	0.162	0.003	0.682	16
	BOTLEACH	0.343	0.012	1.010	22
	CANDLE	0.180	0.093	0.311	18
	IN LINE	0.195	0.054	0.431	20
MG	BEAKER	9.684	0.005	29.000	16
	BOTLEACH	22.950	13.100	36.900	22
	CANDLE	21.217	12.900	29.600	18
	IN LINE	22.625	15.600	34.900	20
MN	BEAKER	3.497	1.510	6.250	16
	BOTLEACH	3.307	2.070	7.080	22
	CANDLE	4.964	2.770	32.700	18
	IN LINE	3.262	2.530	3.900	20
MO	BEAKER	0.152	0.006	1.900	16
	BOTLEACH	0.027	0.006	0.030	22
	CANDLE	0.025	0.006	0.030	18
	IN LINE	0.029	0.006	0.080	20

Table A.2 (continued)  
 CONCENTRATIONS OBSERVED IN LEACHATE  
 FROM THE OAK RIDGE Y-12 PLANT URANIUM PILOT LYSIMETER  
 (MEAN CONCENTRATIONS UP TO OCT 30, 1989)

		mg/L			
		MEAN	MIN	MAX	N
ELEMENT	SAMPLE TYPE				
NA	BEAKER	30.280	3.300	138.000	16
	BOTLEACH	100.332	22.900	210.000	22
	CANDLE	119.528	51.500	155.000	18
	IN LINE	113.830	47.900	167.000	20
NB	BEAKER	0.044	0.010	0.050	16
	BOTLEACH	0.045	0.010	0.050	22
	CANDLE	0.041	0.010	0.050	18
	IN LINE	0.044	0.010	0.050	20
NI	BEAKER	0.145	0.006	0.590	16
	BOTLEACH	0.065	0.030	0.090	22
	CANDLE	0.103	0.040	0.180	18
	IN LINE	0.066	0.020	0.160	20
P	BEAKER	0.520	0.060	2.300	16
	BOTLEACH	0.343	0.210	0.600	22
	CANDLE	0.508	0.250	1.000	18
	IN LINE	0.444	0.170	2.300	20
PB	BEAKER	0.084	0.003	0.100	16
	BOTLEACH	0.090	0.020	0.100	22
	CANDLE	0.104	0.020	0.500	18
	IN LINE	0.088	0.020	0.100	20

Table A.2 (continued)  
 CONCENTRATIONS OBSERVED IN LEACHATE  
 FROM THE OAK RIDGE Y-12 PLANT URANIUM PILOT LYSIMETER  
 (MEAN CONCENTRATIONS UP TO OCT 30, 1989)

ELEMENT	SAMPLE TYPE	mg/L			
		MEAN	MIN	MAX	N
SC	BEAKER	0.001	0.000	0.002	5
	BOTLEACH	0.001	0.000	0.002	12
	CANDLE	0.005	0.000	0.008	9
	IN LINE	0.001	0.000	0.003	8
SR	BEAKER	0.188	0.057	0.656	16
	BOTLEACH	0.392	0.233	0.724	22
	CANDLE	0.412	0.299	0.570	18
	IN LINE	0.389	0.300	0.502	20
TH	BEAKER	0.053	0.010	0.220	16
	BOTLEACH	0.045	0.010	0.050	22
	CANDLE	0.041	0.010	0.050	18
	IN LINE	0.044	0.010	0.050	20
TI	BEAKER	0.098	0.003	1.010	16
	BOTLEACH	0.026	0.002	0.200	22
	CANDLE	0.079	0.010	0.180	18
	IN LINE	0.057	0.003	0.180	20
U	BEAKER	0.033	0.003	0.202	16
	BOTLEACH	0.056	0.005	0.269	22
	CANDLE	0.359	0.077	0.798	18
	IN LINE	0.033	0.006	0.083	20

Table A.2 (continued)  
 CONCENTRATIONS OBSERVED IN LEACHATE  
 FROM THE OAK RIDGE Y-12 PLANT URANIUM PILOT LYSIMETER  
 (MEAN CONCENTRATIONS UP TO OCT 30, 1989)

ELEMENT	SAMPLE TYPE	mg/L			
		MEAN	MIN	MAX	N
V	BEAKER	0.053	0.004	0.570	16
	BOTLEACH	0.020	0.004	0.040	22
	CANDLE	0.062	0.020	0.110	18
	IN LINE	0.028	0.004	0.050	20
Y	BEAKER	0.021	0.001	0.068	11
	BOTLEACH	0.050	0.001	0.125	10
	CANDLE	0.022	0.013	0.029	9
	IN LINE	0.173	0.011	0.412	12
ZN	BEAKER	0.263	0.008	1.690	16
	BOTLEACH	0.141	0.005	0.346	22
	CANDLE	1.447	0.005	5.110	18
	IN LINE	8.286	0.520	20.800	20
ZR	BEAKER	0.014	0.002	0.100	16
	BOTLEACH	0.009	0.002	0.010	22
	CANDLE	0.016	0.010	0.030	18
	IN LINE	0.009	0.002	0.010	20

Table A.3  
 GENERAL CHARACTERISTICS OF BOTTOM LEACHATE  
 FROM THE OAK RIDGE Y-12 PLANT PILOT LYSIMETER

SAMPLE DATE	CHARACTERISTICS			
	ALKAL	BOD	COD	TOC
	mg/L	mg/L	mg/L	mg/L
01JUN89	.	.	490	180
29JUN89	470	260	1900	540
26JUL89	800	2100	3400	1300
30AUG89	640	500	53	500
02OCT89	600	550	1300	520
25OCT89	510	760	1200	470

Table A.4  
ANION CONCENTRATIONS IN BOTTOM LEACHATE  
FROM THE OAK RIDGE Y-12 PLANT PILOT LYSIMETER

SAMPLE DATE	ANIONS		
	ACETATE	CHLORIDE	SULFATE
	mg/L	mg/L	mg/L
29JUN89	11	53	1
26JUL89	1200	110	210
30AUG89	495	115	3
02OCT89	550	79	5
25OCT89	450	85	23

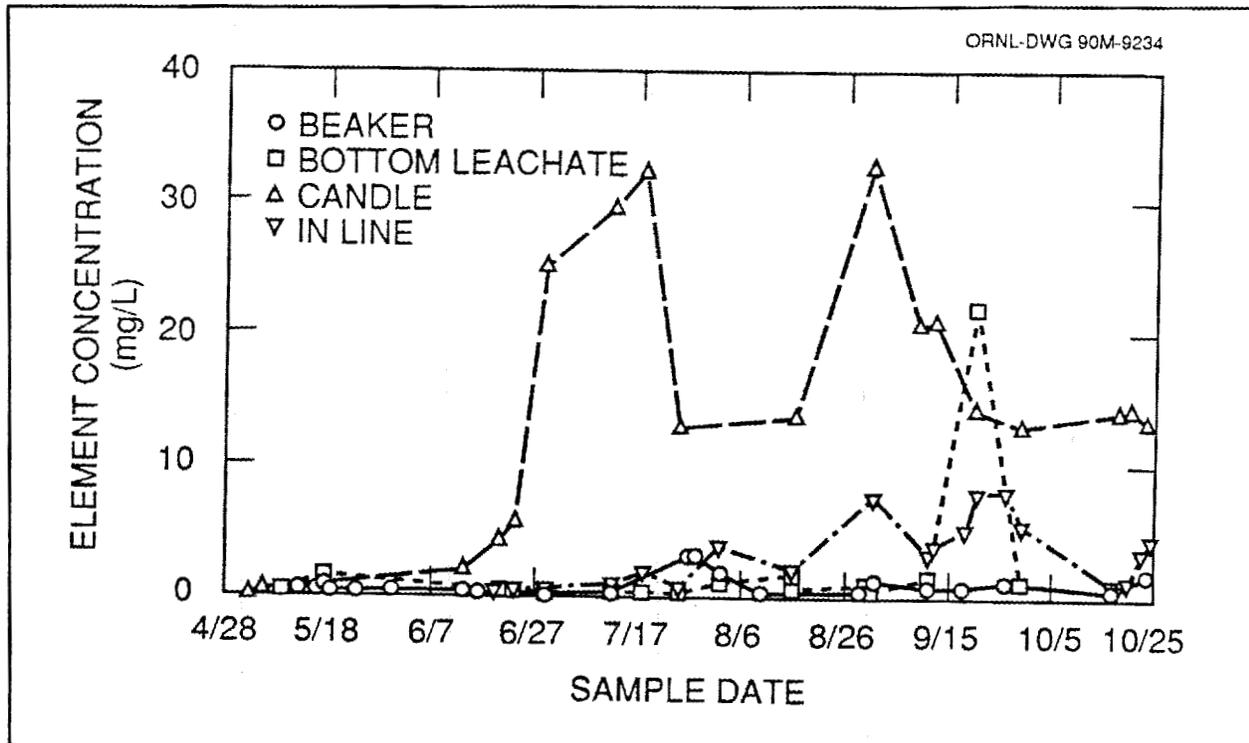


Fig. A.1. Aluminum concentrations in leachate.

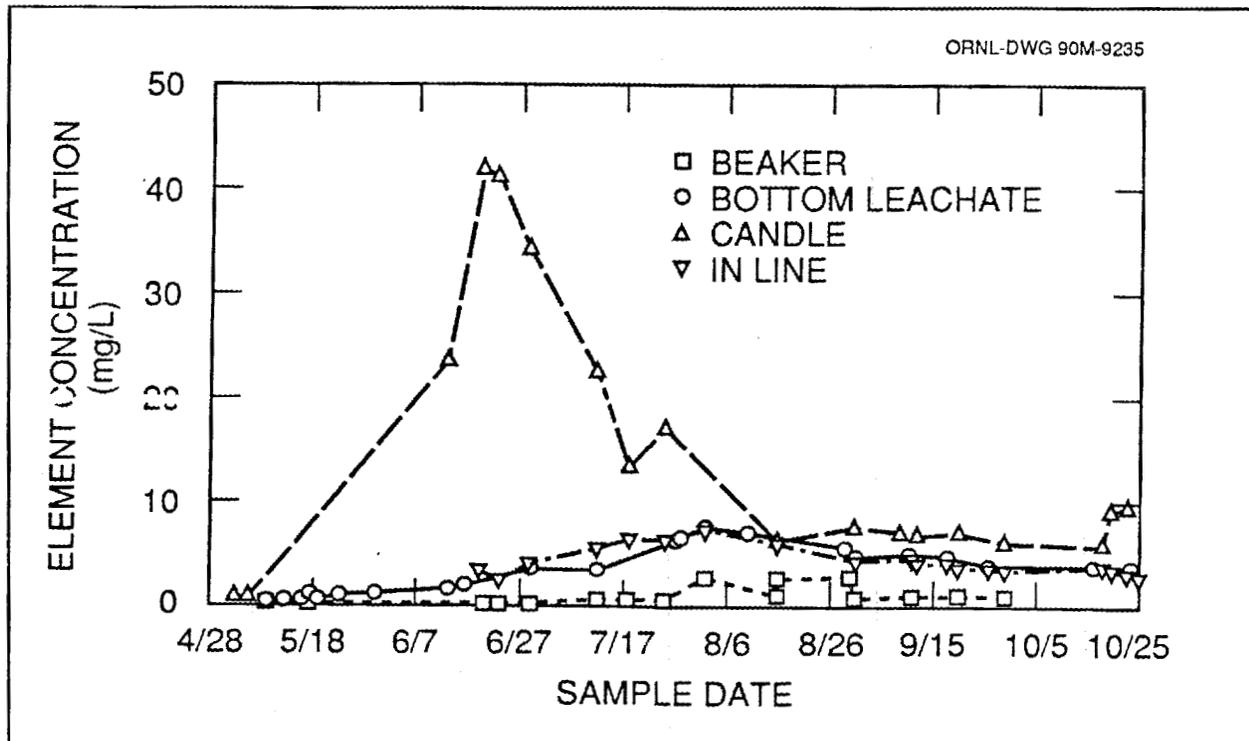


Fig. A.2. Boron concentrations in leachate.

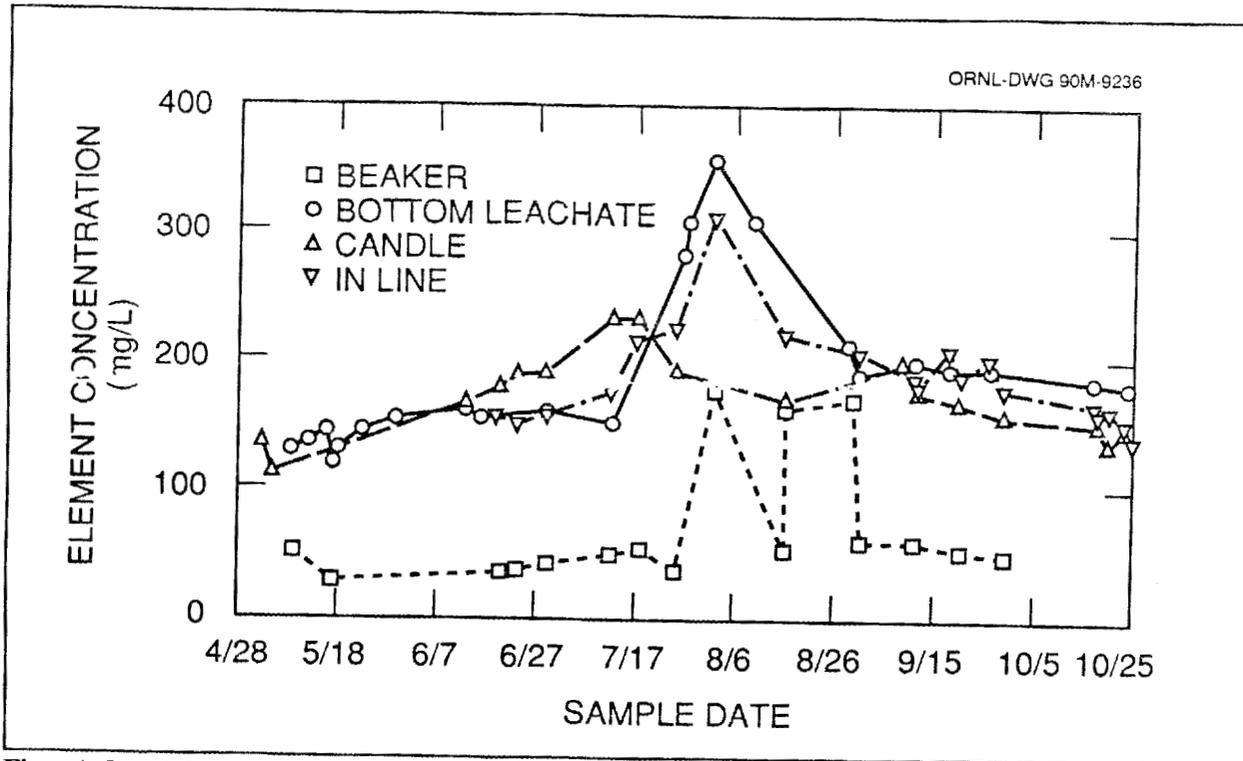


Fig. A.3. Calcium concentrations in leachate.

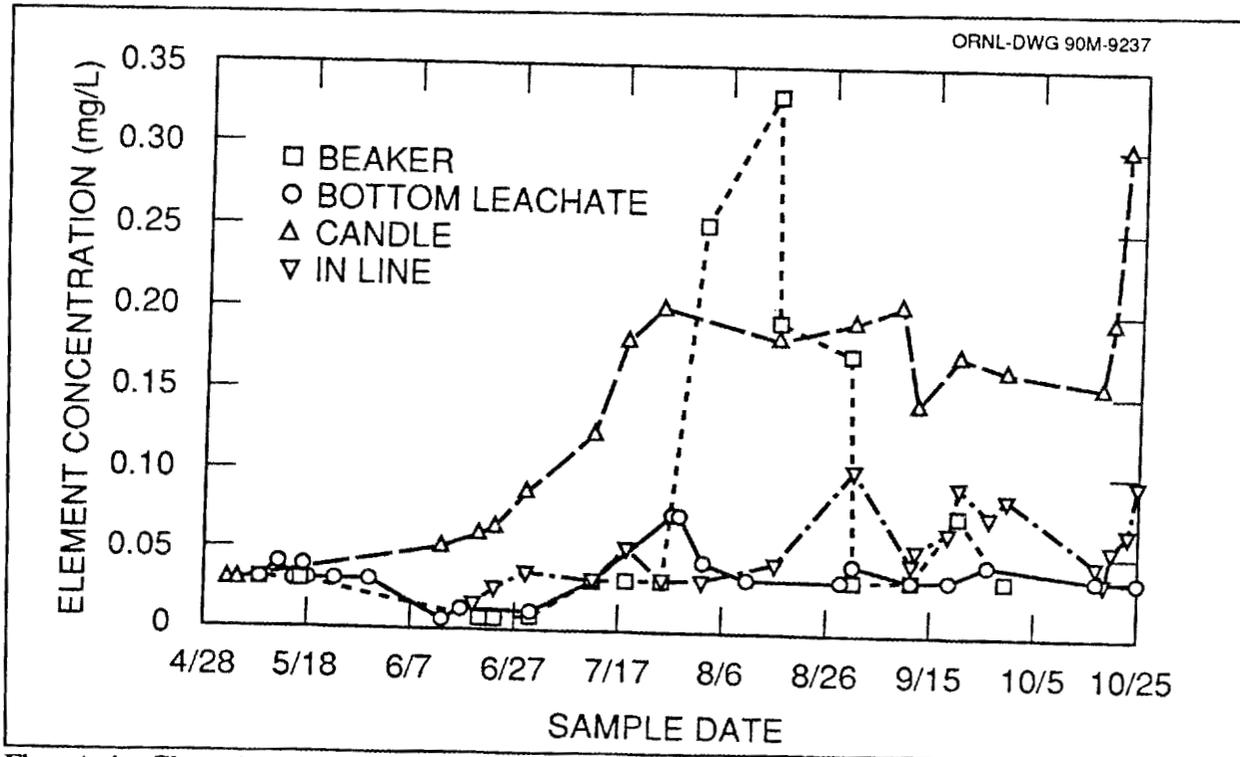


Fig. A.4. Chromium concentrations in leachate.

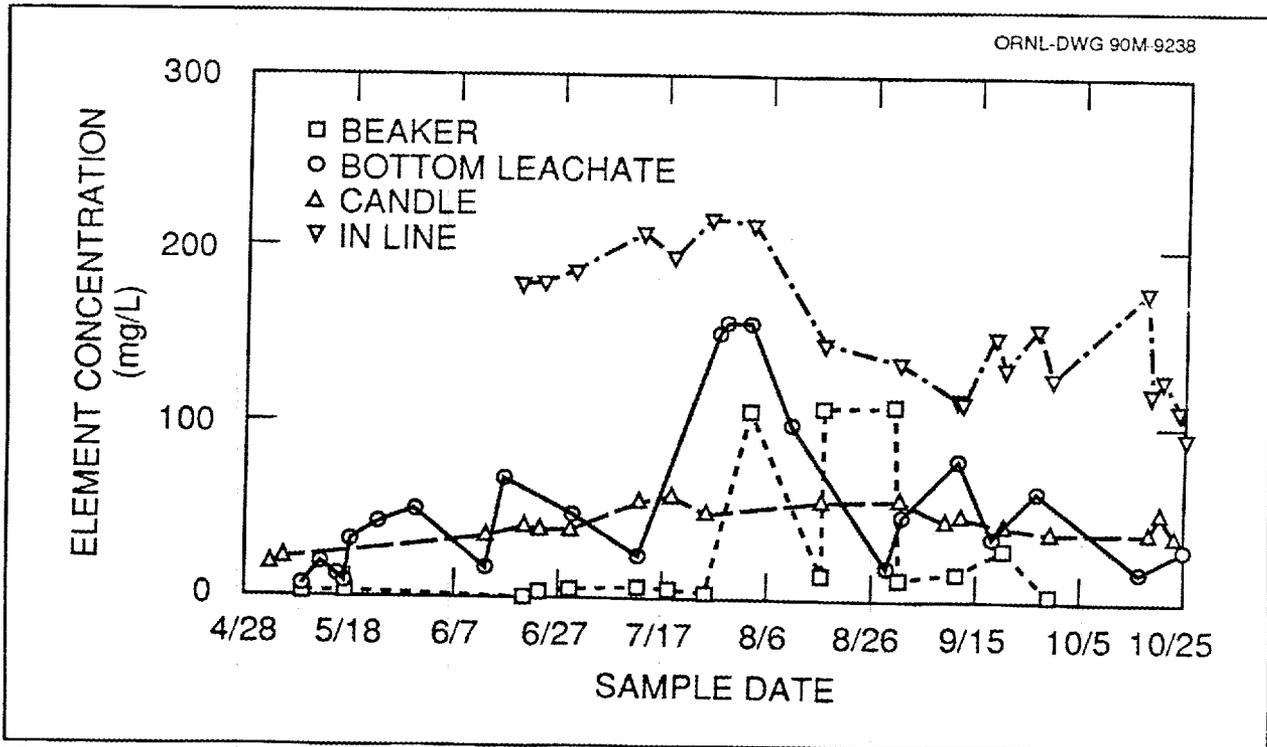


Fig. A.5. Iron concentrations in leachate.

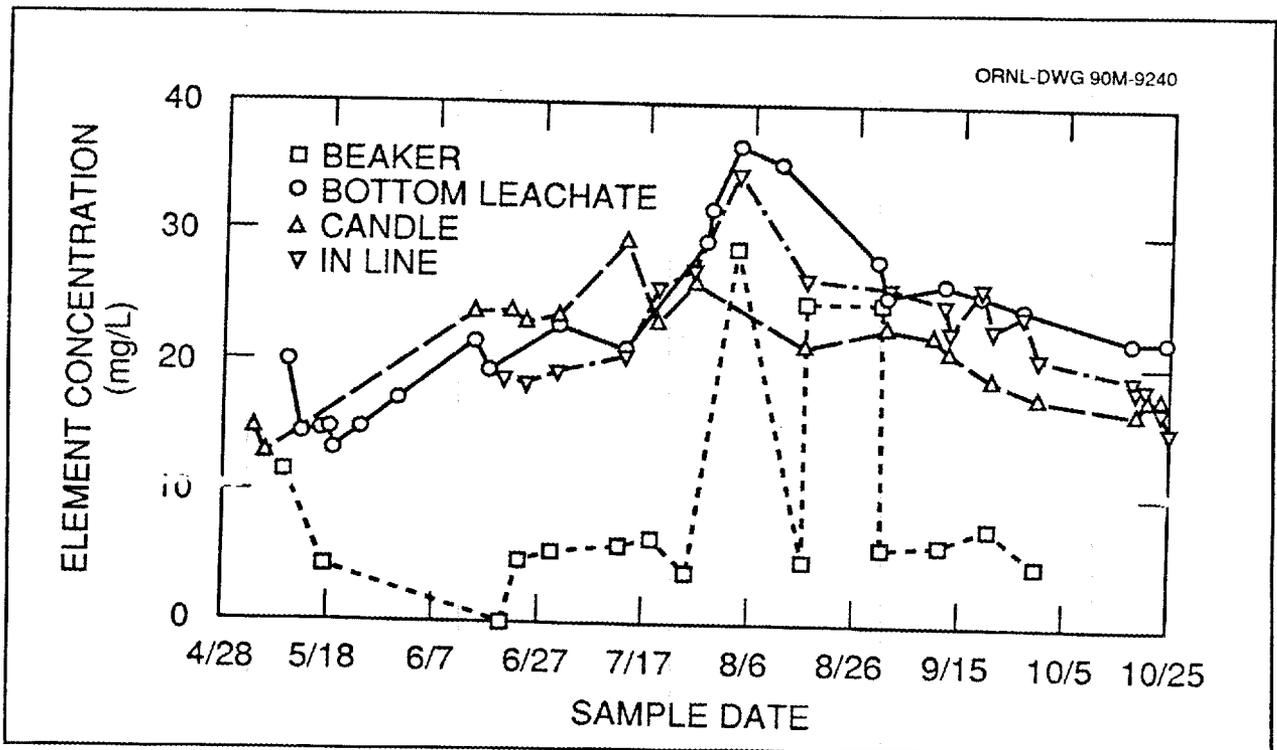


Fig. A.6. Magnesium concentrations in leachate.

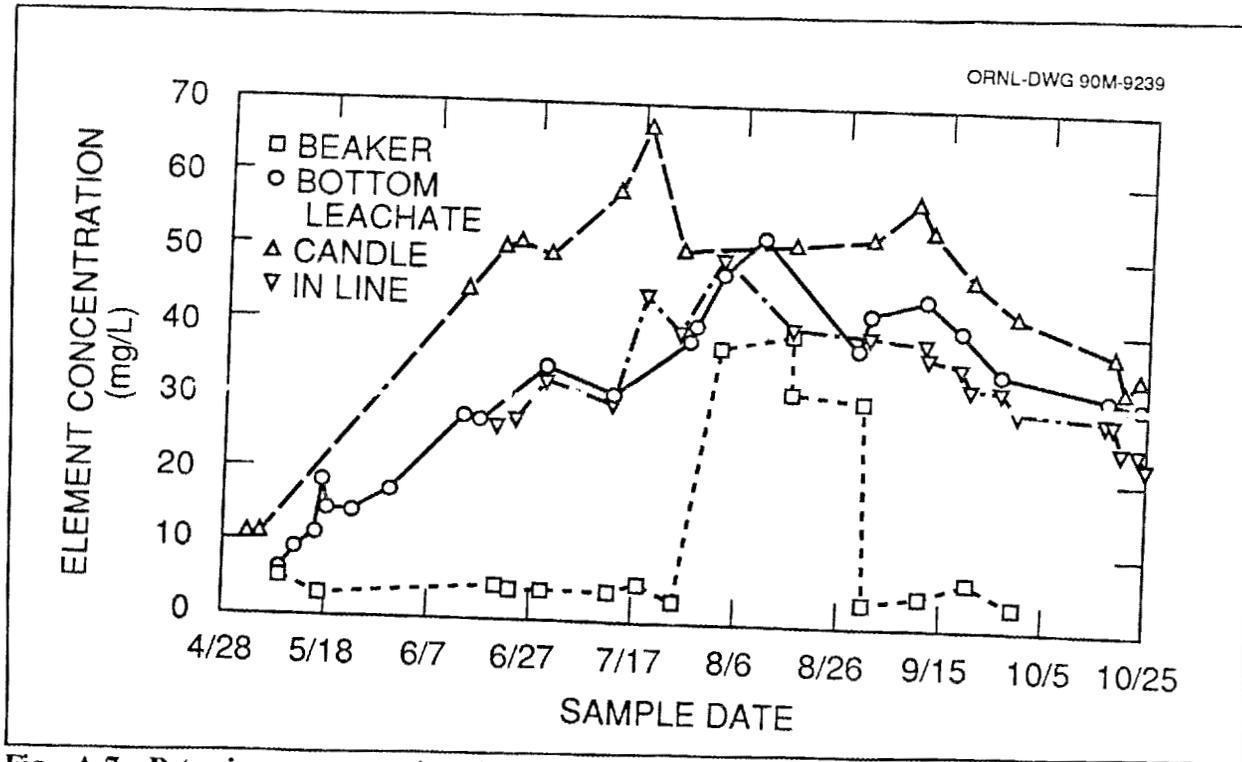


Fig. A.7. Potassium concentrations in leachate.

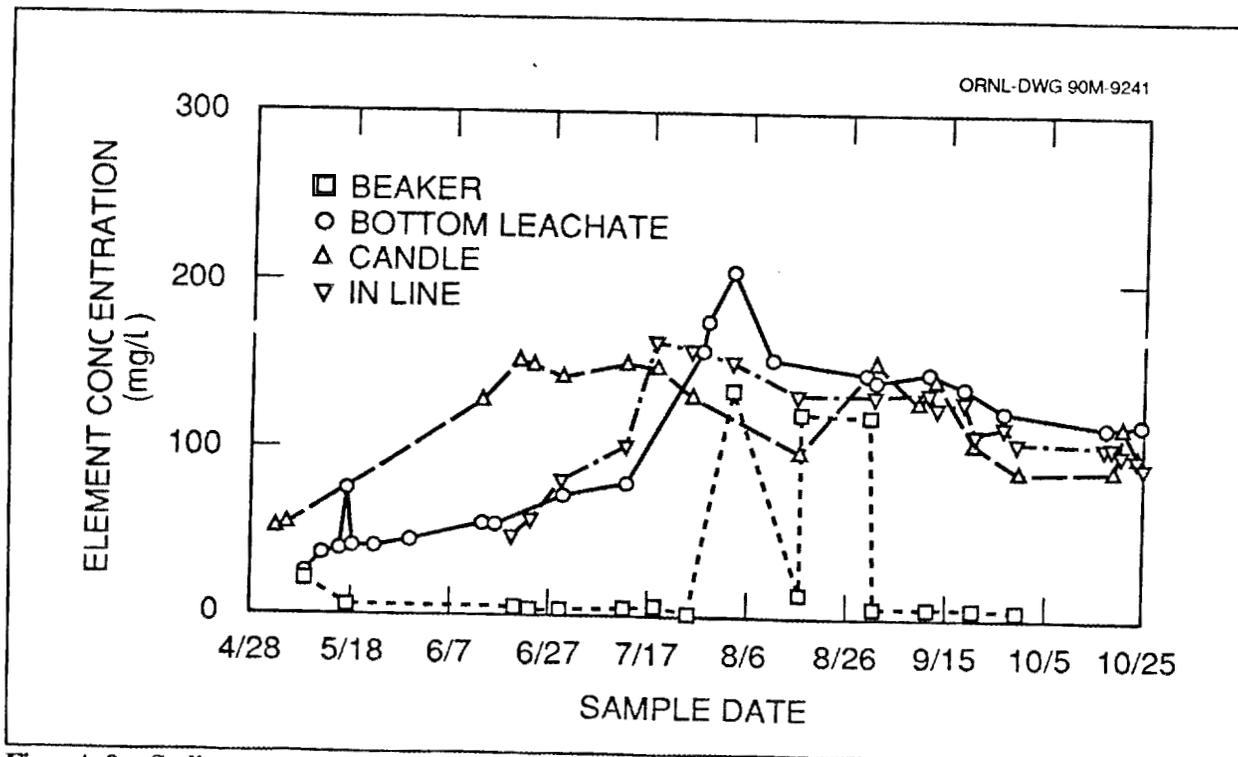


Fig. A.8. Sodium concentration in leachate.

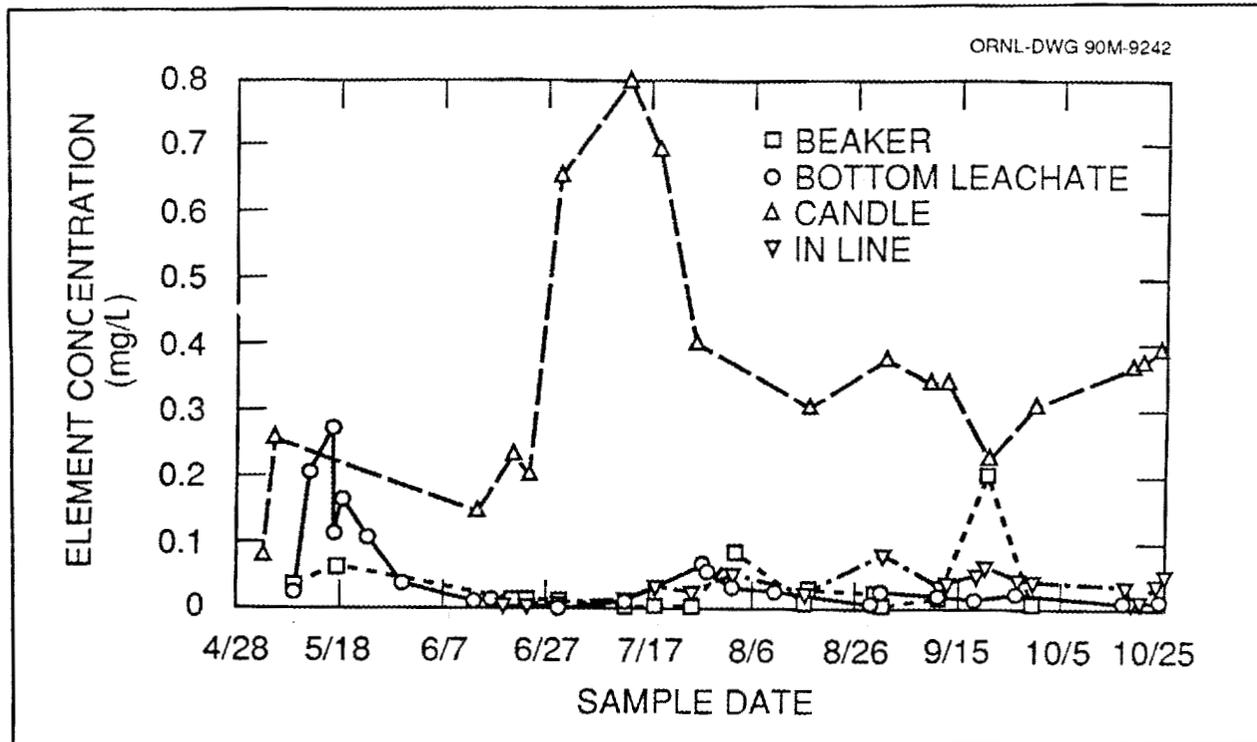


Fig. A.9. Uranium concentrations in leachate.

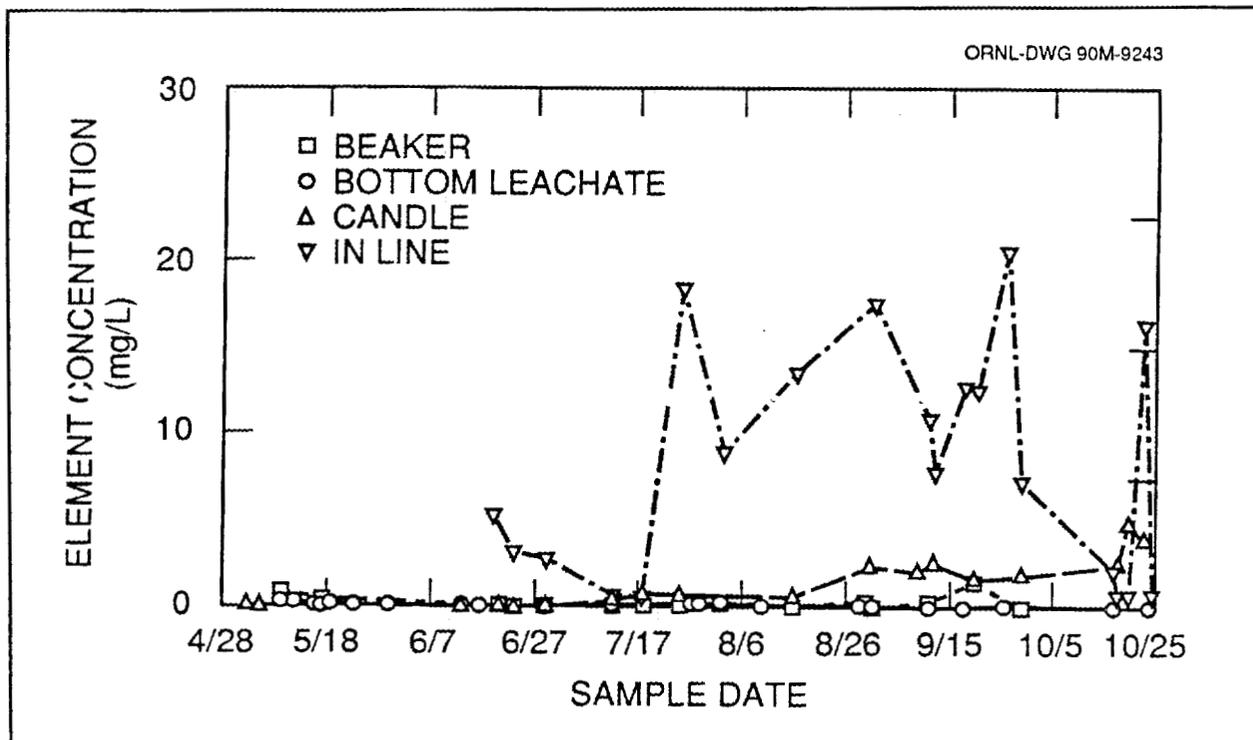


Fig. A.10. Zinc concentrations in leachate.

**APPENDIX B-1990 LEACHING STUDIES**

Table B.1  
 SUMMARY OF LEACHATE ANALYSES  
 1990 Y-12 PILOT LYSIMETER  
 (for only values above detection limits)

ANALYTE	SAMPLE TYPE	CONCENTRATION (MG/L)			
		MEAN	MIN	MAX	N
ALKAL	DRUM	400.0	360.0	470.0	3
	IN LINE	461.7	390.0	540.0	6
Ag	BEAKER	0.01	0.01	0.01	1
Al	BEAKER	11.55	5.45	23.50	3
	CANDLE	2.22	0.19	4.68	16
	DRUM	0.46	0.11	1.70	8
	IN LINE	0.24	0.16	0.40	7
	TRAY	1.08	1.08	1.08	1
	WATER BLANK	0.06	0.06	0.06	1
B	BEAKER	0.10	0.08	0.11	3
	CANDLE	2.04	0.51	4.86	16
	DRUM	1.45	1.23	1.90	8
	IN LINE	1.40	1.08	1.94	7
	TRAY	2.21	2.21	2.21	1
BOD	IN LINE	430.0	360.0	490.0	3
Ba	BEAKER	0.12	0.09	0.16	3
	CANDLE	0.42	0.05	1.56	16
	DRUM	0.23	0.10	0.32	8
	IN LINE	0.24	0.12	0.34	7
	TRAY	0.56	0.56	0.56	1

Table B.1 (continued)  
SUMMARY OF LEACHATE ANALYSES  
1990 Y-12 PILOT LYSIMETER

ANALYTE	SAMPLE TYPE	CONCENTRATION (MG/L)			
		MEAN	MIN	MAX	N
Ba	WATER BLANK	0.00	0.00	0.00	1
Be	BEAKER	0.00	0.00	0.00	1
	CANDLE	0.00	0.00	0.00	7
	DRUM	0.00	0.00	0.00	1
Br	IN LINE	0.53	0.27	0.78	2
COD	IN LINE	796.7	660.0	930.0	3
Ca	BEAKER	34.93	34.10	36.50	3
	CANDLE	101.3	55.10	262.0	16
	DRUM	134.9	102.0	188.0	8
	IN LINE	148.2	96.40	226.0	7
	TRAY	1080	1080	1080	1
Cd	DRUM	0.01	0.01	0.01	1
Ce	BEAKER	0.02	0.02	0.02	1
	DRUM	0.02	0.02	0.02	1
Cl	CANDLE	50.00	50.00	50.00	1
	DRUM	28.67	8.00	40.00	3
	IN LINE	49.17	6.00	150.0	6
Co	BEAKER	0.03	0.02	0.03	3
	CANDLE	0.08	0.02	0.31	16
	DRUM	0.02	0.01	0.03	8

Table B.1 (continued)  
SUMMARY OF LEACHATE ANALYSES  
1990 Y-12 PILOT LYSIMETER

ANALYTE	SAMPLE TYPE	CONCENTRATION (MG/L)			
		MEAN	MIN	MAX	N
Co	IN LINE	0.02	0.01	0.05	6
	TRAY	0.01	0.01	0.01	1
Cr	BEAKER	0.08	0.05	0.10	2
	CANDLE	0.15	0.04	0.30	15
	DRUM	0.03	0.02	0.06	6
	IN LINE	0.02	0.02	0.03	5
Cu	BEAKER	0.14	0.09	0.23	3
	WATER BLANK	0.20	0.20	0.20	1
DOC	IN LINE	180.0	180.0	180.0	1
F	CANDLE	3.20	1.90	4.50	2
	DRUM	0.41	0.41	0.41	1
	IN LINE	5.07	0.38	11.00	4
Fe	BEAKER	16.50	12.40	23.70	3
	CANDLE	43.41	18.30	72.60	16
	DRUM	95.79	49.40	175.0	8
	IN LINE	114.2	95.40	131.0	7
	TRAY	39.10	39.10	39.10	1
	WATER BLANK	0.23	0.23	0.23	1
K	BEAKER	6.10	5.00	8.30	3
	CANDLE	25.96	16.90	79.00	16

Table B.1 (continued)  
 SUMMARY OF LEACHATE ANALYSES  
 1990 Y-12 PILOT LYSIMETER

ANALYTE	SAMPLE TYPE	CONCENTRATION (MG/L)			
		MEAN	MIN	MAX	N
K	DRUM	23.01	17.30	30.00	8
	IN LINE	23.44	18.00	39.00	7
	TRAY	58.00	58.00	58.00	1
Li	BEAKER	0.03	0.02	0.04	3
	CANDLE	0.07	0.05	0.19	16
	DRUM	0.10	0.08	0.13	8
	IN LINE	0.10	0.08	0.11	7
	TRAY	0.05	0.05	0.05	1
Mg	BEAKER	6.57	5.90	7.62	3
	CANDLE	13.06	8.50	30.40	16
	DRUM	16.20	12.80	21.50	8
	IN LINE	17.19	12.10	27.00	7
	TRAY	39.50	39.50	39.50	1
	WATER BLANK	0.45	0.45	0.45	1
Mn	BEAKER	2.96	2.84	3.13	3
	CANDLE	2.41	1.43	4.27	16
	DRUM	2.00	1.21	3.01	8
	IN LINE	2.24	1.72	2.65	7
	TRAY	9.46	9.46	9.46	1
	WATER BLANK	0.02	0.02	0.02	1

Table B.1 (continued)  
SUMMARY OF LEACHATE ANALYSES  
1990 Y-12 PILOT LYSIMETER

ANALYTE	SAMPLE TYPE	CONCENTRATION (MG/L)			
		MEAN	MIN	MAX	N
Mo	BEAKER	0.02	0.02	0.02	1
	CANDLE	0.01	0.01	0.01	1
NO2	DRUM	0.20	0.20	0.20	1
	IN LINE	0.10	0.10	0.10	1
NO3	CANDLE	1.40	1.40	1.40	1
	DRUM	1.00	1.00	1.00	1
	IN LINE	0.27	0.10	0.44	2
Na	BEAKER	7.94	7.40	8.21	3
	CANDLE	47.74	30.70	83.20	16
	DRUM	67.06	51.30	94.10	8
	IN LINE	71.87	52.40	142.0	7
	TRAY	284.0	284.0	284.0	1
	WATER BLANK	0.04	0.04	0.04	1
Nb	DRUM	0.03	0.03	0.03	1
Ni	BEAKER	0.29	0.19	0.43	3
	CANDLE	0.18	0.11	0.49	16
	DRUM	0.05	0.04	0.07	8
	IN LINE	0.06	0.04	0.12	7
	TRAY	0.10	0.10	0.10	1
	WATER BLANK	0.01	0.01	0.01	1

Table B.1 (continued)  
SUMMARY OF LEACHATE ANALYSES  
1990 Y-12 PILOT LYSIMETER

ANALYTE	SAMPLE TYPE	CONCENTRATION (MG/L)			
		MEAN	MIN	MAX	N
O&G	DRUM	4.00	4.00	4.00	1
	IN LINE	4.00	4.00	4.00	1
P	BEAKER	0.90	0.90	0.90	1
	CANDLE	0.16	0.10	0.20	7
	DRUM	0.95	0.20	4.40	6
	IN LINE	0.27	0.10	0.70	4
PO4	IN LINE	0.16	0.16	0.16	1
Pb	BEAKER	0.12	0.10	0.15	3
Phenols	DRUM	0.11	0.11	0.11	1
	IN LINE	0.13	0.03	0.23	2
SO4	CANDLE	13000	13000	13000	1
	DRUM	7900	7300	8500	2
	IN LINE	1353	2.10	4500	4
	WATER BLANK	4.50	4.50	4.50	1
Sc	BEAKER	0.00	0.00	0.00	1
	CANDLE	0.00	0.00	0.00	9
	DRUM	0.00	0.00	0.00	5
	IN LINE	0.00	0.00	0.00	4
Sr	BEAKER	0.08	0.07	0.08	3
	CANDLE	0.25	0.12	0.70	16

Table B.1 (continued)  
 SUMMARY OF LEACHATE ANALYSES  
 1990 Y-12 PILOT LYSIMETER

		CONCENTRATION (MG/L)			
		MEAN	MIN	MAX	N
ANALYTE	SAMPLE TYPE				
Sr	DRUM	0.25	0.20	0.31	8
	IN LINE	0.26	0.20	0.36	7
	TRAY	1.24	1.24	1.24	1
	WATER BLANK	0.00	0.00	0.00	1
TOC	BEAKER	62.00	62.00	62.00	1
	CANDLE	683.3	640.0	710.0	3
	DRUM	182.5	170.0	200.0	4
	IN LINE	240.0	180.0	290.0	5
	TRAY	2600	2600	2600	1
Ti	BEAKER	0.21	0.12	0.30	3
	CANDLE	0.01	0.00	0.04	16
	DRUM	0.00	0.00	0.01	5
	IN LINE	0.01	0.00	0.02	5
	TRAY	0.04	0.04	0.04	1
U	BEAKER	0.06	0.02	0.10	9
	CANDLE	0.26	0.08	0.99	22
	DRUM	0.01	0.01	0.02	8
	IN LINE	0.02	0.01	0.04	7
	TRAY	0.11	0.04	0.17	3
	WATER BLANK	0.01	0.01	0.01	1

Table B.1 (continued)  
 SUMMARY OF LEACHATE ANALYSES  
 1990 Y-12 PILOT LYSIMETER

		CONCENTRATION (MG/L)			
		MEAN	MIN	MAX	N
ANALYTE	SAMPLE TYPE				
V	BEAKER	0.03	0.03	0.03	1
	CANDLE	0.03	0.01	0.16	11
	DRUM	0.01	0.01	0.03	6
	IN LINE	0.01	0.01	0.01	5
Zn	BEAKER	1.44	0.65	1.99	3
	CANDLE	0.50	0.03	3.27	16
	DRUM	0.47	0.05	1.12	8
	IN LINE	0.77	0.25	1.46	7
	TRAY	0.02	0.02	0.02	1
	WATER BLANK	0.10	0.10	0.10	1
Zr	BEAKER	0.01	0.01	0.01	2
	CANDLE	0.02	0.00	0.13	11
	DRUM	0.95	0.25	1.66	2
	IN LINE	0.26	0.13	0.39	2

Table B.2  
FIELD MEASUREMENTS ON BOTTOM LEACHATE

SAMPLE DATE	TEMPERATURE (CELSIUS)	pH	DISSOLVED OXYGEN (MG/L)	CONDUCTIVITY (MMHO/CM)	OXYGEN REDUCTION POTENTIAL (VOLTS)
02MAY90	22.52	6.18	1.75	0.53	0.33
03MAY90	24.51	6.19	0.22	0.57	0.34
04MAY90	20.91	5.17	0.11	0.59	0.45
08MAY90	21.54	5.23	0.08	0.57	0.39
09MAY90	17.34	4.35	0.10	0.48	0.44
11MAY90	13.57	4.72	0.17	0.52	0.41
14MAY90	26.30	4.91	0.09	0.41	0.44
15MAY90	27.40	5.23	0.06	0.42	0.38
18MAY90	21.51	6.53	0.08	0.51	0.37
21MAY90	25.16	3.47	0.14	0.53	0.44
23MAY90	20.34	5.23	0.09	0.60	0.25
25MAY90	23.63	6.62	0.05	0.48	0.28
29MAY90	22.88	4.99	0.05	0.45	0.42
30MAY90	21.16	4.59	0.14	0.48	0.42
01JUN90	22.69	5.35	0.08	0.51	0.42
06JUN90	27.31	4.04	0.04	0.53	0.28
07JUN90	22.63	4.22	0.30	0.55	0.28
08JUN90	27.90	4.28	0.06	0.50	0.39
12JUN90	27.21	5.02	0.06	0.51	0.44
13JUN90	26.16	3.83	0.11	0.03	0.47
15JUN90	27.67	3.88	0.08	0.14	0.38
03JUL90	27.85	4.27	0.06	0.62	0.27
06JUL90	28.20	4.94	0.06	0.51	0.31
10JUL90	30.98	4.50	0.03	0.62	0.23
13JUL90	22.33	4.98	0.11	0.21	0.29
25JUL90	29.66	5.27	0.03	0.71	0.07
27JUL90	27.98	4.85	0.06	0.17	0.08
01AUG90	27.76	4.70	0.92	0.67	0.12

Table B.3  
 Summary of Detection Limits  
 for Toxic Metals in the Primary Drinking Water Standards (PDWS)

	TOTAL ANALYSES	BELOW DETECTION	DETECTION LIMIT (MG/L)		
	N	N	MEAN	MIN	MAX
TOXIC METAL					
Ag	35	34	0.011	0.004	0.020
As	35	35	0.105	0.040	0.200
Ba	35	0	.	.	.
Cd	35	34	0.010	0.003	0.020
Cr	35	7	0.030	0.030	0.030
Pb	35	32	0.051	0.020	0.100

Table B.4  
 Summary of Occasions the Leachate Quality  
 Exceeded Primary Drinking Water Standards (PDWS)

			CONCENTRATION (MG/L)			
			MEAN	MIN	MAX	N
TOXIC METAL	SAMPLE TYPE	PDWS (MG/L)				
Ba	CANDLE	1.00	1.440	1.320	1.560	2
Cr	BEAKER	0.05	0.076	0.050	0.101	2
	CANDLE	0.05	0.155	0.080	0.300	14
	DRUM	0.05	0.057	0.057	0.057	1
Pb	BEAKER	0.05	0.117	0.100	0.150	3

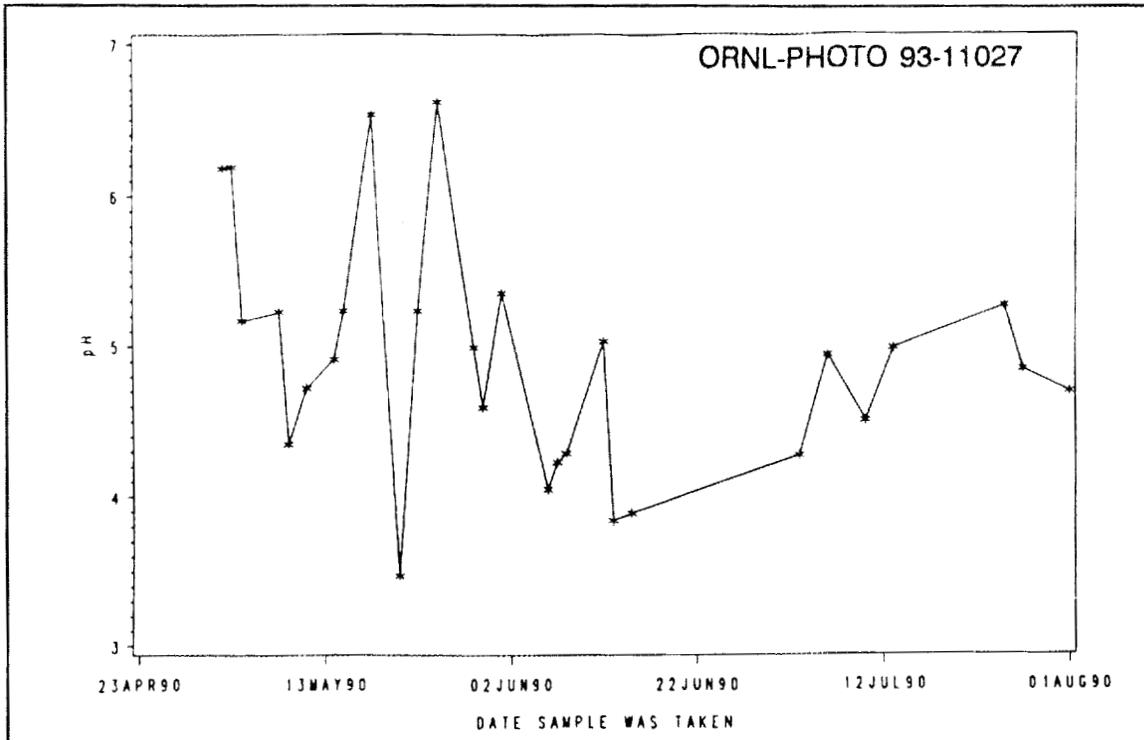


Fig. B.1. Changes in pH of bottom leachate (field measurements from a flow-through cell).

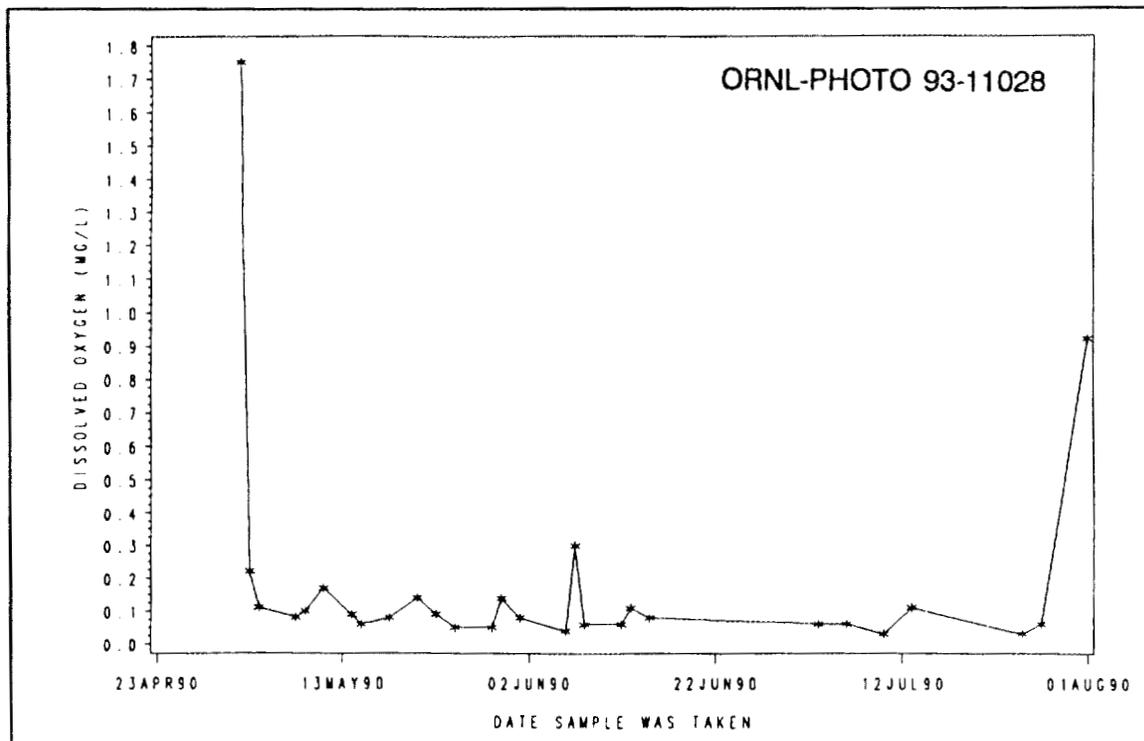


Fig. B.2. Changes in dissolved oxygen (DO) of bottom leachate (field measurements from a flow-through cell).

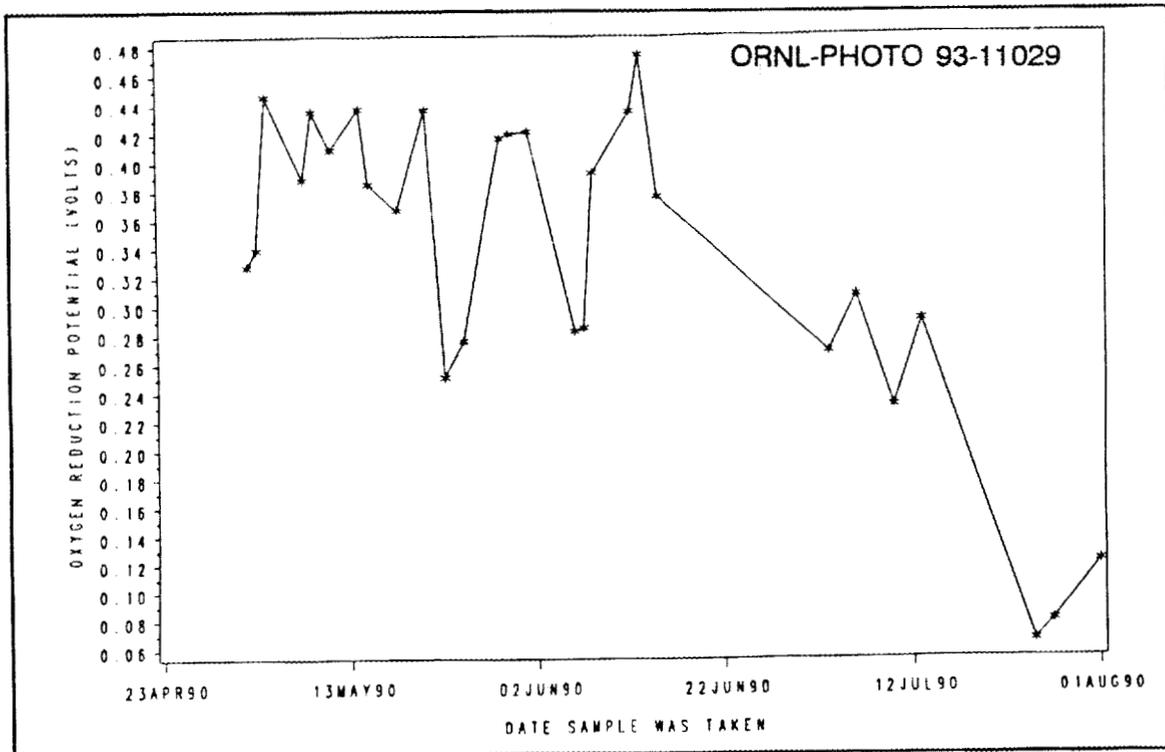


Fig. B.3. Changes in oxygen reduction potential of bottom leachate (field measurements from a flow-through cell).

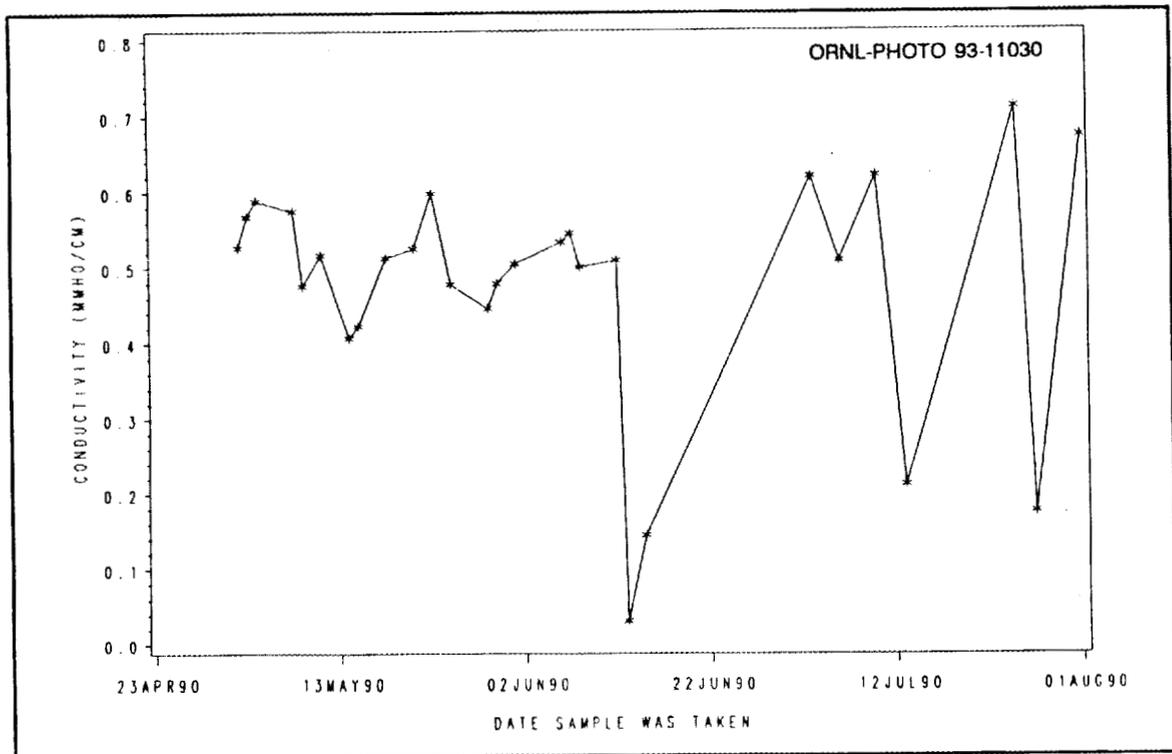


Fig. B.4. Changes in conductivity of bottom leachate (field measurements from a flow-through cell).

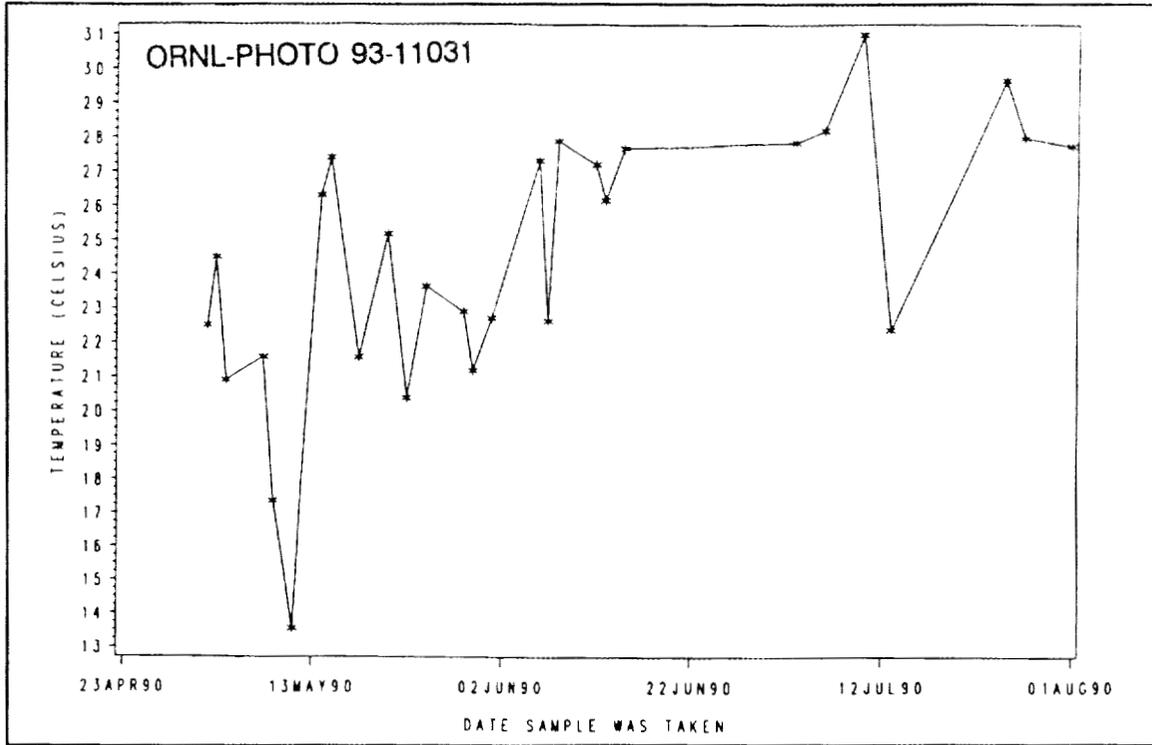


Fig. B.5. Changes in temperature of bottom leachate (field measurements from a flow-through cell).

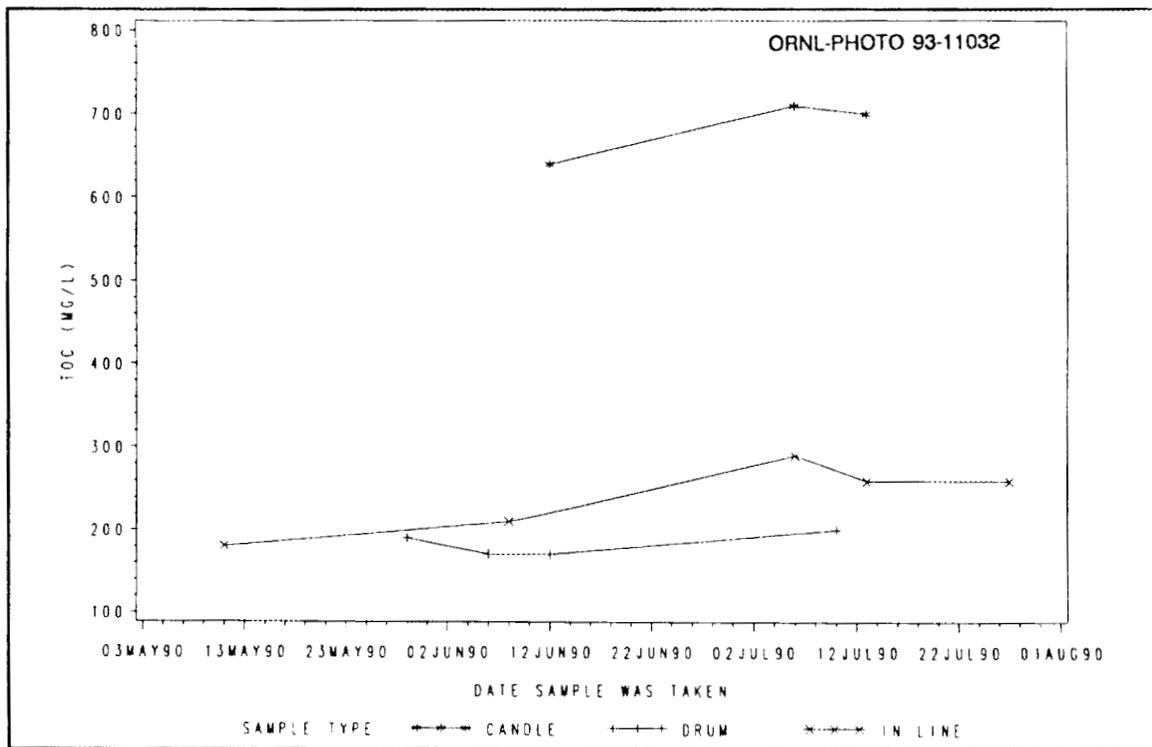


Fig. B.6. Comparison of total organic carbon (TOC) in leachate sampled from several leachate collection devices.

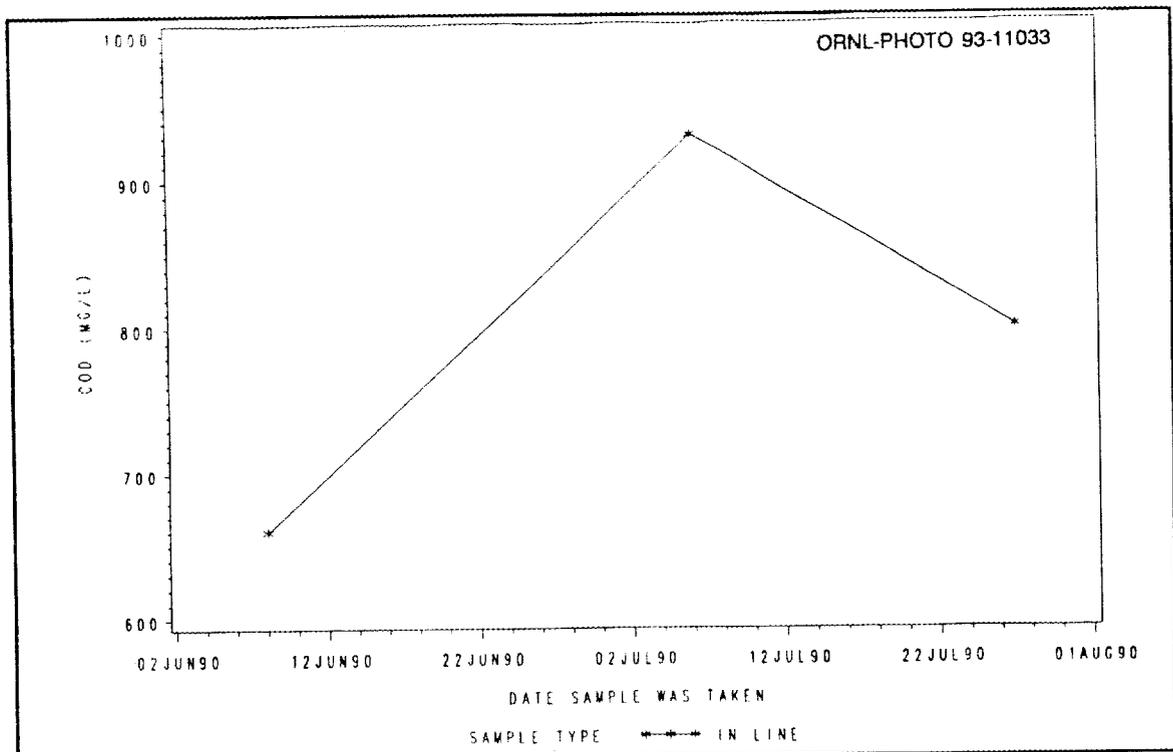


Fig. B.7. Chemical oxygen demand (COD) of bottom leachate over time.

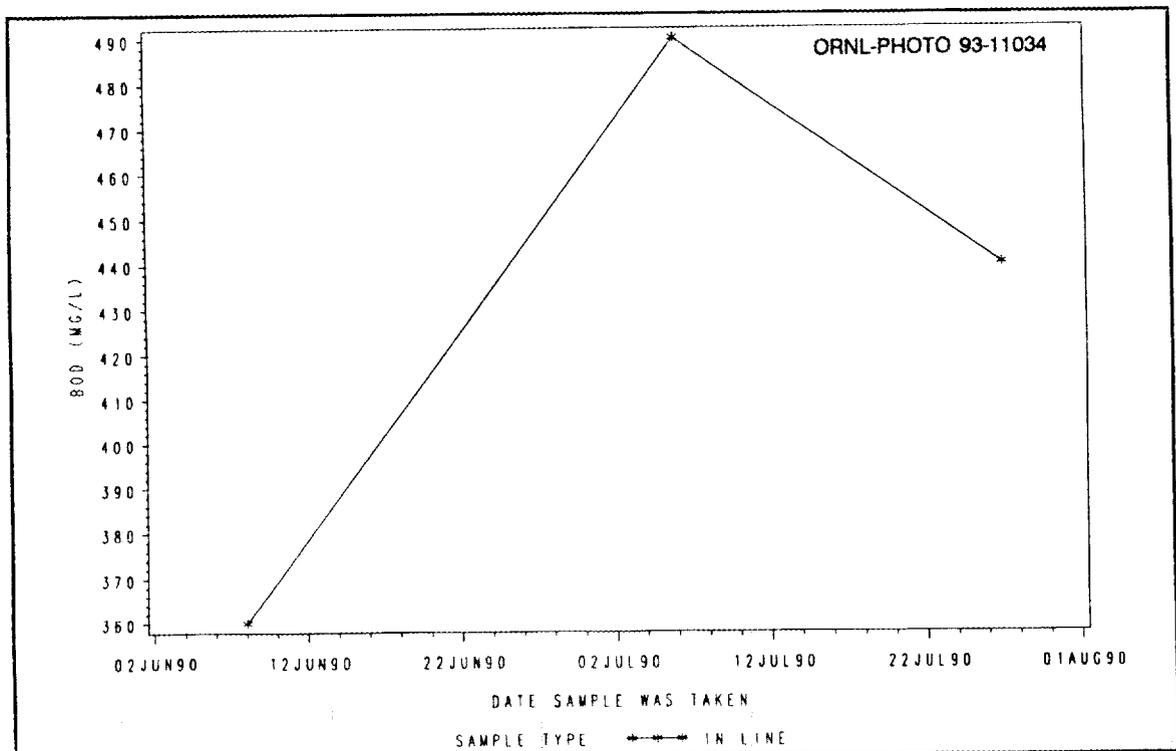


Fig. B.8. Biological oxygen demand (BOD) of bottom leachate over time.

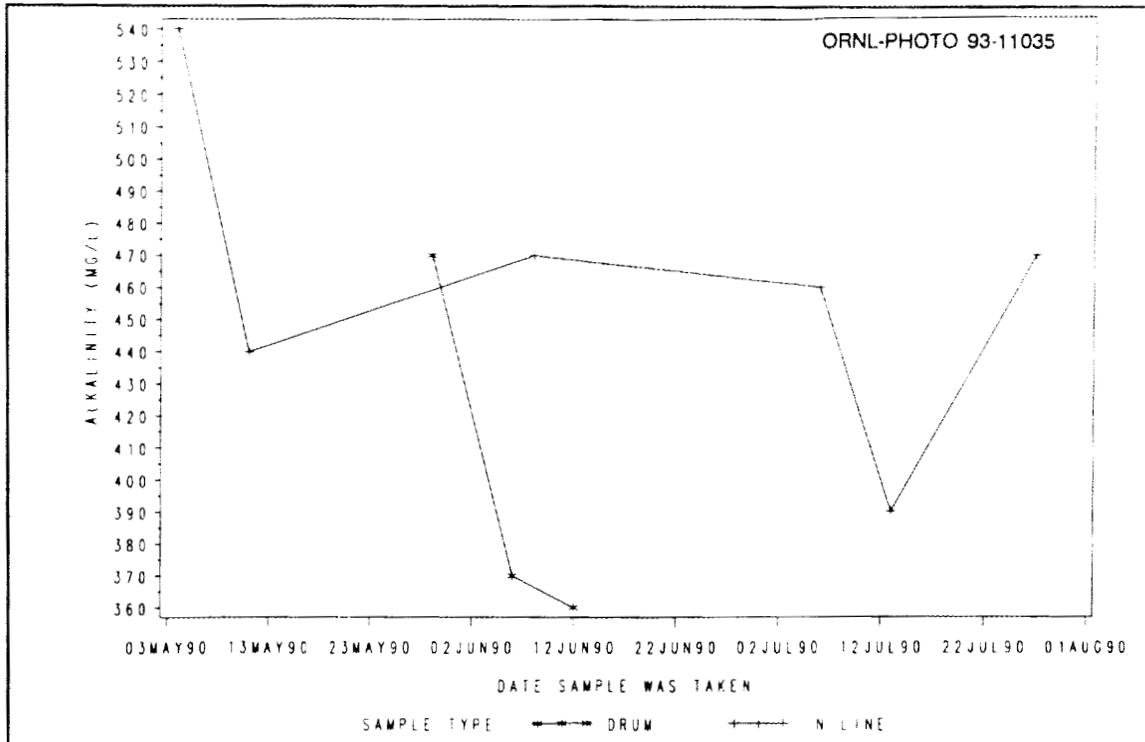


Fig. B.9. Comparison of alkalinity of bottom leachate sampled under anoxic (in line) and oxic (drum) conditions.

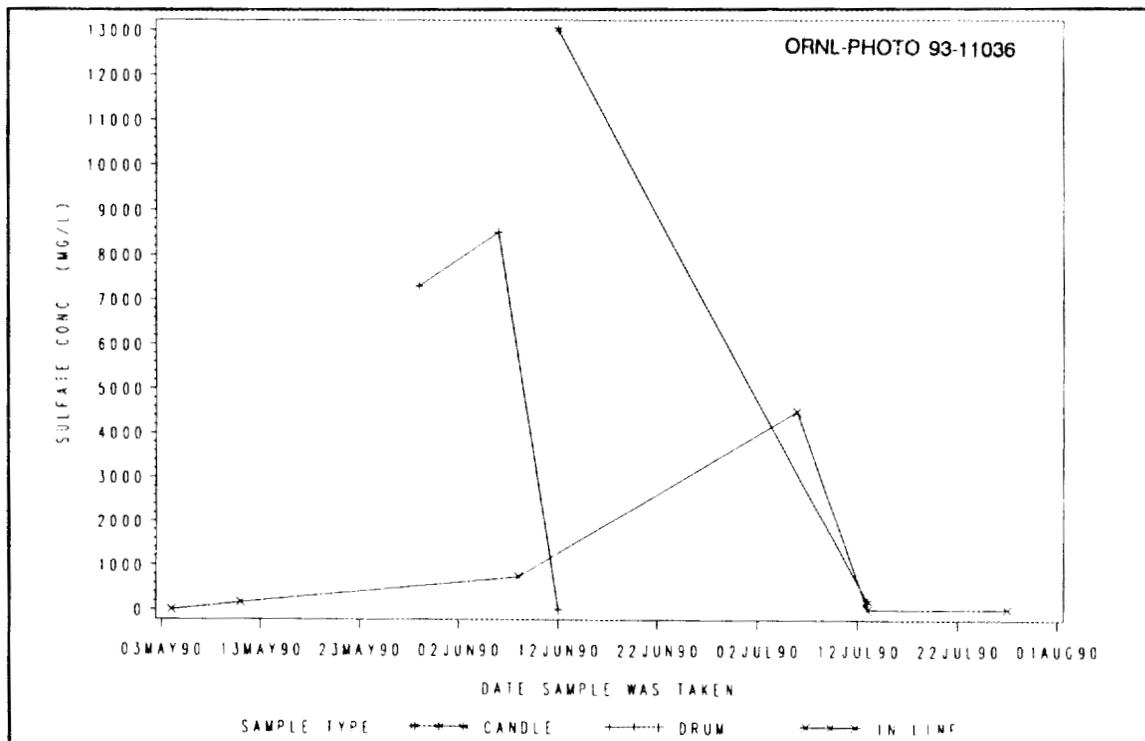


Fig. B.10. Sulfate concentrations in leachate sampled from several leachate collection devices.

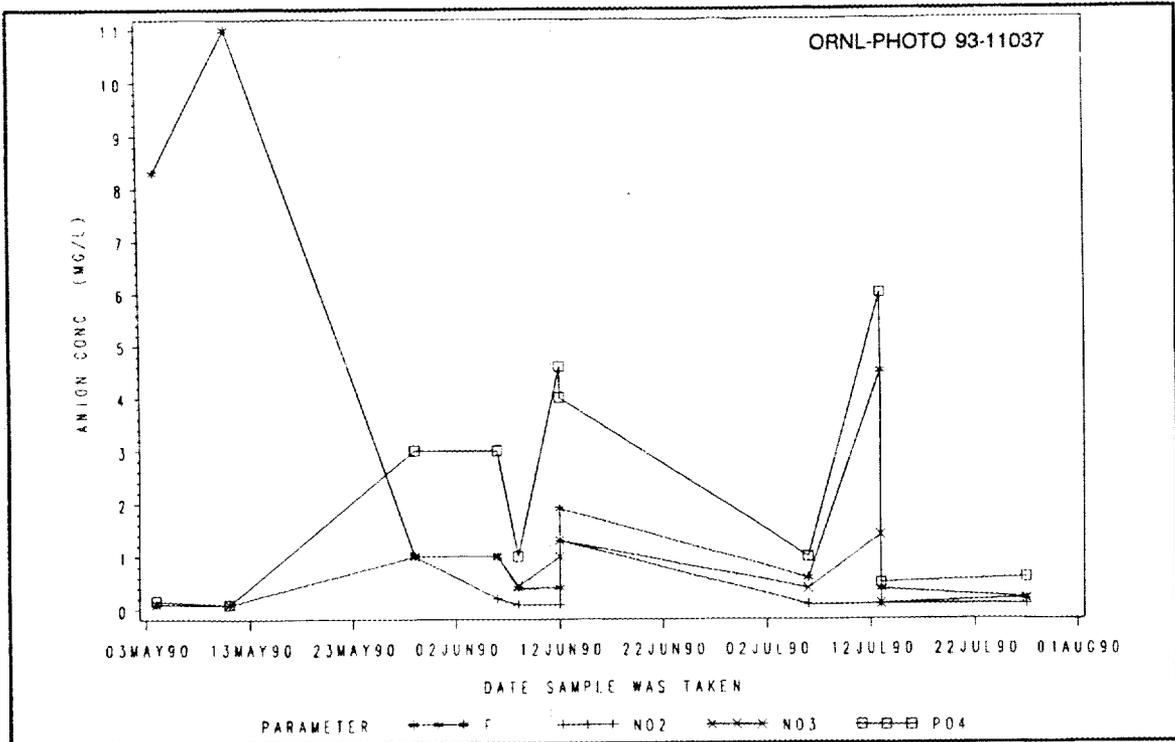


Fig. B.11. Anion concentrations in leachate.

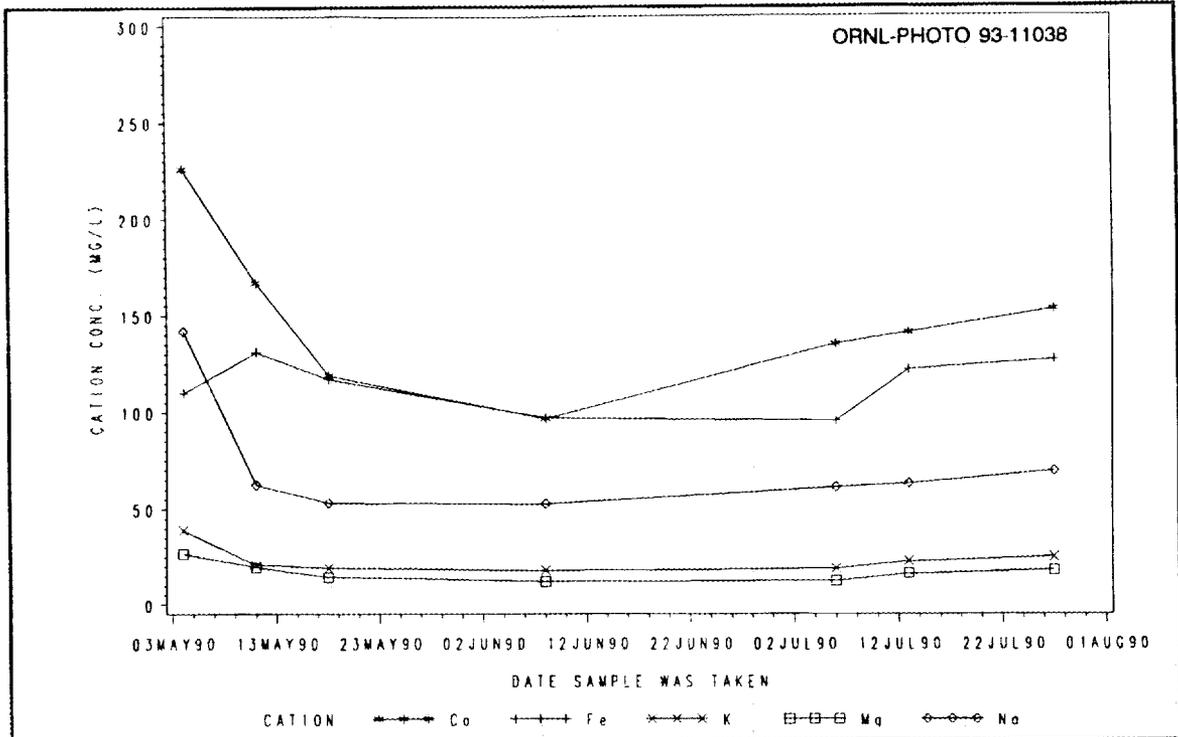


Fig. B.12. Concentrations of selected cations in bottom leachate.

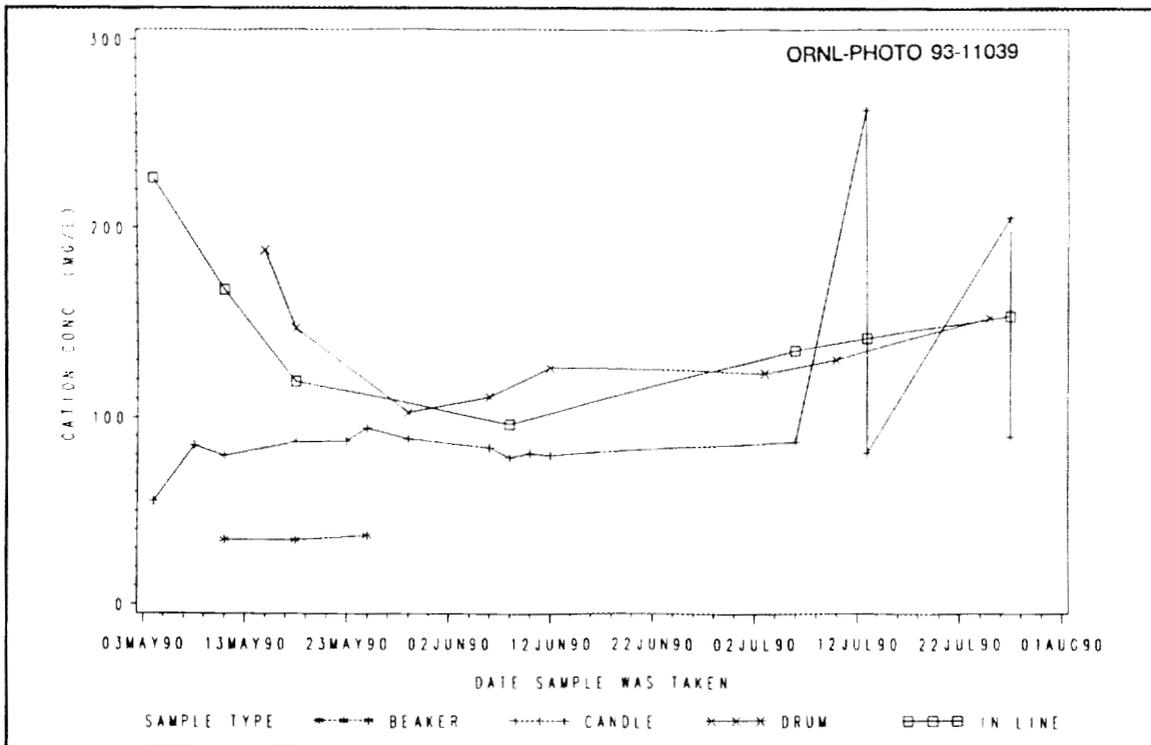


Fig. B.13. Calcium concentrations in leachate sampled from several leachate collection devices.

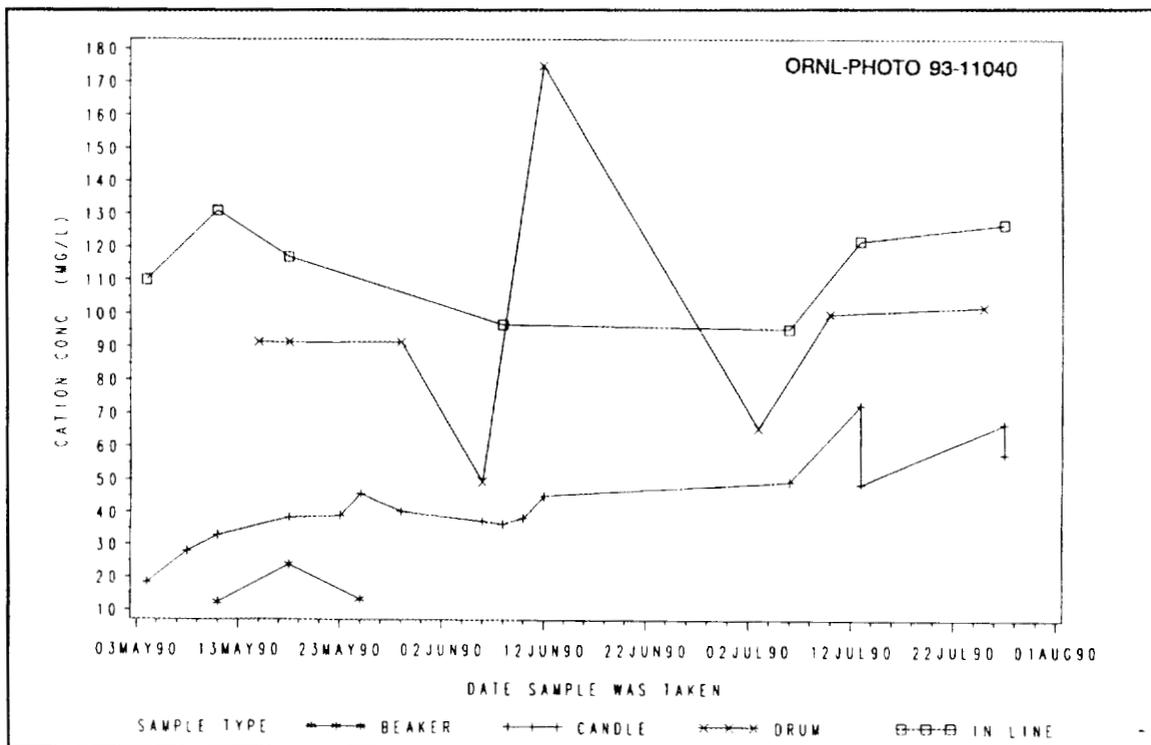


Fig. B.14. Iron concentrations in leachate sampled from several leachate collection devices.

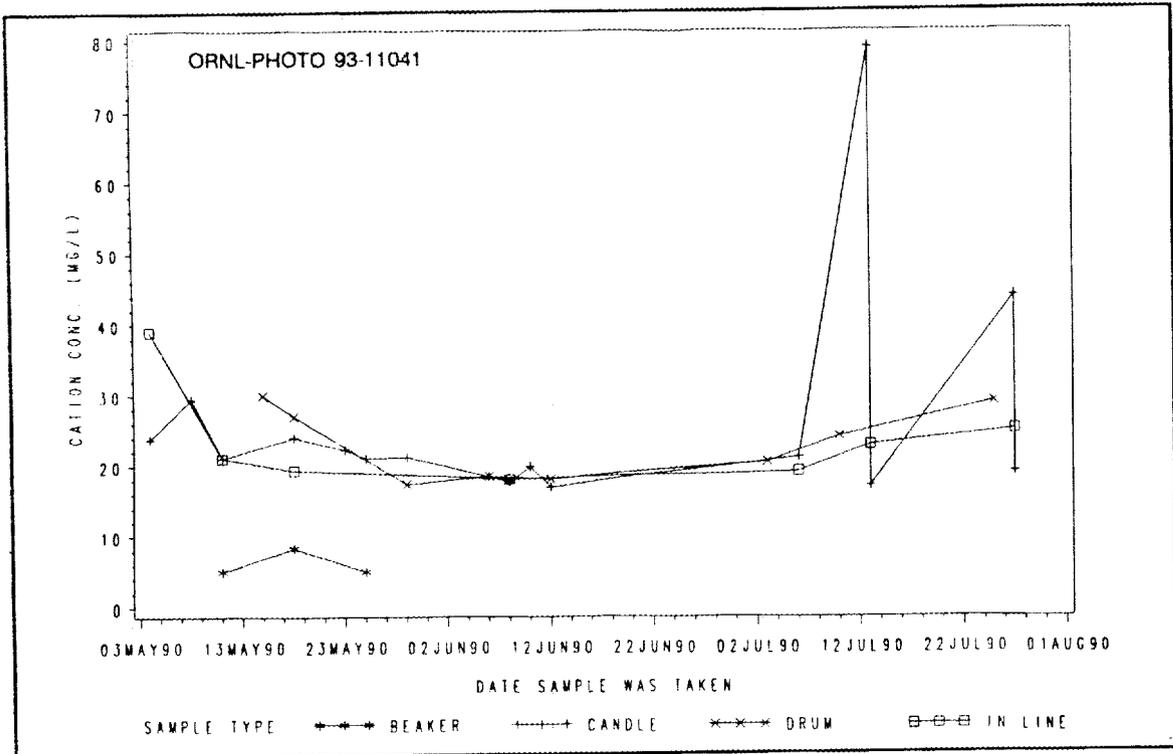


Fig. B.15. Potassium concentrations in leachate sampled from several leachate collection devices.

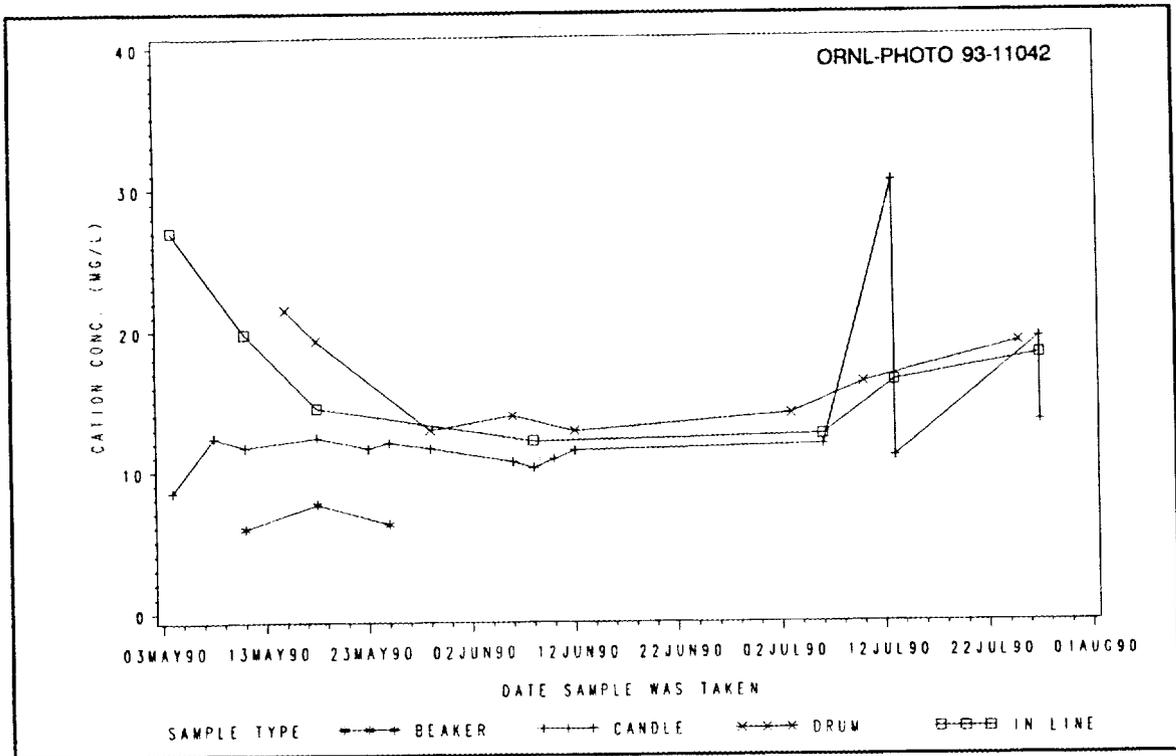
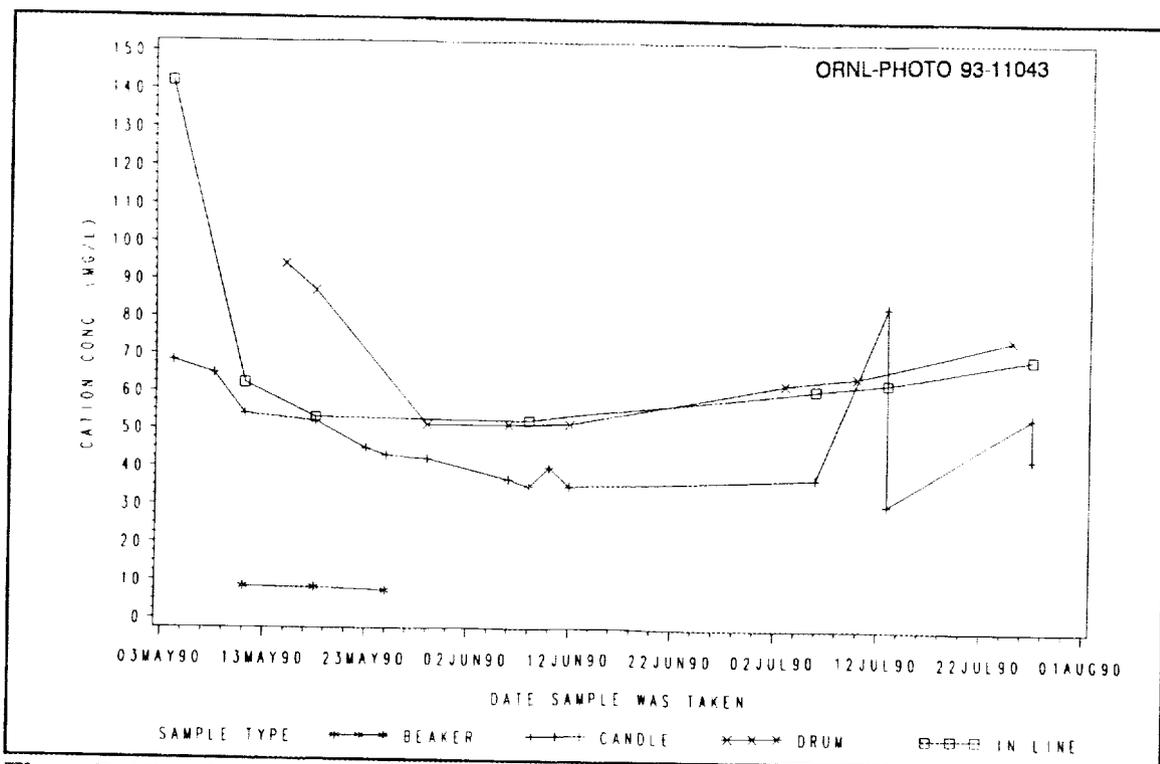


Fig. B.16. Magnesium concentrations in leachate sampled from several leachate collection devices.



**Fig. B.17. Sodium concentrations in leachate sampled from several leachate collection devices.**

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53. S. J. Phillips, Environmental Technology Group, Westinghouse Hanford Group, Post Office Box 1970, Richland, Washington 99352
54. A. Patrinos, Director, Environmental Sciences Division, Office of Health and Environmental Research, ER-74, U.S. Department of Energy, Washington, DC 20585
55. Phillip Reed, USNRC, Office of Nuclear Regulatory Research, MS-260NLS, Washington, D. C. 2005
56. S. Sunder, Research Chemistry, AECL Research, Whiteshell Laboratories, Pinawa Manitoba, Canada ROE 1L0
57. F. J. Wobber, Environmental Sciences Division, Office of Health and Environmental Research, ER-74, U. S. Department of Energy, Washington, DC 20585

- 58. Office of Assistant Manager for Energy Research and Development, U. S. Department of Energy, Oak Ridge Operations, P.O. Box 2001, Oak Ridge, TN 37831-8600
- 59-60. Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge TN 37831.