**A Field Test Facility for Monitoring
Water/Radionuclide Transport
Through Partially Saturated
Geologic Media: Design,
Construction, and Preliminary
Description**

November 1979

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A FIELD TEST FACILITY FOR MONITORING WATER/RADIONUCLIDE
TRANSPORT THROUGH PARTIALLY SATURATED GEOLOGIC MEDIA:
DESIGN, CONSTRUCTION, AND PRELIMINARY DESCRIPTION

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SUMMARY

Shallow land burial has been a common practice for disposing radioactive waste materials since the beginning of plutonium production operations.

Accurate monitoring of radionuclide transport and factors causing transport within the burial sites is essential to minimizing risks associated with disposal. However, monitoring has not always been adequate. Consequently, the Department of Energy (DOE) has begun a program aimed at better assuring and evaluating containment of radioactive wastes at shallow land burial sites. This program includes a technological base for monitoring transport.

As part of the DOE program, Pacific Northwest Laboratory (PNL) is developing geohydrologic monitoring systems to evaluate burial sites located in arid regions. For this project, a field test facility was designed and constructed to assess monitoring systems for near-surface disposal of radioactive waste and to provide information for evaluating site containment performance. The facility is an integrated network of monitoring devices and data collection instruments. This facility is used to measure water and radionuclide migration under field conditions typical of arid regions. Monitoring systems were developed to allow for measurement of both mass and energy balance.

Work on the facility is ongoing. Continuing work includes emplacement of prototype monitoring instruments, data collection, and data synthesis. At least 2 years of field data are needed to fully evaluate monitoring information.

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INTRODUCTION

Radioactive waste materials have been disposed to shallow land burial sites since the advent of nuclear reactor plutonium production operations initiated under the Manhattan Engineering District Project in the early 1940s. The source of buried radioactive waste materials has primarily been plutonium production operations under the auspices of the Atomic Energy Commission (AEC), the Energy Research and Development Administration (ERDA), and the Department of Energy (DOE). Radioactive materials are disposed at government-operated nuclear reservations (defense wastes) and privately owned and/or operated nuclear waste disposal sites (commercial wastes).

Buried radioactive materials are generally classified as fuel-cycle wastes (those wastes originating directly from nuclear reactors and supporting fuel fabrication and reprocessing facilities) and nonfuel-cycle wastes (those wastes originating from radiopharmaceutical, industrial and research-oriented radioisotope producer facilities and operations). The volume of fuel cycle and non-fuel cycle buried waste materials is presently estimated to be $7.0 \times 10^5 \text{ m}^3$ and the projected volume by the year 2000 will approximate $8.0 \times 10^6 \text{ m}^3$ (Smith et al. 1976; Holcomb 1978; Mullarky et al. 1976).

In some instances, radioactive materials have been transported from shallow land burial sites into the biosphere by several geohydrologic and biologic vectors (Means et al. 1976; Webster 1976; Prudic and Randall 1977). The rate, magnitude, and direction of transport of radionuclides influences the present and projected longevity of the sites as nuclear waste isolation structures. However, monitoring of radionuclide transport and factors causing transport has not always been adequate. Consequently, DOE has initiated a program to better assure radioactive waste containment at shallow land burial sites (Steger et al. 1977). Part of the program entails developing a technological base for monitoring shallow land nuclear waste burial sites so that risks associated with disposal will be minimized.

As part of the DOE program, Pacific Northwest Laboratory (PNL) is developing geohydrologic monitoring systems. Specifically, the purpose of this work

is to design monitoring systems applicable to radioactive waste burial sites located in arid regions. The study also involves evaluating radionuclide transport and migration of liquid and vapor phase fluids in the partially saturated (above the water table) media.

This report describes a field test facility that was designed and constructed to assess the migration of radionuclides and water in the partially saturated ground-water zone of arid shallow land radioactive waste burial sites. This facility permits development and testing of monitoring systems which may be used to evaluate site containment performance. Furthermore, this facility is used as a source of information amenable to simulating and predicting water and radionuclide transport through the geologic media pathway.

The field test facility was completed following a planned project chronology (Figure 1). The plan consisted of:

1. evaluating existing monitoring and data recording systems
2. developing criteria for a site/facility that would permit environmental effects to be controlled or quantified
3. selecting a site to meet the criteria
4. designing the site (engineering, drafting)
5. excavating a cavity in the geohydrologic system for the instrument systems and containment structures
6. fabricating structures to control the direction of radionuclide/water transport within the facility and contain radionuclides within the facility
7. fabricating instruments to measure micrometeorological and geohydrologic variables that affect radionuclide/water migration.
8. integrating system components
9. placing structures into the excavation and returning the site to as-near-as-possible pre-excavation conditions
10. placing instruments into geohydrologic and atmospheric systems and interfacing systems to recording devices
11. testing instruments and recording devices.

FIGURE 1. Project Chronology

At the test facility, mass balance variables (factors affecting the quantity of material entering and/or exiting the partially saturated system) are monitored in order to determine if radionuclides will migrate to the biosphere. For example, precipitation, upon entering the partially saturated geohydrologic system, may either migrate vertically downward through buried radioactive waste materials into the saturated zone system or it may migrate only a short distance vertically and then be evaporated.

Energy transfer variables (factors affecting the rate of various mass transfer operations) are monitored to assist in determining the rate of potential radionuclide migration to the biosphere. For example, the sensible heat transfer from and to the geohydrologic system (across the geologic media interface) in part controls the thermodynamic water potential gradient within the geologic media. The potential gradient in turn determines the rate of migration of water to the interface where evaporation may occur, i.e., a mass transfer operation. Thus, it is extremely important to continually monitor inter-related mass and energy factors which can ultimately be used to quantify actual or potential migration of radionuclides from burial sites to the biosphere.

Actual migration of radionuclides within the partially saturated geohydrologic zone is also monitored at the field test facility. Radionuclide monitoring, however, is used to trace water migration as it is the principal mechanism causing radionuclide transport in the geohydrologic system.

This project has developed new monitoring devices to determine mass balance and energy transfer in addition to integrating existing monitoring components into an overall monitoring system. Figures 2 through 4 show the interrelated systems as they exist within the containment structures of the facility. Figure 2 is a cut-away view showing the containment caissons and weighing lysimeters below the ground surface. The figure also illustrates the type and placement of micrometeorological instruments. Vertical access tubes that activate radionuclide/water monitoring logging instruments are shown above the ground surface above each containment structure.

FIGURE 2. Buried Waste Test Facility

Figure 3 is a plan perspective view of the existing facility (the containment caissons and weighing lysimeters, etc., are represented at small angle exterior projections from the vertical). Soil physics instruments within these structures are shown in three general locations as: 1) HDU - heat dissipation units, 2) TC - thermistors/thermocouple, psychrometers/tensiometers, and 3) RB - electrical resistance units. Micrometeorological instruments are also shown. All sensor electronic cords are connected to data collection, display, and synthesis systems located in the center caisson. The original location of contaminants (tritium and cobalt) emplaced in small diameter caissons surrounding the center caisson is also shown represented by solid black disks near the center of the illustration. Destructive sampling locations are illustrated by points shown from the ground surface to the bottom of each caisson. Figure 4 is a perspective view of a weighing lysimeter and associated electronics and water extraction system.

This report is a preliminary description of the field test facility covering activities completed in 1978 and 1979. Continuing work includes: 1) emplacement of prototype monitoring instruments, 2) data collection, and 3) data synthesis. Final reports including final facility description, area analysis, and micrometeorological and soil physics data will be published in the future. A minimum of 2 years of field-collected data is required to fully evaluate monitoring information.

FIGURE 3. Electronic Sensing Devices Installed at the Buried Waste Test Facility

FIGURE 4. Hydrogeologic Instruments Installed Within Weighing Lysimeter

SITE SELECTION AND DESCRIPTION

Selection of a site for the field test facility was based on several criteria. These criteria included: 1) a controlled government reservation, where radionuclides could be used in situ within the facility; 2) a controlled area with limited public access; 3) a site where geologic media was uncontaminated, i.e., at or below background radiation levels with respect to isotopes used; 4) a nominally flat topography such that boundary effects would be minimized; 5) a site where the water table was at sufficient depth to allow the facility to remain under partially saturated conditions at all times; 6) a site where the geologic media was analogous to that media actually used for shallow land burial of radioactive materials and could be made isotropic and homogeneous; and 7) a site where a well was available, in order to evaluate the effects of increased water flux.

The site selected in accordance with the above criteria is located adjacent to an existing nuclear waste burial site in southeastern Washington State (Figure 5). This site is classified as a shrub-steppe grassland (Daubenmire 1970) and is located on a river terrace plain within the DOE Hanford Site approximately 3.5 km from the Columbia River. Figure 6 shows the general topography of the area.

The geologic material consists of glaciofluvial sediments deposited during the Pleistocene geologic epoch. Aeolian sands mantle the ground surface at the site. The undisturbed sediments consist predominantly of horizontally deposited units of coarse to medium sands with lenses of sands containing gravels and cobbles. Figure 7 illustrates the stratigraphy encountered at the test facility.

The water table at the test facility occurs at an approximate depth of 18 m. Several saturated zone monitoring wells are located within 100 m of the site. Two of these wells have permanently installed submersible pumps, thereby providing a permanent accessible water supply.

FIGURE 5. Location of Field Test Facility

FIGURE 6. General Topography of the Area Surrounding the Test Facility

FIGURE 7. Stratigraphy of the Test Facility Site

FIELD TEST FACILITY DESIGN AND CONSTRUCTION

After the appropriate site was selected, an environmental report was submitted to DOE. This report was required to document the pre-operational, operational, and post-operational environmental consequences resulting from the proposed site. Upon approval of the report, facility design and construction proceeded.

FACILITY DESIGN

Construction and installation of the test facility required a design that would produce accurate data. The design was facilitated by defining the requirements of the facility. These requirements are summarized as follows:

- Because liquid radiocontaminated sediments were to be emplaced into the facility, it had to be designed to control the migration of radionuclides so that the surrounding area would not be contaminated. Steel caissons were selected as containment barriers to prevent lateral migration. Concrete and a vulcanizing agent were selected to act as a barrier to vertical downward flow of radionuclides. In addition, the base of the facility, where liquid phase radiocontaminants would possibly accumulate, had to be designed to permit collection and subsequent disposal.
- The facility had to be designed to evaluate accelerated conditions of radionuclide transport. The predominant factor causing accelerated radionuclide transport was found to be precipitation/precipitation intensity (Gee and Simmons 1979). Therefore, systems were needed to permit application of synthetic precipitation. Accelerated precipitation was thought to potentially cause accumulation of water and radiocontaminants at the base of the facility, thereby effectively causing a water-table condition, i.e., an artificial zone of saturation. Thus, the facility required devices that would prevent occurrence of a water-table condition by withdrawing fluid from the bottom of the containment caisson.
- The transport of radionuclides under partially saturated conditions is controlled in part by mass balance factors (those factors controlling the

quantity of materials entering and existing in the geohydrologic system). As a consequence, lysimetry was required to monitor the rate, magnitude, and direction of migration of precipitation entering the geohydrologic system. Lysimeters were specifically designed to measure the mass balance at the test facility. These lysimeters consisted of rhombic steel vessels containing sediments supported on a load platform, which is in turn surrounded by a containment vessel.

- Water in the form of incident precipitation may carry radioactive materials through geologic burial media. The flow of water in the partially saturated shallow land burial conditions occurs predominantly in the vertical downward direction. To evaluate radiocontaminant migration relative to development of monitoring systems, one-dimensional flow was assumed. Thus, facilities were needed to initiate studies under simple geometric flow constraints. Caissons containing sediments contaminated with radionuclides under controlled (additional precipitation) and ambient meteorological conditions, and caissons containing uncontaminated sediments under controlled and ambient conditions were also designed. Access to these caissons in vertical and horizontal directions was required to allow destructive and nondestructive testing of water and radionuclide transport over time.

A preliminary design was modified until a working configuration of a field test facility was completed and reviewed. Engineering drawings of the test facility are enclosed in the Appendix, along with summary explanations.

EXCAVATION

In order to evaluate radionuclide/water transport and monitoring systems performance at nuclear waste disposal sites, a facility had to be constructed that would simulate burial conditions. Waste disposal sites typically consist of backfilled trenches or similar structures excavated below ground surface. Thus, for the test facility, a large excavation was made in order to place the radionuclide containment structures and monitoring systems below ground.

Excavation was initiated by removing $\sim 8.0 \times 10^2 \text{ m}^3$ of topsoil over an area of $\sim 1.4 \times 10^3 \text{ m}^2$ to a depth of $\sim 6.0 \times 10^{-1} \text{ m}$. This operation cleared the site of organic matter and layered soil profiles to a depth where nominally isotropic homogeneous sands were exposed at the excavation surface.

The subsequent operations involved excavation and stockpiling of sand from the 6.0×10^{-1} to 2.4 m depth. Approximately $2.5 \times 10^3 \text{ m}^3$ of sand were excavated within the perimeter of the site where topsoil was removed. The topsoil and sand materials were excavated by large commercial earthmoving equipment. The sand was stockpiled and mechanically mixed at a location $\sim 50 \text{ m}$ distance from the excavation location and then covered with plastic sheeting to preserve the natural water content of the sand. The purpose of the stockpiled sand was for use within the caisson structures and lysimeters and for backfilling immediately around the structures. The stockpiled sand would provide an isotropic, homogeneous, geologic media continuum within and around the caisson and weighing lysimeters.

After excavation and stockpiling of sand materials to a depth of $\sim 6.0 \times 10^{-1} \text{ m}$, further excavation of the site below the sand into a coarser textured material (gravelly coarse to medium sand) was completed to a depth of $\sim 8.1 \text{ m}$. The material was removed to a depth of $\sim 5 \text{ m}$. The excavation was completed to a depth by a dragline operation. The material was removed and stockpiled adjacent to the site for backfilling.

CONSTRUCTION

Construction of the facility included fabrication of: 1) concrete structural pads, 2) caissons, 3) weighing lysimeters, 4) interconnected structures between weighing lysimeters and caissons, 5) leveling rails, 6) irrigation system, and 7) a perimeter fence. Backfilling within and around caissons and weighing lysimeters was also completed during site construction.

The shallow foundation at the bottom of the excavation consists of framing material, steel reinforcement rod, and concrete blocks. This foundation functions to support steel caissons placed vertically within the structure.

Concrete was placed within the foundation structure after emplacement of the caissons. The purpose of the foundation is to prevent the caissons from settling. Furthermore, it provides a barrier to radionuclide transport out of the facility.

The caissons consist of galvanized corrugated steel. Three caissons are ~ 8.1 m by ~ 2.7 m by $\sim 7.4 \times 10^{-2}$ cm in length, diameter, and wall thickness, and four caissons are 7.5 m by 0.6 m by 7.4×10^{-2} cm. These caissons were bolted together to form the seven-caisson array illustrated in Figure 8. The caissons were interconnected with 10-cm long, 5-cm diameter steel tubing in order to allow access to each outer caisson from the central caisson. These tubes were installed at 15- and 30-cm vertical intervals between the instrument access caisson and large diameter caissons and between the instrument caissons and small diameter caissons, respectively. The tubes also provide access for instruments and for destructive sampling of radiocontaminants and other materials within the caissons. All points of interconnection between caissons were sealed to preserve one-dimensional flow of materials through the caissons, and thus contain radionuclides within the caissons.

The interconnected caissons were placed vertically into the excavated area. Approximately 12 m^3 of concrete to a depth of approximately 0.3 m were placed within the foundation structure. The concrete formed a seal within and surrounding the base of each caisson to a depth of ~ 5 cm.

Weighing lysimeters (Figure 9), used for determining mass transfer in geologic media, were acquired from a commercial vendor and modified. These consist of: 1) a peripheral rhombahedral containment cell used to isolate the lysimeter from the surrounding geologic media, 2) a load platform used to determine the change of mass from the geologic media and materials within the geologic media over time, and 3) an inter-rhombahedral containment cell used to contain a known volume of geologic media.

After the caissons were installed, uniform sand was backfilled immediately around the caissons. Nonuniform gravelly sand was backfilled simultaneously away from the caissons. Backfill material external to the caissons

FIGURE 8. Seven-Caisson Array

FIGURE 9. Weighing Lysimeter

was compacted with earthmoving equipment and by water application. Backfill exterior to the caisson array was emplaced from the excavation depths upward to ~ 1.8 m from the pre-excavation ground surface. At this depth weighing lysimeter foundation and concrete pads were constructed and weighing lysimeters installed.

Uniform sand material (the same material used to backfill the exterior of the caissons) was backfilled into the caisson array. Backfilling operations included: 1) screening of the sand to assure greater-than-sand-sized materials would not be introduced into the caissons (Figure 10), 2) continuous emplacement and mixing of the screened sand into the caissons with a large diameter flexible tube (Figure 11), 3) introduction of a continuous layer of uniform coarse quartz sand from ~ 6.0 to 6.3 m depths which provided for evaluation of sediment layering effects relative to partially saturated water and radionuclide migration, and 4) pneumatic compaction of the backfill material to assure a uniform bulk density. Weighing lysimeters were backfilled in a similar manner; however, the coarse quartz sand layer was omitted. Compaction was tested during backfilling operations using Proctor penetrometer tests (ANSI/ASTM 1971).

During backfill operations several monitoring system access tubes and transducers were installed. Within each of the caissons backfilled neutron well instrumentation logging access tubes were installed, three tubes each per large diameter caisson and one each per small diameter caisson. Within the small diameter caissons, these tubes (5.0 cm diameter, 8.1 m long, 0.15 cm wall thickness) also allow access to gamma sodium-iodide scintillation wall logging instruments. With the installation of interconnecting tubes between weighing lysimeters and the instrument access caisson, backfilling was completed to pre-excavation grade.

Leveling rails consisting of ~ 5 cm by 0.3 cm steel angle were emplaced at grade around the caisson array and the weighing lysimeters. These rails provide a fixed structure to maintain the elevation, i.e., depth of materials, within the caisson array and weighing lysimeter. The ground surface elevation varies at this site, primarily because of wind erosion.

FIGURE 10. Screening Special Backfill Material to Remove Rocks

FIGURE 11. Backfilling and Tamping Inside Caissons

Radionuclides within nuclear waste burial sites are typically transported under partially saturated conditions. In order to evaluate radionuclide transport relative to increased quantities and flux of water through contaminated geologic media, irrigation was required. One-half of the field test facility (bilateral symmetry) was irrigated, while the other half remained under ambient conditions. An automated irrigation system was constructed to apply artificial precipitation. This system is illustrated in Figure 12. The system consists of numerous components including: 1) a submersible pump to withdraw water from a nearby well; 2) valves and associated components to transport and regulate the amount of water entering the test facility from the well; 3) an irrigation boom consisting of aluminum pipe, wheels, and connecting structures which serve as a movable structure to permit irrigation water coverage over a large area of the test facility; 4) an electric motor which powers the irrigation boom; 5) a gear reduction device which serves to drive the irrigation boom laterally over the test facility at a given rate; and 6) electrical systems for power supply to the electrical motor and switching mechanisms for reversing directions of the gear reduction device.

FIGURE 12. Overview of Irrigation System

INSTRUMENT SYSTEMS

The migration of water (the agent primarily causing radionuclide transport) works in conjunction with micrometeorological and hydrogeologic phenomena. In order to quantitatively evaluate radionuclide transport within nuclear waste disposal sites, these phenomena must be understood and continuously monitored. Mass transport and energy balance within the hydrogeologic system is dependent on many factors. These factors, illustrated in Figures 13 and 14, require direct or indirect monitoring over sufficient time to determine what influence each has on radionuclide transport.

Numerous instrument systems have been installed at the field test facility. These instrument systems measure variables that control radionuclide transport. The operation, reliability, sensitivity, and operational range of each system is being evaluated. The systems are designed under two categories: micrometeorological instruments, which monitor the conditions above the geologic media/atmosphere interface, and soil physics instruments, which monitor below ground surface conditions. These instrument systems used in concert with weighing lysimeters and radionuclide logging devices will provide accurate assessment of mass transport and energy balance within nuclear waste burial sites.

MICROMETEOROLOGICAL INSTRUMENTATION

Several micrometeorological instruments are used to evaluate energy balance between the geologic media/atmosphere continuum. The energy balance may be evaluated typically by use of an equation of the general form (Munn 1966):

$$Q_T - Q_R + Q_L \downarrow - Q_L \uparrow = \pm Q_N = \pm Q_G \pm Q_H \pm Q_E \quad (1)$$

where

Q_T = short wave solar radiation

Q_R = short wave radiation reflected from the geologic media/atmosphere interface

FIGURE 13. Mass Balance Factors Affecting Transport of Water and Radionuclides

FIGURE 14. Energy Balance Factors Affecting Transport of Water and Radionuclides

$Q_{L\downarrow}, Q_{L\uparrow}$ = long-wave solar radiation reflected at the geologic media/atmosphere interface and long-range radiation emitted from the interface, respectively

Q_N = total spectral solar radiation

Q_G = heat transfer through the geologic media

Q_H = turbulent sensible heat transfer from the geologic media to the atmosphere

Q_E = latent heat of evaporation

Short-wave solar radiation is measured at the field test facility with the use of pyranometers. Pyranometers continuously monitor the total radiation between wavelengths of 0.2 to 4.5 μ over the irrigated (controlled) and ambient sides of the field test facility. These instruments are installed vertically so as to effectively measure incoming and reflected radiation. The pyranometers oriented vertically downward measured either reflectivity or albedo.

Long-wave solar radiation is extremely difficult to measure and is often not a significant factor contributing to total radiation. Thus, the net radiation of all-wavelength radiation is continuously monitored over the controlled and ambient sides of the facility, the difference between all-wavelength and short-wavelength being long-wavelength radiation. Net radiation measurement instruments are installed in a configuration similar to the pyranometers previously discussed. These devices ideally measure the differential temperature of the atmosphere caused by direct solar and reflected radiation.

Turbulent sensible heat transfer above the geologic media/atmosphere interface is continuously measured by thermistors and thermocouples. The thermal gradient is measured from the interface to a height of 2.0 m. The geologic media surface temperature determines the direction of sensible heat flux. The surface additionally determines the heat flux within the geologic media. Temperature of the geologic media surface is monitored periodically by an infrared radiation thermometer. This device remotely integrally senses the temperature at the geologic media/atmosphere interface over areas of $\sim 1.0 \text{ m}^2$ on the controlled and ambient sides of the test facility.

The transport of vapor phase materials, e.g., water vapor, noble radioactive gases, etc., and contaminated particulate matter from nuclear waste disposal waste burial structures depends in part on the atmospheric wind turbulence. Accordingly, wind velocity at the test facility is continuously monitored at two locations in geometric configuration at two elevations above the surface, 1 and 2 m. The wind direction is also continuously monitored. Cup anemometers and standard wind vanes are used to measure velocity and direction, respectively.

Mass and energy transfer across the geologic media/atmosphere interface is directly coupled with the humidity of the vapor phase near the interface. At ambient temperatures encountered under site field conditions, water readily changes phases and evaporates or condenses and/or solidifies. Additionally, with a phase change, heat release or adsorption occurs as latent heat of evaporation or latent heat of fusion. Thus, humidity of the atmosphere/geologic media interface is primarily responsible for transfer of heat and mass. Relative humidity is continuously monitored at the facility. Relative humidity is measured by an electrical resistance monitoring transducer system.

Atmospheric precipitation is the most obvious factor contributing to the change of mass of the geologic media over time. The mass balance within the geologic media is typically evaluated by a generalized equation of the form:

$$P_T + A_A - R = E_T \pm D \pm \Delta PW \quad (2)$$

where

P_T = total precipitation in the form of rain, snow, dew, frost, etc.

A_A = applied artificial precipitation typically in the form of irrigation

R = runoff

E_T = total water evaporation

D = drainage of water downward out of the active partially saturated ground-water zone

ΔPW = change of water volume within the geologic media at specified depths

Rain gages are used to quantitatively evaluate the precipitation at the test facility. Lysimetry also provides quantitative information concerning atmospheric precipitation. A tipping bucket rain gage measures the amount of incident ambient rainfall, and a cumulative rainfall measurement is recorded. On the controlled side of the test facility artificial rainfall is induced. A tipping bucket rain gage is used to measure precipitation in the form of irrigation only when irrigation water is applied.

Runoff is water not infiltrated into the geologic media during or after a rainstorm or rapid snowmelt. Meteorological events and the geologic media occurring at the test facility are not conducive to runoff. Thus, no instrument systems are used to monitor this parameter.

Total evaporation is the amount of water evaporated or sublimated from the geologic media to the atmosphere (phase change and mass transfer). Weighing lysimeters are used in part at the test facility to measure actual evaporation. The weighing lysimeters consist of a monolithic volume of geologic media of $\sim 3.5 \text{ m}^3$ with a length dimension of $\sim 1.52 \text{ m}$ per side. The geologic media is encased within a steel vessel which rests on a load platform. The encasement vessel and load platform are encased within an outer vessel such that the weighed volume is structurally decoupled from the surrounding geologic media. The change in mass of the lysimeter over time with an accuracy of 1 part in 2000 is continuously monitored, thus providing mass transfer/evaporation data. Weighing lysimeters monitor both controlled and ambient sides of the test facility.

SOIL PHYSICS INSTRUMENTATION

Several soil physics instruments are used in conjunction with the micro-meteorological instrumentation systems at the field test facility. These systems together monitor energy and mass balance through the geologic media/atmosphere continuum (Equations 1 and 2). Soil physics instruments basically monitor thermal and water contents and gradients.

Heat is transferred through the geologic media by three principal mechanisms: conduction, convection, and radiation, with conduction being the primary mechanism. Heat transfer in turn influences water and solute

(radionuclide) transfer within the geologic media. The driving force of heat transfer is the thermal gradient and the thermal conductivity/diffusivity.

The in situ temperature of the geologic media over the depth of the test facility is determined by basic monitoring instruments. These instruments include thermistors and thermocouples. Soil heat flux plates have also been calibrated for in situ use for monitoring the direction of heat flux at the test facility. Thermistors and thermocouples installed throughout the facility under controlled and ambient conditions are continuously monitored. These transducers measure thermal gradients primarily in the vertical direction; however, several arrays have been installed horizontally to investigate edge effects potentially caused by thermal anomalies due to the caissons installed within the geologic media.

The transfer of water is directly responsible for energy gradients. Potential energy and implicit kinetic energy of water within geologic media are influenced by numerous factors. Total potential is evaluated in a general equation as follows:

$$\psi_T = \psi_m + \psi_g + \psi_p + \psi_\pi + \psi_\Omega \quad (3)$$

where the subscripts m, g, p, π , and Ω represent matrix, gravity, pressure, osmotic, and overburden potentials, respectively.

For the purpose of monitoring, the only potential of significance for the test facility is ψ_m . Matrix potential involves the mutual attraction of the geologic media and water molecules across solid-liquid-air interfaces. The matrix potential is a direct function of water content; thus, monitoring of potential and water content will result in compatible data. Matrix potential of the geologic media at the test facility is measured by three transducer systems: heat dissipation units, thermocouple psychrometers, and electrical resistance units.

Heat dissipation units are used to monitor water content, i.e., matrix potential. These units operate on the principle of heat flow within the geologic media as a function of water content. In other words, as liquid phase water content decreases a larger thermal gradient is required to dissipate

heat within a given volume of partially saturated geologic media. Providing an in situ thermal pulse for a given time from a point source and measuring the temperature rise and decline from a nearby point will give the thermal conductivity/diffusivity data equatable to matrix potential. Heat dissipation units routinely monitor matrix potential at various depths at the field test facility.

Thermocouple psychrometers operate on the Peltier effect by condensing water vapor on a bimetal junction and measuring evaporative cooling. Thermocouple psychrometers determine the relative humidity of the vapor phase of the geologic media atmosphere by determining the partial pressure of the vapor phase and the equilibrium partial pressure at saturation. Measuring the relative humidity of the vapor phase at precise temperatures thus determines quantitative data relative to matrix potential. Thermocouple psychrometers are routinely used to monitor matrix potential at various depths at the field test facility.

Electrical resistance units operate simply on the basis of electrical resistance between two electrodes. The electrodes are typically positioned within a porous material, such as ceramic or nylon, which contacts the geologic media. Water dynamically transferred into or from the porous sensor by matrix potential results in changes in electrical resistance. The measured electrical resistance is then a function of: the affinity of the sensor material and the geologic media for water, the water content, and the electrical conductivity of the water in and surrounding the sensor. Electrical resistance units are routinely used to monitor matrix potential at various depths in the field test facility.

Tensiometers are also used within the weighing lysimeter located in the controlled side of the facility. Tensiometers monitor the water tension or matrix function/potential exerted by the geologic media on the partially saturated ground water. These sensors monitor matrix potential by measuring the negative pressure of water films on particles within the backfill material through water within a ceramic cell which is in hydraulic contact with the backfill material. Any action such as evaporation or precipitation which disturbs hydraulic equilibrium is monitored by determining the negative pressure

exerted on a pressure transducer affixed to the tensiometer. Tensiometers at various depths have been installed for use under near-saturated conditions (within the physical operational range of tensiometers) when they occur at the test facility.

Water content is directly monitored at the test facility by in situ neutron well logging. Neutron logging operates on the principle of determining the equilibrium between fast and thermalized (epithermal) neutrons in the geologic media by determining their concentration and capture cross section of absorbing hydrogen nuclei. Hydrogen nuclei in the geologic media are primarily attributable to water molecules. Monitoring water content by neutron logging basically entails, at any depth, providing a standardized point source of neutrons provided by an americium-241 beryllium source and counting thermalized neutrons at a nearby boron trifluoride point source detector. The count rate after calibration is equated directly to the water content. A neutron logging tool is used on a routine basis to measure water content as a function of depth at the field test facility.

INSTRUMENT INSTALLATION

Soil physics instruments used to monitor energy and mass balance must be placed into the geologic media in a way that physical properties of the media are not altered. After construction of the main field test facility structure, individual instruments were installed. Access to these instruments was provided through horizontal tubes connecting the center instrument caissons to the outlying caissons and lysimeters. Through these tubes were placed the heat dissipation units, thermocouple psychrometers, thermocouples, thermistors, electrical resistance units, and tensiometers. Several sensors were emplaced during backfilling operations; however, the majority were emplaced after backfilling operations were completed.

Installation tools were fabricated to perform three basic functions; 1) horizontal coring of the geologic media, 2) insertion of a specific instrument, and 3) backfilling of a core. As an example, Figure 15 illustrates the heat dissipation unit installation tool. This figure shows an auger guide

FIGURE 15. Heat Dissipation Unit Installation Tool

tube which is mechanically driven, with an impact driver, through the instrument access tube to a desired horizontal distance within the geologic media. An auger is used to remove and collect the geologic media from within the auger guide as the tool is progressively inserted. The instrument is then installed through the auger guide and affixed in intimate contact with the geologic media. The backfill material is simultaneously replaced while the auger guide is removed by the impact driver. After instrument installation is completed the sensor lead wires are inserted through a rubber stopper and the instrument access tube is capped and sealed with a vulcanizing agent.

INSTRUMENT DATA COLLECTION AND REDUCTION DEVICES

Continuous monitoring of factors that control the movement of water in partially saturated geologic media systems is essential to quantitatively evaluate the rate and magnitude of radionuclide/water flux. Continuous monitoring requires data collection and reduction devices that will operate over sufficient diurnal, seasonal, and annual cycles to provide information to simulate, predict, and understand migration mechanisms within the geologic media. Much of the atmospheric and soil physics data are currently automatically collected, reduced, and recorded from the test facility by data loggers.

Data loggers monitor data both on a stochastic and deterministic basis depending on the type of sensors monitored. Deterministic input, e.g., wind direction and velocity, temperature, and relative humidity, is typically integrated over a specific time interval and subsequently recorded, whereas stochastic data are taken at specific time intervals and recorded. A schematic of a data logger is shown in Figure 16. This data logger accepts data directly from sensor lead cables into specific modules. These function modules provide signal conditioning for each input. The data logger outputs data at a specific time on printed hard copy paper and on magnetic tape.

FIGURE 16. Multiparameter Data Logger

RADIONUCLIDE/WATER TRACERS AND MONITORING SYSTEM

The magnitude and direction of transport depends on various physicochemical factors influencing the geologic media, the radionuclides or both. In order to monitor the migration of radionuclides and water in situ, cobalt-60 and tritium were emplaced into the geologic media of the test facility. These radioisotopes were selected as tracers which could migrate analogously to water, thus providing additional information to support results determined by instrument systems. Cobalt-60 complexed with ethylenediamine-tetraacetic acid (EDTA) was selected to trace the liquid phase. For the soil used in this test facility, cobalt-60 EDTA has a low distribution coefficient ($K_d = 0.01$), hence it is not readily adsorbed onto the geologic media under partially saturated conditions and migrates relatively freely with the water phase. Tritium was selected to trace both the liquid (HTO) and vapor (HT) phase water. Tritium similarly has a negligible K_d .

Radioisotope tracers were prepared and installed at the field test facility. Cobalt-60 EDTA solution was added to two 4.71 kg samples of stock backfill material to a concentration of $6.4 \mu\text{Ci/kg}$. Tritium was similarly added to the backfill material to a concentration of 6.37 mCi/kg . The sample weight of 4.71 kg equaled an equivalent volume of $\sim 0.2 \text{ m}^3$; i.e., a layer of geologic media when evenly distributed laterally within a radionuclide containment vessel would be 1.0 cm in depth. The radionuclide contaminated media was thoroughly mixed and placed in air-tight containers and promptly transported to the test facility. The in situ content at the depth of tracer emplacement was approximately maintained throughout tracer preparation.

Radionuclide containment caissons were excavated to a depth of 60.5 cm. The backfill material excavated from these caissons was placed in containers to maintain field water content. The radionuclide contaminated geologic media previously prepared in the laboratory was then put into the caissons (Figure 17) and distributed and compacted over a 1.0 cm depth within the caissons. Cobalt-60 and tritium were emplaced within a caisson within the controlled and ambient sides of the test facility.

FIGURE 17. Emplacement of Radionuclide Contaminated Geologic Media
 Into Caisson

At completion of radionuclide contaminated geologic media emplacement, the media and caisson walls were surveyed with radiological instruments to assure no contamination above ~59.5 cm was present. Finally, the previously excavated backfill was re-emplaced and compacted into the caissons to maintain the original media depth and density.

ACTIVE AND PASSIVE MONITORING OF RADIONUCLIDES

The migration of radionuclides which act as tracers for water movement through the partially saturated system is monitored by radiological counting systems. At the test facility, the migration of cobalt-60 is actively monitored in situ vertically through access wells installed through radionuclide containment caissons. In situ monitoring is conducted by portable logging equipment. Figures 18 and 19 illustrate the cobalt-60 counting system. A sodium-iodide scintillation detector and multi-channel analyzer system quantitatively determine the relative concentration by evaluating the 1.173 and 1.332 Mev gamma photon energy peaks of cobalt-60 over the entire depth of each caisson monitored. Atmospheric in situ tritium in the vapor phase will be monitored by a gas flow proportional counting system.

This system has been designed and tested on a preliminary basis in the laboratory. Figure 20 schematically illustrates the major components of the anti-coincidence flow proportional counting system. This system will monitor the relative concentrations of vapor phase tritium emanating from radionuclide containment caissons within which tritium has been emplaced at the 60.0-cm depth.

Passive monitoring of radionuclide concentration as a function of depth within the radionuclide containment caissons is also conducted. Passive monitoring permits extremely accurate determinations of radionuclide concentration, although the analytical results are not immediately available. Cobalt-60 and tritium monitoring samples are collected by withdrawal of geologic media from radionuclide containment caissons through tubes from the instrument access caisson. Contaminated samples are routinely collected by disposable sampling devices. Samples are subsequently taken from the test facility to the laboratory for analysis. Cobalt-60 concentration within the geologic media is directly counted by sodium-iodide spectrometry. Liquid phase tritium is counted by liquid extraction and liquid scintillation spectrometry.

FIGURE 18. Downwell Radionuclide Counting System

FIGURE 19. Downwell Radionuclide Counting System Electronics

FIGURE 20. Anti-coincidence Flow Proportional Counting System

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APPENDIX

ENGINEERING DRAWINGS FOR FIELD TEST FACILITY

APPENDIX

ENGINEERING DRAWINGS FOR FIELD TEST FACILITY

The five engineering drawings include details of location, excavation, and fabrication design of the test facility as summarized below:

(H-3-41654)

- Key Plan - illustrates the location of the test facility within the Hanford Site relative to the Columbia River, the Yakima River, the Washington Public Power Supply System (WPPSS), Nuclear Reactor Complex, the Fast Flux Test Facility (FFTF), and the City of Richland, Washington.
- Excavation Plan and Cross Section - illustrates the sediment excavation areal extent and depths.

(H-3-41655)

- Continuation and Detail from H-3-41654

"C-C" - details the caisson and weighing lysimeter installation within the excavation (plan view). Large caissons labeled Lysimeter I and II are designed to contain uncontaminated sediments. The middle caisson is designed for access. The four smaller caissons in the interstices of the larger caissons are designed for containment of radionuclide contaminated sediments. The connecting tube from the middle instrument caisson to one weighing lysimeter is also included. One weighing lysimeter (1 of 2) is designed to connect to the center caisson.

"B-B" - details the caisson installation within the excavation (cross section). Steel reinforced concrete is designed as a base to support the caissons and to provide a barrier to radionuclide transport out of the facility. Backfill material surrounding the caissons is also illustrated.

"D-D" - details the weighing lysimeter-instrument access caisson interconnection (cross section). A steel reinforced concrete pad with a center drain connects with the instrument access caisson as does the large tube interconnecting the weighing lysimeter. Backfill material surrounding the weighing lysimeter and caissons is also illustrated.

1 - details the tubes that interconnect the instrument access caisson to the surrounding caissons.

2-3 - detail the interconnection of the large caisson/weighing lysimeter tube. This tube is connected from the instrument access caisson to the weighing lysimeter with a flexible boot. This tube is sufficient in radial dimension to permit access to the base of the weighing lysimeter.

(H-3-41656)

- Weighing Lysimeter Pad - details weighing lysimeter pads which support the load platforms and weighing lysimeter vessels.

(H-3-41657) (1 of 2)

- Plan Upper Level - details the structure that covers the top of the instrument caisson (plan view). The cover extends over the instrument access caisson within which an entrance is provided.
- Plan Lower Level - details the structure that supports instruments within the instrument access caisson. A hatch is shown which permits access to the bottom of the instrument access caisson.

"A-A" - details the emplacement of: upper and lower level structures. Continuous access to the surrounding caisson is provided by interconnecting tubes, which can be reached by ladders.

"B-B" - details the hatch through the lower level.

(H-3-41657) (2 of 2)

- 1 - details the upper hatch cover used for entrance into the top of the instrument access caisson.
- 2 - details the lower hatch cover used for entrance through the sub-floor within the instrument access caisson.
- 3 - details the ladder used for access from the top through the intermediate level and to the base of the instrument access caisson.
- 4 and 5 - detail interconnection of hatch cover supports to the instrument access caisson.

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