SUBSURFACE INVESTIGATIONS AT THE RADIOACTIVE WASTE MANAGEMENT COMPLEX OF THE IDAHO NATIONAL ENGINEERING LABORATORY

Brent F. Russell
Joel M. Hubbell
Tom G. Humphrey
Idaho National Engineering Laboratory
Idaho Falls, Idaho 83415

ABSTRACT

The Subsurface Investigation Program is a part of a continuing effort at the Radioactive Waste Management Complex (RWMC) of the Idaho National Engineering Laboratory (INEL) to identify potential pathways and mechanisms for waste radionuclides to migrate through the unsaturated and saturated zones, and eventually to man. The objectives of this program are to: (1) develop a field calibrated computer model to predict the long-term migration of radionuclides in the unsaturated zone, and (2) measure the actual migration of radionuclides to date, in order to determine whether there is a problem from a public health and safety standpoint. Four methods for the collection of data in support of these objectives and several specific studies have been initiated. Two years of field data has been collected and techniques refined. Installation of instrumentation and contamination control techniques have been thoroughly tested and demonstrated to be effective. Specific methods and studies are presented including a discussion of the contamination-control measures and a variety of unsaturated zone instrumentation employed for the study.

INTRODUCTION

The Subsurface Investigation Program is part of a continuing effort at the Radioactive Waste Management Complex (RWMC) of the Idaho National Engineering Laboratory (INEL) to identify potential pathways and mechanisms for waste radionuclides to migrate through the subsurface environment and eventually present a potential hazard to man. Four methods for the collection of data and 15 specific studies will be employed to accomplish this objective and are presented in A Plan for Studies of Subsurface Radionuclide Migration at the Radioactive Waste Management Complex of the Idaho National Engineering Laboratory (1).

The unsaturated zone encompasses all geologic materials between the ground surface and the water table of the Snake River Plain Aquifer (∿180 m). Included are relatively thin sedimentary units at the surface and at depths of about 34 and 73 m. Also included in the unsaturated zone are the basalt flows which compose most of the geologic sequence.

Four methods for the collection of data in support of the investigations have been employed since initiation of the field work during the summer of FY-1985. The four methods involved are: 1) Shallow Drilling, 2) Deep Drilling, 3) Test Trench, and 4) Weighing Lysimeter. Four specific studies, Solution Chemistry, Net Downward Water Flux, Computer Model Development, and Radiochemical Analysis, were continued or initiated in FY-1986.

This paper provides a technical review of the work performed in support of the Subsurface Investigations Program. The work reported was performed by professionals from the INEL and the U.S. Geological Survey (USGS) INEL Project Office. All work was per-formed under the direction of the U.S. Department of Energy, Idaho Operations Office.

RATIONALE AND STATEMENT OF OBJECTIVES

The RWMC was established near the southwestern corner of the INEL in 1952 as a controlled area for the management of solid radioactive waste. The RWMC encompasses an area of 58 hectares with the buried waste contained in the 36-hectare Subsurface Disposal Area (SDA).

The radioactive waste buried at the RWMC is a potential hazard to the environment if its confinement is not maintained. Some radionuclides in the waste are long-lived, so there is a potential of their long-term migration.

The concern for subsurface migration of radionuclides is of particular interest for an eventual Department of Energy (DOE) decision regarding possible retrieval of buried transuranic waste from the RWMC. Evidence of migration could be used to argue for retrieval of approximately 57000 m^3 of waste. Conversely, the lack of such evidence could support arguments for leaving the waste in place. Therefore two overall program objectives were established by DOE. These objectives are:

- Field calibrate a model to predict long-term migration of radionuclides in the unsaturated zone. Achieving this objective will require measuring hydrologic transport properties, accounting for radionuclide behavior and radioactive decay, obtaining or developing a computer program for the model, and field-calibrating the model.
- Measure the actual migration of radionuclides to date, in order to determine whether there is a problem from a public health and safety standpoint. Achieving this objective will require collection, preparation, and analysis of geologic

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samples from the unsaturated zone. Strict contamination control methods will be followed to ensure the integrity of the analytical results.

BRIEF HISTORY OF PROGRAM

Studies of possible subsurface migration of radionuclides at the RWMC began in 1960. Until initiation of the Subsurface Investigation Program in 1985, the most recent study was conducted in 1979. These earlier studies are reported in documents authored by Schmalz (2), Barraclough (3), Burgus and Maestas (4), Humphrey and Tingey (5), and Humphrey (6). The results obtained from these previous efforts have provided useful but inconclusive evidence regarding potential migration of radionuclides. The techniques employed in several cases were susceptible to possible cross-contamination during sample collection or handling processes. Also, data required to model radionuclide transport through the subsurface environment have not been collected.

Therefore, DOE requested scientists at the INEL and the USGS INEL Project Office to prepare a comprehensive plan. Specifically, the plan must provide data to determine the extent of subsurface radionuclide migration, if any, and to collect data to develop and field calibrate a computer model to help project the long-term migration of radionuclides.

The planning effort for the current program was initiated in FY-1982 and completed early in FY-1984. The plan integrates data requirements from a variety of technical disciplines to address the program objectives. Specific hydrogeologic and geochemical data requirements were established to field-calibrate a subsurface transport model to predict long-term migration. These data requirements were used to design field and laboratory studies to collect the necessary data.

The activities and studies were then integrated into an overall program and subjected to a comprehensive external peer review. Details of the review are presented in the 1983 DOE report. The plan was approved in early FY-1984. The remainder of FY-1984 was spent preparing the shallow drilling procedures. These drilling procedures are designed to eliminate/minimize the potential for cross-contamination. The procedures were subjected to a peer review and finalized after a period of nearly 12 months. The procedures represent a state-of-the-art approach to drilling and sampling in a contaminated environment. Activities conducted through FY-1986 and the available results are presented in the subsequent discussion beginning with the data collection methods and concluding with the specific studies (7,8).

METHODS

The Subsurface Investigation Program relies on four methods (or activities) to provide for the collection of data to support the individual specific studies. This paper will highlight the shallow and deep drilling methods.

Shallow Drilling

The objectives of the shallow drilling activity are to define geologic and hydrologic characteristics of the surficial sediments and to delineate spatial variability of radionuclide contamination within the SDA surficial sediments. The shallow drilling activity consists of drilling and sampling surficial sediments in and around the SDA. Hollow stem auger holes are drilled from land surface to the uppermost basalt unit. These holes range in depth from 0 to approximately 6 m. Continuous split-spoon samples are collected during drilling; contamination control procedures are strictly followed to prevent cross-contamination of these samples. These samples are analyzed

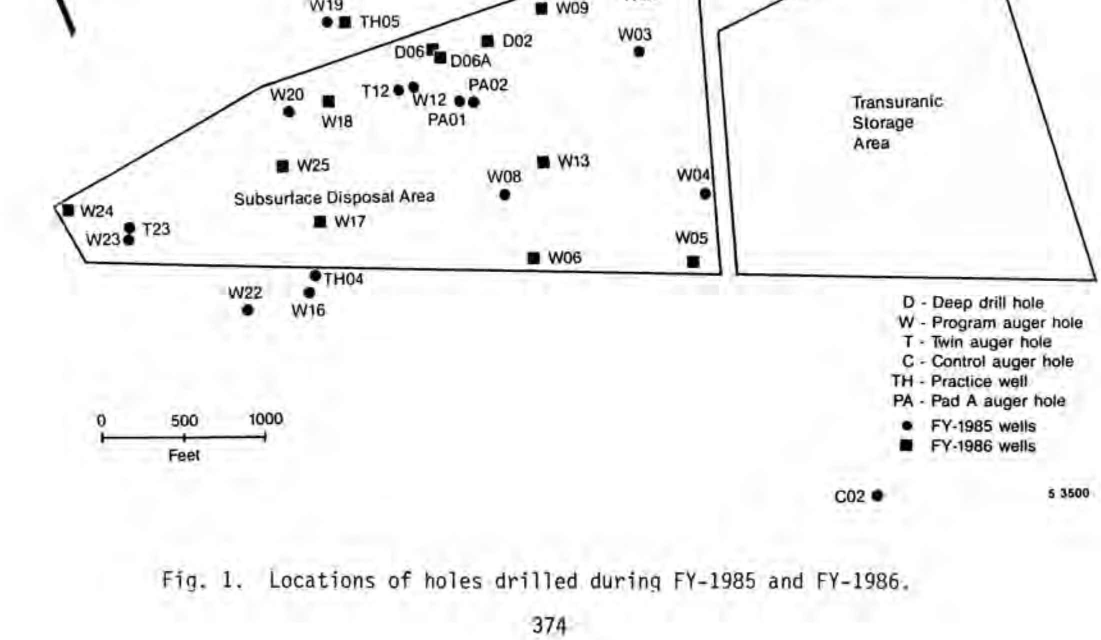

Fig. 1. Locations of holes drilled during FY-1985 and FY-1986.

for selected radionuclides. Thin wall tube samplers (Shelby tubes) are also used periodically to collect soil samples for permeability and dispersivity tests. Soil moisture monitoring and collection equipment is installed in these auger holes as they are backfilled.

A total of 32 shallow holes have been drilled since initiation of the field work in 1985. Each of the auger holes were backfilled with native materials and unsaturated zone monitoring instrumentation at various depths (see discussion on net downward flux for the instrumentation of the borehole). Nearly 100% core recovery was attained using the augering and samp ling methodology. Figure 1 provides an illustration of the shallow holes drilled during FY-1985 and FY-1986.

All equipment subject to cross-contamination was cleaned, swiped, and triple-bagged before and after each use. To date, approximately 5,000 swipes were counted in an alpha spectrometer and beta/gamma counter. None of the swipes have indicated the presence of contamination on the drilling equipment or field support laboratory. Fifteen percent of these swipes were composited and sent to the laboratory for wet chemical analysis. These analyses confirmed the results obtained from the field analysis.

Geologic descriptions were recorded at intervals of 30 or 51 cm for the material present in the drive shoe of the sampler or the Shelby tube, depending on sampling methodology. Depth, texture, color, moisture, presence of roots, and reaction to 5% HCL were recorded.

Field descriptions indicate that the predominant textural class of soil was sandy or clayey silt, composing approximately 85% of the total number of drive show samples. The remainder of the samples were made up of sand and gravel (<1%), sand (10%), and clay (5%).

Soil moisture samples were collected from the drive shoe of the split-spoon sampler while processing the samples for storage. Samples were sealed in aluminum container and analyzed within a week after collection. Moisture contents were determined by the graviometric technique. Moisture contents ranged from 3.1 to 45.4% (by mass). The mean moisture content was 15.8% (by mass). The frequency distribution for moisture content is given in Table I.

TABLE I

Frequency Distribution for Moisture Content of Auger Hole Samples

Moisture Content (% by mass)	Number of Samples	Percent of Total	Cumulative Percent
0-5	5	5	5
5-10	13	12	17
10-15	31	29	46
15-20	32	30	76
20-25	20	19	95
25-30	5	5	100
35+	1	>1	100
	107	100	

The moisture content data indicated that the soil samples collected from the top meter of the soil column were dry and then demonstrated increased moisture content at depth. The southern half of the SDA had cover material added in 1985, to facilitate drainage away from the trenches, pits, and vaults. Cores from this area, collected in July of 1986, indicated that the soil was dry at land surfaces, moist to a depth of nearly 2.1 m, and became dryer to a depth of more than 2.7 m. The material between 2.1 and 2.7 m is believed to be the old land surface that was covered. These data suggest that redistribution of moisture at dry conditions is a slow process.

Nearly 100% core recovery was obtained from the split-spoon samplers. The sampler was driven a total of 50.8 cm/sample. Most all of the core samples experienced some compaction from the sampling technique. On the average, samples appeared to be compacted to 77% of their original size. The sand samples usually showed little or no compaction.

The auger holes were backfilled with native material while placing soil moisture monitoring and sampling instruments at various depths. Bentonite layers were placed between each of the layers of instruments and beneath the surface casing. An 20.3 cm diameter steel pipe with locking cap and moisture seal was placed in the top .91 m of the auger hole and cemented in place to protect instrument leads. The instrumentation employed is discussed later in this paper.

Deep Drilling

The objectives of the deep drilling activities are to provide representative samples of the main interbeds and to prepare boreholes to instrument with in situ monitoring instrumentation. The deep drilling activity consists of drilling and sampling the basalt and interbeds in the SDA. Samples of the primary interbeds at 34 and 73 m, along with samples from surficial sediment, will be used to define the geologic and hydrologic characteristics of the sediments and to provide samples for laboratory determination of selected radionuclides.

Procedures for deep drilling sample collection and soil-moisture monitoring equipment installation were prepared and reviewed by representatives for DOE-ID, USGS INEL Project Office, Grand Junction Field Office (DOE), Los Alamos National Laboratory, Los Alamos Technical Associates, and EG&G Idaho. Comments from these reviewers were incorporated into the final working document. In all, approximately 30 people had input into these procedures. These procedures were refined to provide the largest degree of protection from cross-contamination of the core samples at the drill site.

As in the shallow drilling activities, all equipment was thoroughly cleaned and swiped to ensure that no contamination was present. Fifteen percent of the swipes were composited and analyzed by a laboratory using wet chemistry techniques. To date, no contamination problems have been identified.

Two drill rigs were used for the deep drilling, a CME-55 and a CP-690. The CP-690 is a larger drill rig and was used to ream the surficial sediment and basalt and to set casing.

Three deep holes were drilled and sampled during the 1986 campaign. Two of the deep holes penetrated the 34 m interbeds and one of the holes was completed through the 73 m interbed. The third hole was used to sample from a discontinuous sediment layer at a depth of approximately 12.8 to 14.6 m (total depth of 15.2 m). The wire line core sampler employed to collect sample from the 34 m interbed proved unsuccessful for both of the deepest boreholes. The sampler's success was hampered by the interbed being thinner than anticipated, thus minimizing the opportunity to refine the sampling technique. The wire line core sampler was also used on the 73 m interbed with marginal success (~40% core recovery). Therefore a Shelby tube was tried and achieved 83% core recovery. The core sampler was also used on the shallow 12.8 to 14.6 m interbed, with approximately 50% core recovery.

The samples collected from these holes have been prioritized for radiochemical analysis in FY-1987. Samples from the Shelby tubes will be used for the net downward flux and solution chemistry specific studies. Depth, texture, color, moisture, and reaction to 5% HCL (for sediments) were recorded.

The field descriptions of the interbeds indicate that the 12.2 m interbed at D06A was dry to moist, while the 73 m interbed in D02 was moist. Moisture contents have not been determined; however, the samplers are sealed for future analysis. The color of the interbed sediments were yellowish red to light red. The sediment samples classified as clayey or sandy silt and silt typically reacted strongly to HCL, but the sandy samples did not react with HCL except where individual grains of calcium carbonate were present in the sand.

The boreholes were logged with three types of geophysical tools and also TV logged. The gamma-gamma logs were run to measure the relative density of the surrounding materials. Gamma-ray logs were used to identify sedimentary beds within the basaltic sequence since the sediments at the RWMC emit more gamma radiation than basalt. Neutron logs were employed to measure the relative moisture content of the material adjacent to the borehole. Sediment interbed or fracture zones with sediment in-filling within the basalt intervals typically indicate the highest moisture contents. These logs were ultimately employed to assist in the planning for instrument installation.

SPECIFIC STUDIES

Four specific studies have been initiated for the Subsurface Investigation Program. Three of the four specific studies are discussed below with an emphasis on the FY-1986 activities. Since the fourth study, computer model development was just started, it will not be presented.

Solution Chemistry

The first objective of the Solution Chemistry Study is to determine the major ion chemistry, pH, and redox potential of solutions in soil and basalt at the RWMC. The information will be used in the predictive model of radionuclide transport at the RWMC. The second objective is to define the actual radionuclide migration by monitoring for radionuclides in soil waters using porous cup lysimeters. The Solution Chemistry Study consists of installing porous cup lysimeters in augered and drilled holes, collecting samples of soil moisture, analyzing the water samples, and utilizing the resultant data for prediction of radionuclide migration.

Since the study was initiated in FY-1985, 34 porous cup lysimeters have been installed in 1 deep hole and 20 shallow holes. In FY-1986, 14 lysimeters were installed in shallow sediments, one in a sedimentary interbed, and one in a fracture zone in the basalt. A number of lysimeters have developed slow leaks. As a result, air entering the lysimeter reduces the vacuum inside the lysimeter before a water sample can be collected. By increasing the effective volume of the lysimeter, a water sample can be collected before air leakage reduces the vacuum. This increase in volume is accomplished by attaching a reservoir tank to the airline of the lysimeter.

Prior to lysimeter installation, water is added to the silica flour surrounding the porous cup of the lysimeter. The water is added to assure that good contact is achieved between the native soil and the lysimeter. This water, however, must be removed before a true sample of soil water can be obtained. For the FY-1986 installations, a potassium bromide (KBr) tracer was added to the water. Water samples obtained from these installations can be analyzed for the potassium bromide tracer to determine when valid samples can be collected. The makeup water used to install the lysimeters is a 10 mg/L solution of KBr. Analyses of water samples collected from lysimeters installed in FY-1986 show a consistent decrease of bromide tracer in samples.

In FY-1986 lysimeters were installed in a deep well. Two lysimeters were installed at 26.8 and 13.4 m depth respectively in drill hole D06 (Fig. 1). Because of the depth of installation, special lysimeters were used. A cutaway view of this type of lysimeter is shown in Fig. 2. To collect the water sample from the lysimeter, a fairly high pressure must be placed on the lysimeter (at least 275 kPa). This high pressure can force the water sample back out through the porous ceramic cup. To prevent loss of the water sample, a check valve is placed in the lysimeter, preventing pressurization of the porous cup when the remainder of the lysimeter is pressurized.

Table II shows results of chemical analyses for major ion chemistry of samples collected from lysimeters installed during FY-1985. There is a broad range in composition of soil waters from the RWMC. The only parameter to show any consistency is dissolved silica. The concentration recorded is indicative of equilibrium with fine-grained silica and is the result of equilibration with the silica flour, not the result of natural soil processes.

Although the available data is limited, the initial results from the lysimeter installation would suggest that recharge to the groundwater is associated with the drainage channels within the SDA. This is evidenced by the high concentrations of magnesium and chloride, primary constituents of a solution used to treat the roads to minimize dust, detected in a lysimeter installed in Well TH4 near a road and drainage channel. Additional analysis of the chemistry data will require more samples for detection of trends.

Net Downward Water Flux

The objectives of this study are to determine the volume and rate of moisture inflow through the SDA surface, identify pathways of moisture migration, characterize the effects of lithologic interfaces on moisture movement, and develop data describing moisture entry into the ground and moisture movement through the unsaturated zone for verification of a simulation model.

This study employs in situ field equipment to measure and monitor soil water content at the RWMC. The intent is to define the volume and rate of mois-

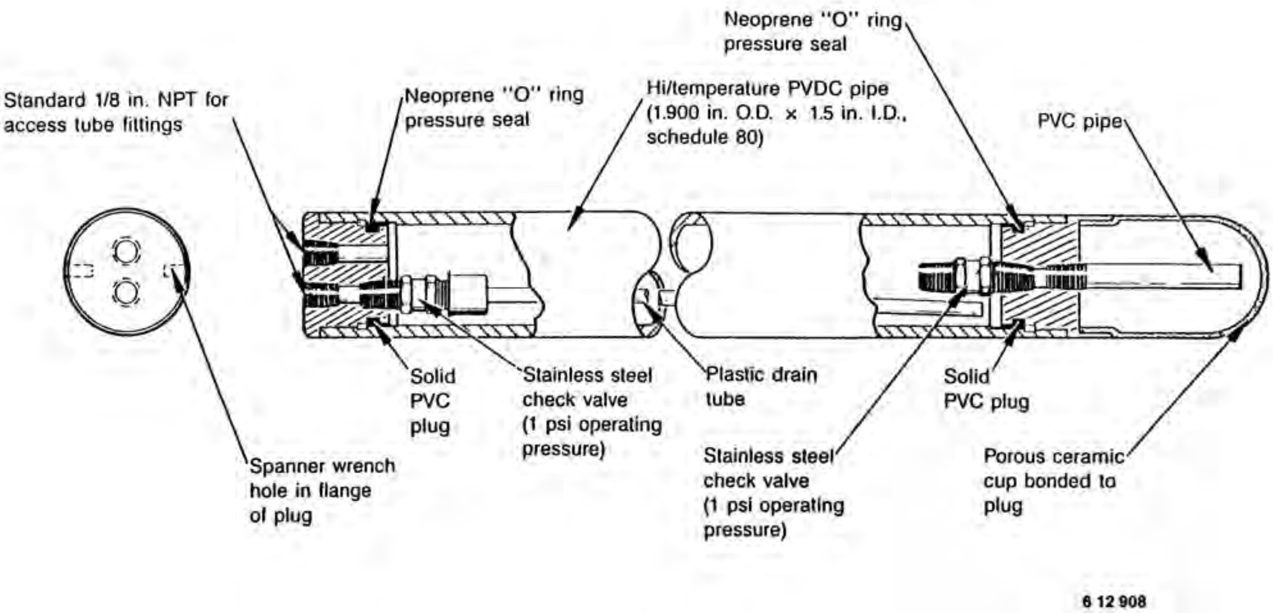

Fig. 2. Cutaway view of porous cup lysimeter used in deep drill holes.

TABLE II

Major Ion Chemistry in Soil-Water Samples from the RWMC

		(mg/L)													
	Date Collected	Na	K	Ca	Mg	Sr	Zn	SiO_2	HCO_3	Cl	F	SO_4	NO_3	Br	TDS
L03	06/11/86	701	4.1	100	37	0.7	0.85	73	---------------Not determined---------------						
L05	06/11/86	117	2.8	125	95	1.3	0.41	77	720	134	0.5	120	15	0.0	1062
L08	06/11/86	1590	17.0	655	175	2.9	0.36	73	---------------Not determined---------------						
L09	06/11/86	965	6.7	88	73	1.1	0.25	78	587	803	0.8	836	31	1.1	3186
L13	06/11/86	174	14.5	77	50	0.8	0.16	75	626	61	0.6	128	44	0.0	922
L15	06/11/86	579	4.9	72	38	0.6	0.00	72	1480	142	1.7	183	13	0.0	1836
L16	06/11/86	380	5.6	158	82	1.3	0.00	78	711	96	0.6	747	48	0.0	1962
L18	06/11/86	1360	9.5	513	1047	6.0	0.69	74	363	4507	0.4	1510	13	10.0	9422

ture movement into and through the unsaturated zone and to delineate moisture migration pathways through the unsaturated zone. This data will be used to field calibrate a model to predict long-term migration of radionuclides in the unsaturated zone. The study will require instrumentation throughout the SDA to characterize moisture availability, variability, and movement.

Five types of instruments were installed in boreholes in FY-1986 at the RWMC. These instruments were installed in augered holes for the shallow drilling and in a drilled hole for the deep drilling activity. All of the shallow auger holes and one of the deep drill holes were instrumented; in addition, neutron access tubes were placed adjacent to several shallow auger holes.

Two types of instruments, heat dissipation sensors and neutron moisture probes, were used for the first time in FY-1986. The remaining three instruments installed during 1985 and 1986 included tensiometers, thermocouple psychrometers, and gypsum blocks (resistance blocks). These instruments have the ability to measure moisture content through a broad range of conditions ranging from very dry to moist.

All the instruments were installed in the boreholes as the hole was being backfilled. The instruments were placed as close as practicable to the surficial sediment/basalt interface and at depths of 6.1, 4.6, 3.0, 1.5 and .91 m below land surface. All instruments are identified by tags attached to the lead or the gauge. Heat dissipation sensors and gypsum block leads were connected to mechanical switches to reduce the time required to read the instruments.

Backfilling the hole was done systematically so the natural flow systems in the unsaturated soil would not be significantly affected. Auger cuttings were used to backfill the holes. The cuttings were tamped in 5 cm layers with a long metal rod to approximate the original bulk density.

Bentonite was used to seal the hole between each instrument and above the instrumentation closest to land surface. This will inhibit downward saturated flow along instrument leads and isolate the borehole at discrete depths to allow the potentials to equilibrate laterally. Bentonite layers 5 to 10 cm thick were typically placed at least .3 m away from the instruments. Plastic pipes were used to place the bentonite layers to reduce the amount of bentonite sticking to the side walls of the borehole.

A total of 32 shallow and one deep drill holes have been instrumented with vadose zone monitoring and sampling equipment in FY-1985 and FY-1986. Over 240 instruments have been placed in and around the SDA to measure matic potential and soil moistures or sample water from the unsaturated zone. Instruments to measure matic potential in soil, including heat dissipation sensors, tension meters, psychrometers and gypsum blocks have been installed in 22 of the shallow bore holes and the one deep drillhole. Two shallow holes have neutron probe access tubes placed next to them to measure moisture content; porous cup lysimeters were installed in 20 of the shallow hole and the deep holes to collect soil moisture samples.

Data collected to date on soil moisture content at the RWMC indicate the soil is generally moist. Moist conditions indicate that fluid movement does occur within these soils. The driest soils are those near land surface where the influence of evapotranspiration is largest. Soils at depth tend to get moisture indicating water is recharging the system periodically. The chemistry of soil water with TDS at the 1000-2000 mg/L range indicates water is not stagnant within this system.

Radionuclide Concentrations

Selected soil samples obtained during drilling activities are subjected to three analytical procedures to determine the presence of seven radionuclides: (1) gamma spectroscopy for determining ^{144}Ce, ^{137}Cs, and ^{60}Co concentrations; (2) alpha spectroscopy for ^{238}Pu, $^{239,240}Pu$, and ^{241}Am; and (3) beta counting for ^{90}Sr. Soil-water samples collected from porous cup lysimeters are subjected to tritium analysis. Soil and soil-water analyses will help to determine the extent of radionuclide contamination and the degree of contaminant mobility.

A total of 112 soil samples from 17 FY-1985 auger holes have been submitted for radiochemical analysis. Each sample has been analyzed for the presence of 7 radionuclides. The results of these analyses produced 61 positives (~8% of all samples and analyses conducted) and are reported on Table III. A positive

TABLE III

FY-1985 Shallow Wells
Positive Radiochemical Results by Depth

Depth (m)	^{238}Pu	$^{239,240}Pu$	^{241}Am	^{90}Sr	^{144}Ce	^{137}Cs	^{60}Co
.76	7	7	8	5	0	7	0
.76-1.27	2	2	1	3	0	2	0
1.27-1.78	1	2	1	1	0	2	1
1.78-2.29	2	2	1	1	0	0	0
2.29-2.79	0	0	1	1	0	0	0
Greater than 2.79	0	0	0	1	0	0	0

is defined as a measured concentration which exceeds the uncertainty by a factor of three. (The 99 percentile). Note the concentrations measured are at environmental levels of 10-8 and 10-9 µCi/g for the nuclides analyzed. With the exception of 3 positives, all of the positive occurs at depths of 2.29 m or less. Virtually all of the data suggest a vertical gradation--the most number of positives near the surface.

The positive results from samples acquired near land surface probably indicate transport by surface water rather than lateral subsurface migration from buried waste. Some of the positive results, however, are from deeper in the surficial sediments. The exact transport mechanism or pathway for these radionuclides is not yet understood but is under ongoing investigation as a part of this program.

CONCLUSIONS

The RWMC Subsurface Investigations represent a comprehensive approach to evaluate radionuclide migration from the buried waste and predict the long-term effects of the buried waste on the environment and man. In the past the drilling activities have been emphasized for the collection of data and placement of instrumentation. The limited data collected thus far suggest that the moisture flow is the greatest in the immediate vicinity of the drainage ditches inside and adjacent to the SDA. More extensive monitoring may be necessary in these areas than originally planned. The radiochemical data shows the surficial materials at the SDA have the most positive results, but vertical migration has not been significant. The FY-1987 activities will focus on the analysis of data from the FY-1985 and 1986 activities. The results of the data analysis in FY-1987 will be employed to modify the methods and specific studies planned for FY-1988.

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