LA-UR -82-1692

Conf-820674--1

MASTER

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

LA-UR--82-1692

DE82 018374

TITLE: SOME INTERACTIVE FACTORS AFFECTING TRENCH-COVER INTEGRITY ON LOW-LEVEL WASTE SITES

DISCLAIMER

AUTHOR(S): T. E. Hakonson,
L. J. Lane, LS-
J. G. Steger, L:
G. L. DePoorter,

SUBMITTED TO: To be presented at the Symposium on Low-Level Waste Disposal: Site Characterization and Monitoring, Arlington, Virginia, June 16-17, 1982.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FORM NO. 836 R4
ST. NO. 2629 5/81

SOME INTERACTIVE FACTORS AFFECTING TRENCH COVER INTEGRITY ON LOW-LEVEL WASTE SITES

T. E. Hakonson
L. J. Lane
J. G. Steger
G. L. DePoorter

Environmental Science Group
Los Alamos National Laboratory
Los Alamos, NM 87545

ABSTRACT

This paper describes important mechanisms by which radionuclides can be transported from low-level waste disposal sites into biological pathways, discusses interactions of abiotic and biotic processes, and recommends environmental characteristics that should be measured to design sites that minimize this transport. Past experience at shallow land burial sites for low-level radioactive wastes suggests that occurrences of waste exposure and radionuclide transport are often related to inadequate trench cover designs. For example, many of those radionuclide transport occurrences relate to processes involving water (excess runoff, erosion, and percolation) and biota (inappropriate vegetative cover and biological intrusion). We believe that site characterization should involve a careful analysis of excess surface runoff and erosion, soil moisture in the cover profile, vegetation on the cover surface, biological intrusion, excess interactions, and in addition, climatic variability.

Meeting performance standards at low-level waste sites can only be achieved by recognizing that physical, chemical, and biological processes operating on and in a trench cover profile are highly interactive. Failure to do so can lead to improper design criteria and subsequent remedial action procedures that can adversely affect site stability. For example, efforts to reduce infiltration of water through the trench cover with a moisture barrier near the surface can drastically alter the water balance in the cover profile. Important consequences of that action might include reducing infiltration of surface water with a subsequent increase in runoff and erosion of cover soil.

Based upon field experiments and computer modeling, recommendations are made on site characteristics that require measurement in order to design systems that reduce surface runoff and erosion, manage soil moisture and biota in the cover profile to maximize evapotranspiration and minimize percolation, and place bounds on the intrusion potential of plants and animals into the waste material. The use of shallow land burial designs that reduce erosion, manage moisture in the cover profile, and prevent plant and animal intrusion into the waste material will result in control of major pathways of radionuclide migration that lead to man.

Major unresolved problems include developing probabilistic approaches that include climatic variability, improved knowledge of soil-water plant erosion relationships, development of practical vegetation establishment and maintenance

procedures, prediction and quantification of site potential and plant succession, and understanding the interaction of processes occurring on and in the cover profile with deeper subsurface processes.

INTRODUCTION

The disposal of waste by shallow land burial has a history almost as old as man. In recent times the waste that seems to have attracted the most attention is radioactive waste. Substantial research has been directed to radioactive waste management since the mid-1940s. In fact, in TID-3311 (1) there are over 22,000 abstracts on the subject. Despite the voluminous literature, our ability to present convincing evidence for shallow land burial (SLB) site safety is less than desirable, as evidenced by only 3 of the 6 commercial sites that are currently operational.

This paper identifies and discusses trench cover related processes by which radionuclides from low-level waste disposal sites may enter biological pathways, based on a review of past performance of commercial and Department of Energy sites, and on an analysis of the interdependence of those processes using a state-of-the-art water balance model. From that analysis, information needs for site characterization and monitoring are identified to assist in designing effective trench cover systems and to monitor site performance.

TRENCH COVER FAILURE MODES—OPERATING EXPERIENCE

The long term integrity of sites used for SLB of low-level radioactive waste (LLW) will depend on the complex interactions between the physical, chemical, and biological processes that modify the waste containment system. The containment system for low-level waste usually consists of a trench of from about 1 to 45 m wide, 2 to 11 m deep, and 6 to 300 m long (2). Diverse physical and chemical forms of waste are placed into the trench, with or without backfill, until the trench is nearly full. A final cover of about 1 to 2 m of soil is applied, often followed by attempts at revegetation to minimize erosion, and secondarily, to increase aesthetic appearance of the site.

Environmental processes that result in radionuclide transport from a burial site primarily involve water and/or biota. At present there appears to be considerable concern about the ground water transport pathway as evidenced by the minimum technical requirements in 10CFR61 (3). Extensive efforts are underway to measure transfer coefficients, develop models, and calculate potential human exposure via ground water pathways. There is no question that concern with ground water contamination is justified because this media is not readily subject to remedial action.

There are, however, several other important pathways, particularly in arid sites, by which radionuclides can be transported from SLB sites. Most of those pathways, either directly or indirectly, involve the trench cover.

Trench covers are exposed to a very dynamic environment and must perform (i.e., isolate waste) under harsh temperature regimes, dramatic changes in plant and animal species composition as natural succession occurs, and under extreme conditions of wetting and drying. Failure to perform in any of these areas can result in the failure of engineered barriers within the cover, excessive erosion of the cover soil, excess percolation of water into the trench, and plant and animal intrusion and imobilization of the waste. Under these constraints, it is not surprising that the most frequent failure mode at existing LLW sites in the U.S. involves processes interacting with the trench cover. Fortunately, the accessibility of the trench cover facilitates required remedial action to correct contamination problems, in direct contrast to correcting the problems arising from ground water contamination.

Documented examples of radionuclide transport arising from cover related processes (1,4,5,6) suggest that management of surface water and biota can be an important consideration in the long-term isolation of wastes in both humid and arid regions (Table 1). Some problems that have occurred because of surface water include erosion at West Valley and Maxey Flats, seeps from the down slope trenches at Oak Ridge, and bath tub overflow at West Valley, Maxey Flats, and Oak Ridge caused by permeable trench covers and backfill in relatively impermeable host soils (Table 1).

Arid sites do not completely escape problems with water, as evidenced by trench flooding at Idaho National Engineering Laboratory (INEL) caused by rapid snow melt. However, over 40 years of operating experience at LLW sites in the arid west suggests that percolation of water through the trench cover and into the trenches is generally a low-order process despite the very intense rainstorms and dramatic flooding events that occur in this region.

Plants are frequently involved in radionuclide transport from trenches in both arid and humid LLW sites, and at least in some arid sites requires frequent remedial action. For example, uptake of ^{90}Sr by Russian thistle has been a chronic problem at Hanford, while ^{3}H in flowering vegetation with the potential for transfer of tritiated water to honey bees and honey, is at least partially responsible for summer mowing of vegetation on a LLW site at Los Alamos (Table 1). Humid sites reporting radionuclides in vegetation growing on LLW sites are Savannah River, Maxey Flats, West Valley, and Oak Ridge. Plant uptake of radionuclides at arid sites has been reported for INEL, Hanford, and Los Alamos (Table 1).

Table 1. Reported Releases from Low-Level Waste Sites by the Surface Pathway (Refs. 1, 4, 5)

Surface Waters

Humid Sites
- Seeps - Oak Ridge
- Erosion - West Valley, Maxey Flats
- Bath tub effect - Maxey Flats, West Valley, Oak Ridge

Arid Sites
- Snowmelt - Idaho

Plants

Humid Sites
- Uptake - Savannah River, Maxey Flats, Oak Ridge

Arid Sites
- Uptake - Los Alamos, Hanford, Idaho

Animals

Arid Sites
- Nesting - Los Alamos
- Nutrients - Hanford
- Burrowing - Hanford, Idaho, Los Alamos

Because of the overwhelming concern about ground water pathways at humid LLW sites, animal intrusion is generally considered to be unimportant as evidenced by the lack of references on the subject. Animal intrusion into trench covers at humid sites simply may not occur or it may be a minor transport pathway that can be disregarded. Present data are not sufficient to support either contention.

There is accumulating evidence that animal intrusion into arid LLW sites can be important in transporting wastes to the ground surface and in altering the long-term integrity of the trench cover. Burrowing animals have intruded into sites at Hanford, INEL, and Los Alamos (Table 1).

Operating experience at the 11 LLW sites in the U.S. suggests that many of the problems that relate to radionuclide transport often do not involve ground water and invariably involve interactions that occur with the trench cover. Those interactions, which involve both water and biota, are not well understood, particularly the role that plants and animals play in regulating the water balance in the cover profile and the importance of biological intrusion through the cover and into the waste as a radionuclide transport pathway. Few comprehensive long-term pathway analyses have been attempted to determine the relative importance of subsurface and surface processes in transporting LLW to man (7). Under a home farm scenario whereby a family living on an abandoned low-level waste site at Savannah River Laboratory derived most of their food and water from the site, uptake of ^{90}Sr by cereal grains used as food provided the most significant, albeit very low, dose to the family.

A similar analysis for a site at Los Alamos indicated that mechanical disturbances caused by tilling resulted in the highest doses to humans farming the site (8).

To provide a basis for information needs during site characterization and monitoring, the following sections will examine some of the important relationships between water and biota in the trench cover.

HYDROLOGIC INTERACTIONS WITH TRENCH COVERS

A Water Balance Approach

A conceptualization of some of the processes affecting SLB site integrity (Figure 1) illustrates the interdependence of water and biota in the trench cover. Falling precipitation on the site is subject to interception by the plant canopy, removal as surface runoff, and/or infiltration into the soil profile. Water that infiltrates into the soil can be removed by evaporation (E) from the soil surface and plant transpiration (T) or as the combined process of evapotranspiration (ET). Water remaining in the soil can be stored or can infiltrate deeper into the waste and backfill. By definition, water that moves below the plant root zone will be termed seepage or percolation. As will be discussed later in more detail, plants and animals can also intrude into the waste via root and burrow systems (Figure 1).

Interactions of those processes can be expressed in a water balance equation for the trench cover profile as follows:

$$\frac{dS}{dt} = P - Q - ET - L \qquad (1)$$

where

S = soil moisture,
P = precipitation,
Q = runoff,
ET = evapotranspiration,
L = seepage or percolation, and
t = time.

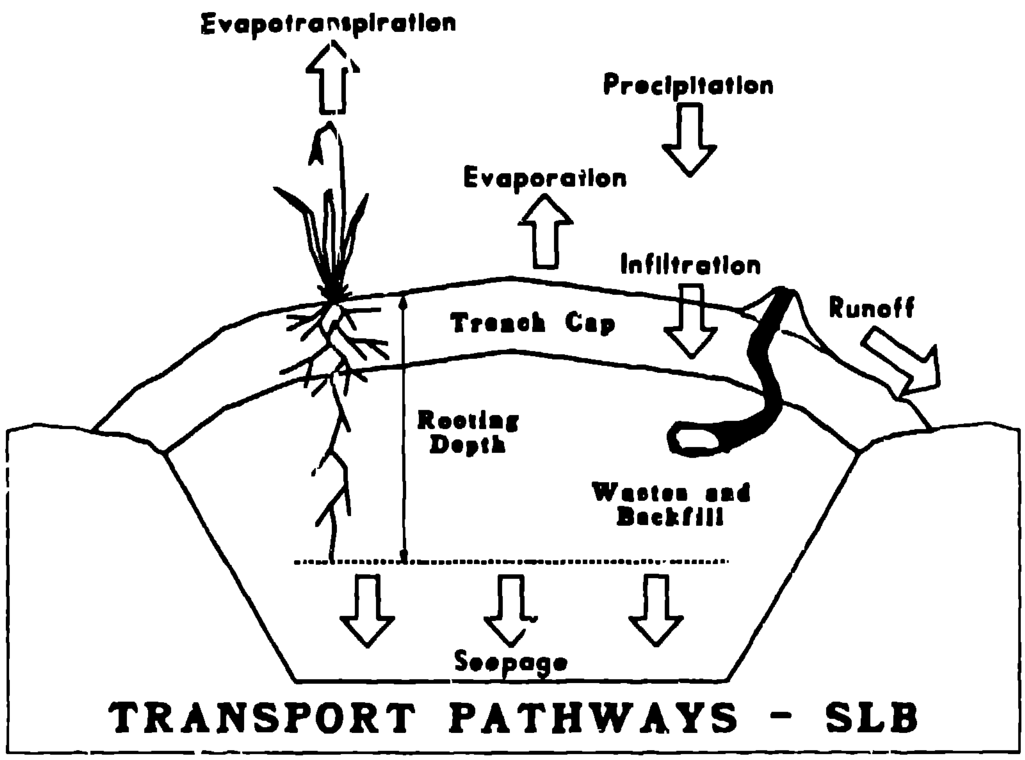

Figure 1. Water and Biota - Related Processes Contributing to Radionuclide Transport at Shallow Land Burial Low-Level Radioactive Waste Sites.

The rate of change in soil moisture (as stored in the cover profile) is equal to the difference between input (P) and output (Q, ET, and L) as illustrated in Figure 1. Units of the terms in Eq. 1 are generally expressed as volume per unit area per unit time, or equivalently, depth/time (e.g., mm per day, month, or year).

The amount of soil moisture (S) stored in the profile is a function of the water holding capacity of the soil, plant rooting depth, and the antecedent and current values for the variable on the right side of Eq. 1. Precipitation (P) is a function of the climate at a particular waste burial site and is highly variable in time and space. Runoff (Q) is a function of precipitation, soil type, vegetation, surface management practice, and soil mosture. Evapotranspiration (ET) is a function of climatic variables (e.g., precipitation, temperature, solar radiation), soil properties vegetation type, and soil moisture. Percolation (L) is a function of soil properties and soil moisture.

Because soil erosion and sediment transport are strongly related to precipitation and runoff, they are also related to the other terms in the water balance equation. Finally, because plant and animal intrusion through the trench cap affect the water balance, they also affect infiltration rates and erosion.

Based on the foregoing discussion, most of the components of the water balance equation illustrated in Figure 1 also illustrate contaminant transport pathways that can result in dose to man. Specific examples include:

- erosion of the trench cover and exposure of the waste,
- percolation of surface water into the trench with subsequent leaching and transport of the waste,
- capillary forces created by evapotranspiration, which transport waste to the ground surface, and
- plant and animal transport of the waste to the ground surface.

In order to control those pathways and to determine site characteristics that must be measured to ensure control, we must recognize that we are dealing with an interactive system. For example, suppose we adopt a conservation measure to control trench cover erosion by reducing surface runoff. We need to know how this conservation measure influences other terms in the water balance equation, and, by extension, the other contaminant transport pathways such as plant uptake and percolation. Likewise, if we install a biological intrusion barrier system (e.g., a rock layer within the cover profile) to prevent plant and animal access to the buried waste, we need to determine how this action might influence the water balance equation and, again by extension, contaminant transport pathways associated with runoff, erosion, and percolation.

The Need for a Simulation Model

Because climatic, hydrologic, and biologic processes are highly variable in time and space, it is impossible to measure or monitor them under conditions representative of all possible combinations of soils, climate, topography, vegetative cover, and land use. Consequently, there is a need for mathematical models to predict those processes under a wide range of environmental conditions. Procedures to estimate runoff, erosion, infiltration, percolation, evapotranspiration, and soil moisture in trench cover systems, such as are illustrated in Figure 1, will be essential in designing and monitoring the performance of future SLB sites.

In response to similar needs for agricultural systems, the U.S. Department of Agriculture (USDA) developed a reasonably simple computer simulation model called CREAMS (Chemicals, Runoff, and Erosion in Agricultural Management Systems) (9,10,11,12,13), which included hydrology and erosion/sediment transport components. The model was intended to be useful without calibration or collection of extensive site specific data to estimate parameter values by taking advantage of extensive experimental data sets (9) derived over the years by USDA and others.

The CREAMS model has received wide use and acceptance (14) and recently has been proposed as a useful tool in waste management studies (15,16). Although the model has been applied to shallow land burial sites, additional research will be required to estimate model parameters under semiarid conditions and under unique cover profile conditions such as wick systems, moisture barriers, and biobarriers that have been considered for shallow land burial systems. Toward this end, experiments are underway (15,16) to provide information on parameter values at locations representative of large areas of the western United States and under conditions representative of shallow land burial systems.

Overview of the CREAMS Model

The hydrology component includes two options. The first is a daily rainfall model based on the Soil Conservation Service runoff equation and the second, an infiltration model using time-intensity rainfall data (17). The soil profile, to the plant rooting depth, is represented by up to seven layers (which can represent multilayered cover systems), each with a representative thickness and water storage capacity. The evapotranspiration calculations are based on a procedure developed by Ritchie (18) and include soil evaporation and plant transpiration estimates based on monthly air temperature, solar radiation, and a leaf area index. Flow through the root zone is computed using a soil water storage-routing routine and percolation is estimated when soil moisture exceeds field capacity. These calculations maintain a water balance as described by Eq. 1.

Using storm inputs from the hydrology component, the erosion/sediment yield component computes soil detachment, sediment transport, and deposition by routing sediment through overland flow and concentrated flow (13). Gross erosion and sediment yield are computed by sediment particle size classes, which include soil aggregates.

Conservation Research Report No. 26 (9) includes a more detailed description of these components, results of model testing and evaluation, a sensitivity analysis, and a users manual for preparing model input.

Applications in Predicting Water Balance

Anticipated applications of the CREAMS model in waste management (site selection and characterization, evaluating management alternatives, remedial actions, and experimental design) were described previously (15,16). The following discussion compares measured soil moisture, under a variety of enviromental conditions, with simulated results based on the CREAMS model.

Input data for the comparison were obtained from a moisture cycling experiment at Los Alamos, New Mexico (19) and using data from Rock Valley on the Nevada Test Site (20). Data from Los Alamos represent a semiarid site (mean annual precipitation of 470 mm) and data from Rock Valley represent an arid site in the northern Mojave Desert (mean annual precipitation of 165 mm). Input data consisted of daily precipitation, mean monthly air temperature and solar radiation, textural analysis and water holding capacity of the soil, plant rooting depths, and vegetative cover density. Data from Los Alamos were for a 6 month period (July-December 1981), and data from Rock Valley were for a 5 year period (1968-1972).

Soil moisture was measured at Los Alamos with neutron probes to a depth of 120 cm in 90 cm wide by 150 cm deep culverts filled with a sandy backfill material (crushed tuff) used in shallow land burial operations at Los Alamos. One plot was maintained with a bare soil surface (unvegetated) and vegetation (barley, *Hordeum vulgare*) was established on the other plot. Soil moisture at the Rock Valley site was estimated from gravimetric analysis of samples collected at depths of 15 and 35 cm. Soil moisture measurements were made about once a week at Los Alamos and about once every two weeks at Rock Valley. Although the CREAMS water balance model simulates soil moisture in layers from the surface to the rooting depth, measurements at Los Alamos and Rock Valley were for soil moisture at depths of 15 cm or greater, whereas simulated soil moisture was averaged throughout the entire soil profile. Despite that difference, we compared simulated and measured soil moisture, averaged over the entire soil profile, to examine performance of the model in reproducing the measured seasonal trends.

Components of the monthly water balance for the unvegetated plot at Los Alamos are shown in Figure 2. In general, computed evaporation rates from the unvegetated plot were less than water application rates. As a result, average soil moisture in the profile continued to increase from July to December. Figure 3 shows similar data for the vegetated plot at Los Alamos. In general, evapotranspiration (ET) rates exceeded water application rates, and as a result, average soil moisture in the profile decreased from July to December. Computed ET was greater by about a factor of 2 on the vegetated plot than on the bare-soil plot; these computations are supported by the measured soil moisture data (Figures 2 and 3). Moreover, the simulated soil moisture closely matched trends in the observed soil moisture.

The observed data in Figures 2 and 3 suggest that establishing and maintaining vegetation on a trench cover can be an effective means of managing moisture in the cover profile. Those data also suggest that the CREAMS model can account for soil moisture differences caused by increased ET on the vegetated plot.

Components of the monthly water balance for a natural vegetation community at Rock Valley are shown in Figure 4. Computed ET rates were less than measured precipitation for the months of December, January, and February. These are the months in which soil moisture is stored in the soil profile. Precipitation is less than computed ET during March, April, and May and is reflected by soil moisture depletion. During the remainder of the year, monthly ET is essentially equivalent to monthly precipitation. These trends are reflected in the measured and simulated soil moisture as shown in Figure 4. Although there are differences in measured and computed values of average monthly soil moisture, the model explained the observed seasonal trends.

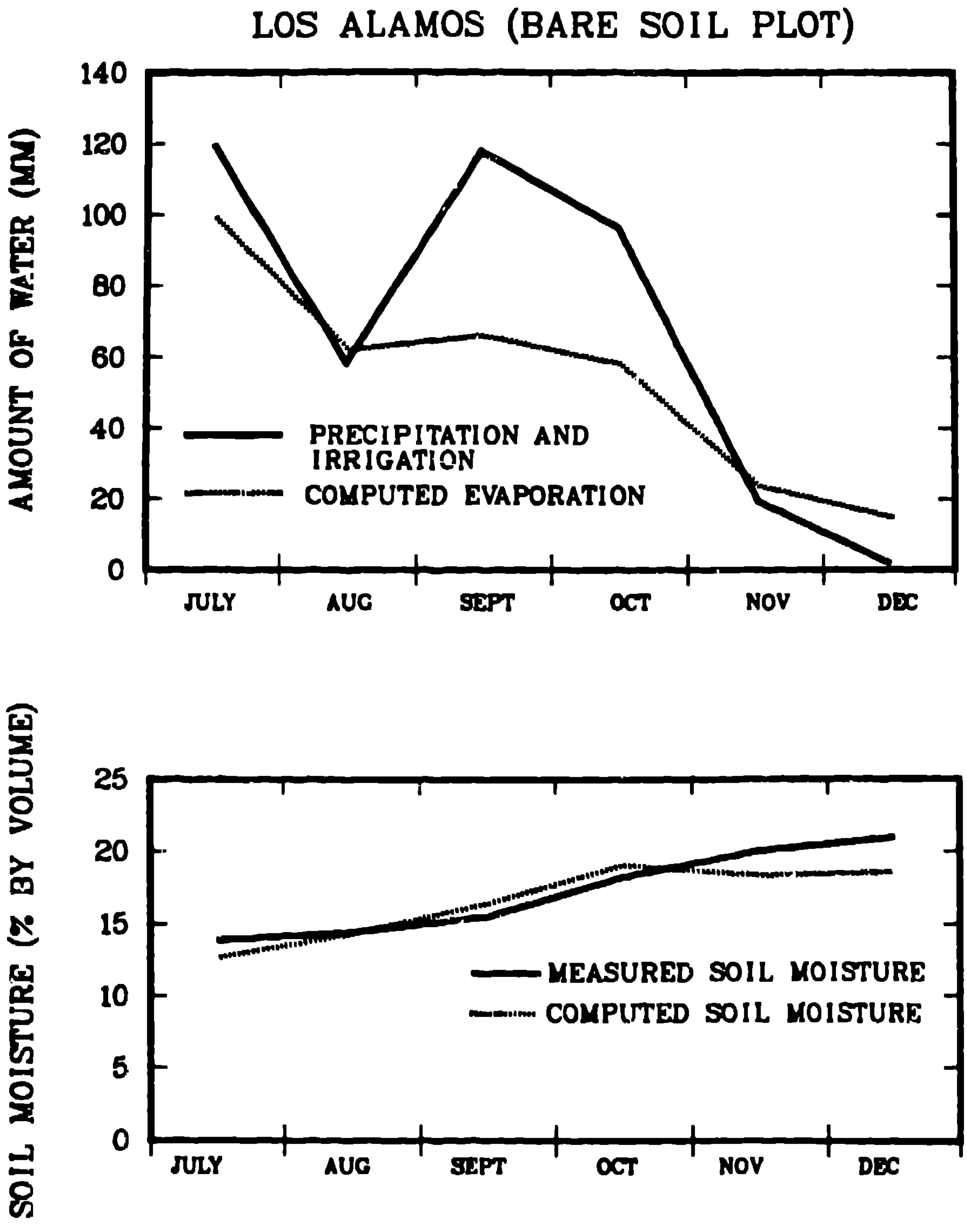

Figure 2. Components of the Monthly Water Balance for Los Alamos, NM; Bare Soil Plot, 1981.

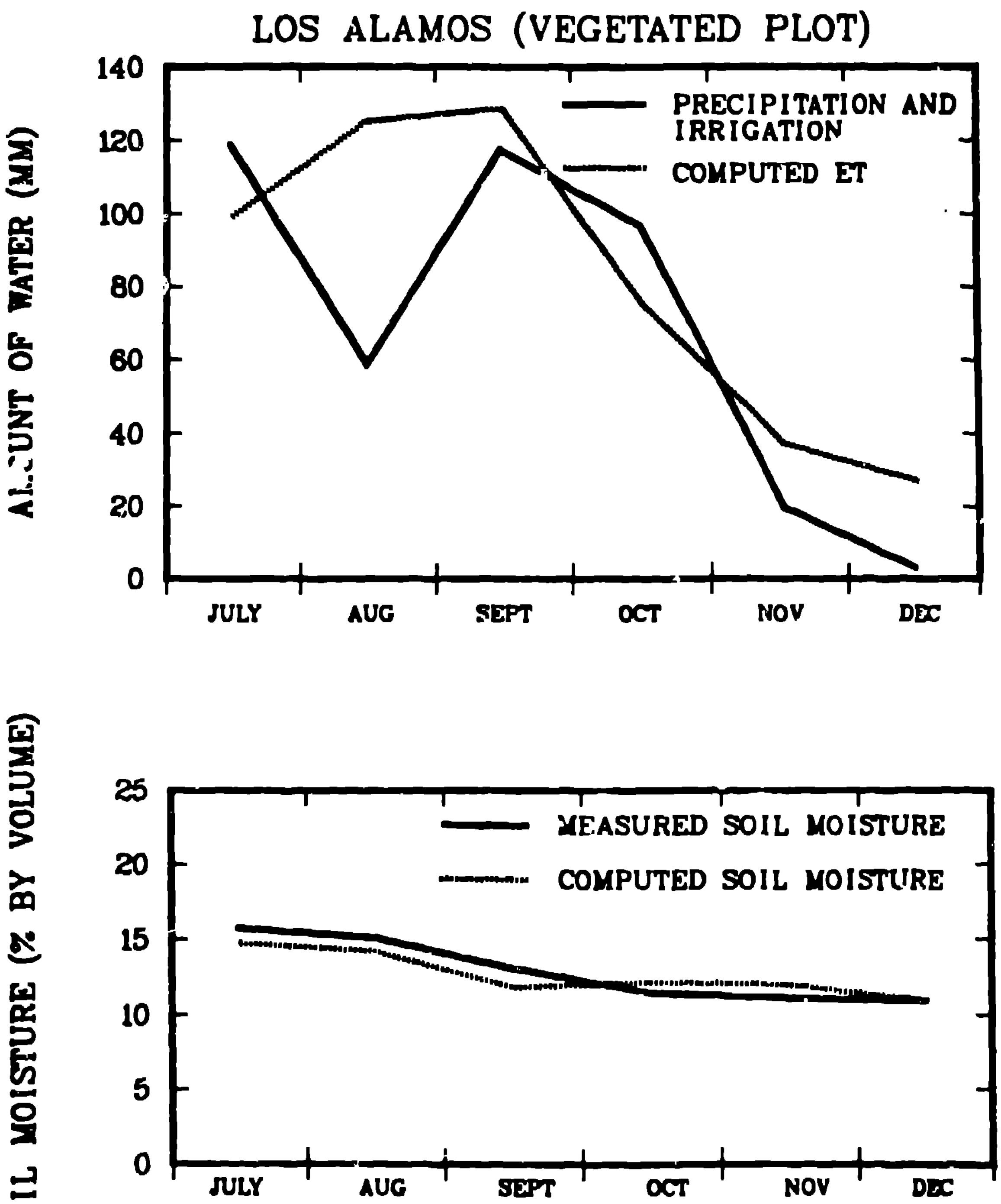

Figure 3. Components of the Monthly Water Balance for Los Alamos, NM: Vegetated Plot, 1981.

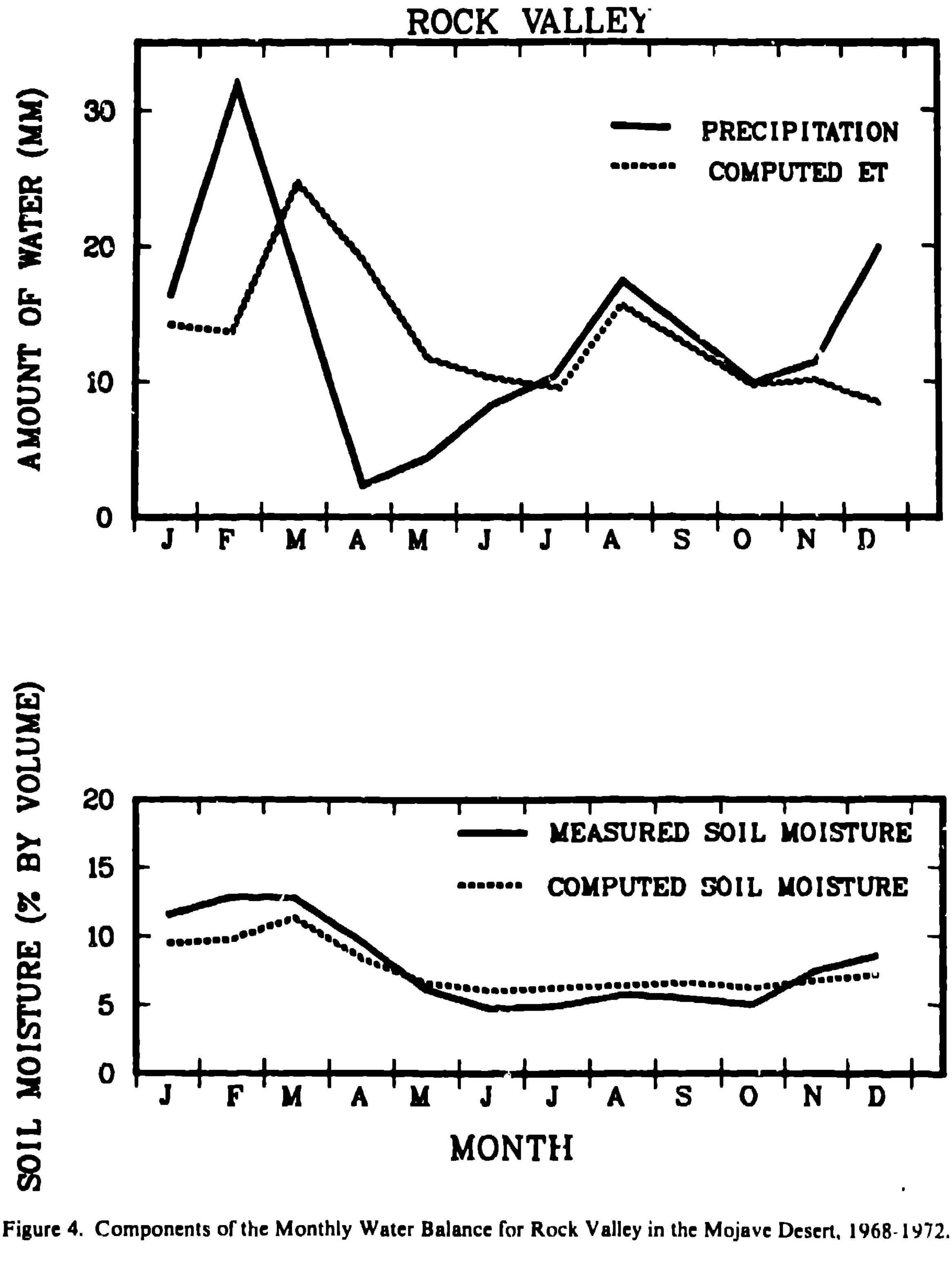

Figure 4. Components of the Monthly Water Balance for Rock Valley in the Mojave Desert, 1968-1972.

The relationship between measured mean monthly soil moisture and estimates based on the CREAMS simulation model (Figures 2, 3, and 4) suggest significant errors in estimated soil moisture for individual values, but the model explained most of the variation in monthly soil moisture ($r^2 = 0.93$ for combined data sets). Based on previous analyses, the CREAMS model has applications for cultivated agriculture. Based on the analysis of data from Los Alamos and Rock Valley, the model appears to have potential for estimating the water balance in semi-arid and arid areas.

Of course, adequate evaluation of the model, under varied waste disposal conditions in arid and semi-arid regions, will not be possible until experimental data are available for erosion and all components of the water balance. Such data are now being collected using large lysimeters, runoff-erosion plots, and experimental watersheds (19).

BIOLOGICAL INTERACTIONS WITH TRENCH COVERS

Despite the important role of vegetation in controlling the water balance in the cover profile, deep rooted plant species can access radionuclides and bring them to the soil surface. Radionuclides in plant tissue can be ingested by herbivores or nectar collecting organisms such as honey bees. At Los Alamos, one of the pathways of radionuclide transport away from the Laboratory's closely controlled SLB sites is via the soil moisture-plant nectar-honey bee-honey pathway (21), although radiation doses to humans that might consume this honey are estimated to be very small.

The importance of preventing buried waste from reaching the ground surface is illustrated by a pathway model of plutonium behavior in terrestrial ecosystems (Figure 5). Radionuclides buried below the ground surface can be absorbed by plant roots and deposited in above ground tissue. However, when the radionuclides are present in surface soils, as is the case at several LLW sites, physical resuspension of soil particles (especially the clays) by wind and water can deposit contaminated soil particles on plant surfaces (i.e., leaves, stems, and fruiting bodies). Field studies (22) with plutonium, as well as other radionuclides, show that for every picocurie taken up by plants roots, at least 10 (and often 100 to 1000) picocuries can be deposited on foliage surfaces. Of course, most herbivores consume those radionuclides whether they are on or in the plant. Even in the case of humans, who presumably wash vegetable crops before consumption, as much as 50% of their radionuclide intake from consuming certain garden vegetables may be from very small soil particles (clays) not removed from crop surfaces by standard household food washing procedures (23).

The importance of burrowing activities within a trench cover is generally disregarded except in those cases, primarily in arid sites, where problems have arisen (24,25). Trench covers are disturbed soil systems, often loosely compacted and are readily invaded by native plants and animals. Burrowing animals utilize the void spaces left after trench backfilling as natural tunnels and nesting sites (26).

Burrowing activities by animals play an important role in chemical cycling in the soil profile. The vertical transport of Fe, Se, Al, Ca, Mg, U, Ra, and Th from deep soil layers to the surface by the mechanical action of rodents (27,28) has given rise to the statement that burrowing rodents serve as "nutrient pumps" that bring insoluble materials to the soil surface for weathering (29,30). As mentioned before, soil and chemicals brought to the surface are more readily available for resuspension and transport by physical processes.

Although burrowing animals can gain access and transport waste to the ground surface, less obvious interactions with the cover and trench backfill may be of greater importance. For example, pocket gophers inhabiting a LLW site at Los Alamos excavated about 12,000 kg of soil per hectare from a trench cover during a one year period (31). Displacement of that amount of soil created about an 8 m^3 void space in the cover or about 2800 m of tunnel system. Soil disturbance of a similar or greater magnitude, caused by burrowing animals, has been documented in many parts of the Western U.S.

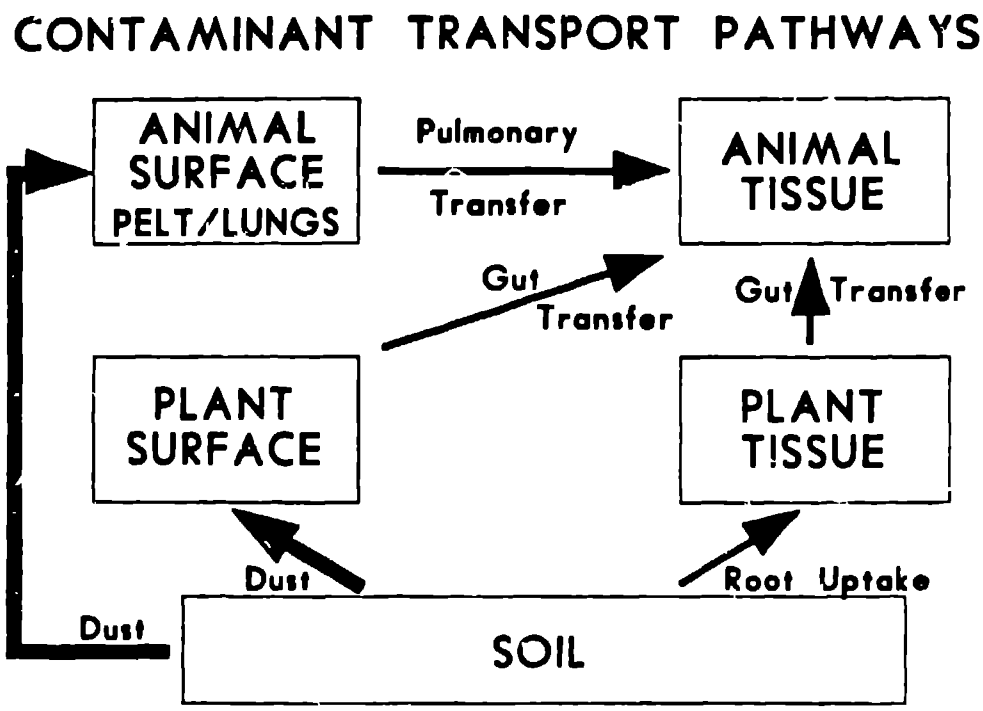

Figure 5. Transport Pathways for Plutonium and Other Radionuclides Deposited in the Soil Compartment of Terrestrial Ecosystems. Physical Resuspension of Soil Particles with Subsequent Deposition on Biological Surfaces Dominates in the Transport of Many Soil Contaminants to Biota.

(32,33,34,35,36). Tunnel systems created by pocket gophers in Colorado have been shown to increase rates of water infiltration (by decreasing bulk density) into the soil profile by a factor of two over similar but undisturbed profiles (37,38). Compared with undisturbed vegetated soil surfaces, soil cast to the surface by burrowing activity is also subject to accelerated erosion (33).

Burrowing animals can also greatly alter the integrity of engineered, multi layer soil profiles by penetrating through such profiles and/or by vertically displacing the layers. In native ranges, under high population densities, pocket gophers are estimated to turn over 15 to 25% of the soil surface in a single year (35,36).

Despite the foregoing evidence supporting the important role that animals play in modifying the soil profile, our understanding of this role in relation to long-term LLW site stability is minimal. Information is needed on relationships of burrowing animals to erosion, infiltration rates of water into the soil, and effects on plant density and succession. Likewise, successional patterns for animals that occupy LLW sites are needed to determine changes in the long-term intrusion potential for the species that occupy the sites.

ECOLOGICAL INFORMATION REQUIRED FOR SITE CHARACTERIZATION

Trench covers, important components in a shallow land burial systems, have proved to be a frequent source of problems relating to waste transport from sites. As we have shown, using a water balance approach, environmental processes operating on and in a trench cover profile are highly interdependent. The CREAMS model assembles these basic processes into a forecasting tool that can be used in site characterization, site monitoring, optimization of trench design, and performance evaluation. For example, the fundamental role of vegetation in trench cover water balance indicates the need to measure soil-plant-water relationships to fully exploit the benefits of plant cover in managing surface water and, hence, site performance. Likewise, the controlling influence of precipitation dictates that we have good estimates of climatic variability and climatic extremes in order to develop probabilistic approaches to designing trench covers and predicting performance.

Relationships in the CREAMS model were, for the most part, derived from cultivated agricultural land and should be immediately useful in design and evaluation of humid LLW sites. Less information is available for semiarid and arid regions. Information required for input to CREAMS (Table 2) also identifies measurements that should be made during site characterization. Data that are relatively easy to obtain or derive from the literature are topography, soil type, and soil characteristics. Less information is available on plant-soil-water relationships, particularly for the nonagricultural plant species often used in revegetation of LLW sites.

A number of studies are currently underway at Los Alamos to provide technical data on the water balance in the cover profile (15,16,19). Those studies address questions relative to plant rooting depth, evapotranspiration, and the effect of vegetation cover on runoff and erosion.

The importance of biological intrusion in mobilizing waste and in altering water relationships in cover profiles cannot be fully assessed at this time because of the lack of pertinent data and attempts to assess the relative importance of the various radionuclide transport pathways at LLW sites. Some of the important information needs relative to biological intrusion are listed in Table 2. An important question regarding both plants and animals is how intrusion potential changes as biotic species change because of natural succession. At Los Alamos, in as little as 35 years, LLW site ground cover can change from a bare, unvegetated surface to a near climax vegetation community consisting of large trees and shrubs (39). Several studies are underway in the U.S. to develop biological intrusion barrier systems that limit plant root and burrowing animal access to the waste (40,41,42).

SUMMARY

Based on a review of operating experiences at several low-level waste sites in the U.S., occurrences of radionuclide transport from these sites generally involve failure of the trench cover. Furthermore, transport pathways often do not involve ground water, but rather lead to contamination of soil and biota on the trench cover surface. The availability of a procedure to accurately estimate soil water balance allows for *a priori* identification of critical features of SLB trench covers that can be manipulated to optimize designs and to select features for monitoring to evaluate site performance.

The CREAMS model has been showsn to reflect changes in soil moisture under varying conditions of precipitation, evapotranspiration, runoff, and percolation as influenced by soils, vegetation, land use, and climate. Of special significance is the ability to quantify the role that vegetation plays in the soil water balance.

The role that plants and animals play in transporting radionuclides from burial trenches cannot be fully assessed, although there are indications that these transport pathways cannot be dismissed as unimportant. Past studies have shown that radionuclides brought to the soil surface can be transported by wind and water to offsite areas and that these physical transport processes dominate in the movement of soil contaminants through food webs.

Major unresolved problems include developing probabilistic approaches that include climatic variability, improved knowledge of soil plant water erosion relationships, development of practical and optimum revegetation and cover maintenance schemes, prediction and quantification of plant and animal succession, and understanding the interaction of processes occurring on and in the trench cover with deeper subsurface processes.

Table 2. Examples of Information Needs Relative to Low-Level Waste Burial Site Trench Covers

Water Balance Interactions--Input Data for the CREAMS Model
Topography
• Position of facility in the watershed
• Slope steepness, length, and shape
Soil Characteristics in the Trench Cover
• Soil type, texture, and erodibility
• Soil depth, structure, and layering
• Water holding capacity and hydraulic conductivity
Vegetative Cover
• Plant rooting depth
• Seasonal leaf area index for evapotranspiration
• Plant density and canopy height for erosion estimates
Climatic Data
• Daily precipitation
• Mean monthly air temperature and solar radiation
Biological Intrusion Potential
• Rooting depths of major plant species
• Burrowing depths of major animal species
• Plant and animal successional patterns and their interactions

ACKNOWLEDGMENTS

This work was supported by the Department of Energy under contract W-7405-ENG-36 with Los Alamos National Laboratory.

We gratefully acknowledge the assistance of M. Hakonson, E. Montoya, W. Hansen, and G. White in completing this manuscript.

REFERENCES

1. USDOE, Radioactive Waste Processing and Disposal, USDOE TID-3311, Suppl. 1-9 (January 1980).

2. J. O. Duguid, Assessment of DOE Low-Land Radioactive Solid Waste Disposal Storage Activities, BMI-1984 (November 1977).

3. 10CFR61, Licensing Requirements for Land Disposal of Radioactive Waste, (Proposed Rule) Federal Register 46(142) (July 1981).

4. D. G. Jacobs, J. S. Epler, and R. R. Rose, Identification of Technical Problems Encountered in the Shallow Land Burial of Low-Level Radioactive Wastes, ORNL/SUB-80/136/1 (March 1980).

5. J. J. Clancy, D. F. Gray, and O. I. Oztunali, Data Base for Radioactive Waste Management, NUREG/CR-1759, Vol. 1 (November 1981).

6. R. Kahle and J. Rowlands, Evaluation of Trench Subsidence and Stabilization at Sheffield Low-Level Radioactive Waste Disposal Facility, NUREG/CR-2101 (May 1981).

7. C. M. King, "Radionuclide Migration Model for Buried Waste at Savannah River Plant," Waste Management 82, Tucson, AZ (March 1981).

8. W. R. Hansen, D. C. Nelson, G. Maestas, W. J. Wenzel, F. A. Guevara, J. L. Warren, J. C. Rodgers, and J. M. Graf, Alternative Transuranic Waste Management Strategies at Los Alamos National Laboratory, LA-8982-MS, UC-70 (September 1981).

9. W. G. Knisel, Jr. (Ed.), CREAMS: A Field-Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems, USDA-Conservation Research Report No. 26 (May 1980).

10. W. G. Knisel, Jr., A System for Evaluating Non-Point-Source Pollution - An Overview, International Institute for Applied Systems Analyis, Laxenburg, Austria, Rept. No. CP-78 11 (December 1978).

11. W. G. Knisel, Jr., "Erosion and Sediment Yield Models - An Overview," ASCE Watershed Management Symposium, Boise Idaho (July 1980).

12. W. G. Knisel, Jr. and G. R. Foster, "A System for Evaluating Best Management Practices," W. E. Jeske (Ed.) in Economics, Ethics, Ecology: Roots of Production Conservation, Soil Conservation Society of America, Ankevy, Iowa (1980).

13. G. R. Foster, L. J. Lane, J. D. Nowlin, J. M. Laflen, and R. A. Young, "Estimating Erosion and Sediment Yield on Field-Sized Areas," Trans. ASAE 24(5):1253-1262 (1981).

14. R. C. Warner and B. C. Dysant, "Erosion Modeling Approaches for Construction Sites," ASCE Watershed Management Symposium, Boise, Idaho (July 1980).

15. L. J. Lane and J. W. Nyhan, Cover Integrity in Shallow Land Burial of Low Level Wastes: Hydrology and Erosion, Third Annual Information Meeting, DOE Low-Level Waste Management Program, ORNL/NFW-81/34, New Orleans, LA (December 1981).

16. J. W. Nyhan and L. J. Lane, "Use of a State of the Art Model in Generic Designs of Shallow Land Repositories for Low-Level Wastes," Waste Management 82 Symposium, Tucson, AZ (March 1981).

17. R. E. Smith and J. R. Williams, "Simulation of the Surface Water Hydrology," W. G. Knisel, Jr. (Ed.) in CREAMS: A Field-Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems, USDA-Conservation Research Report No. 26 (May 1980).

18. J. T. Ritchie, "A Model for Predicting Evaporation from a Row Crop with Incomplete Cover," Water Resources Research 8(5):1204-1213 (1972).

19. G. L. DePoorter, Arid Site Technology Development at the Los Alamos National Laboratory: Model Verification, ORNL/NFW-81/34 (November 1981).

20. E. M. Romney, V. Q. Hale, A. Wallace, O. R. Lunt, J. D. Childress, H. Kaaze, G. V. Alexander, J. E. Kinnear, and T. L. Ackerman, Some Characteristics of Soil and Perennial Vegetation in Northern Mojave Desert Areas of the Nevada Test Site, UCLA 12-916, TID-4500 (June 1973).

21. T. E. Hakonson and K. V. Bostick, "The Availability of Environmental Radioactivity to Honey Bee Colonies at Los Alamos," J. Environ. Qual. 5:307-310 (1976).

22. W. C. Hanson (Ed.), Transuranic Elements in the Environment, TIC-22800 (1980).

23. G. C. White, T. E. Hakonson, and J. L. Alquist, "Factors Affecting Radionuclide Availability by Vegetables Grown at Los Alamos," J. Environ. Qual., 10:294-299 (1981).

24. T. P. O'Farrell and R. O. Gilbert, "Transport of Radioactive Materials by Jackrabbits on the Hanford Reservation," Health Phys. 29:9-15 (1975).

25. E. L. Klepper, L. E. Rogers, J. D. Hedlund, and R. G. Schreckhise, Radioactivity Associated with Biota and Soils of the 216-A-24 Crib, PNL-1948-UC-70 (1979).

26. R. A. Connolly and R. E. Landstrom, "Gopher Damage to Buried Cable Materials," Materials Research Society, 9:13 (1969).

27. B. D. Abaturov, "The Role of Burrowing Animals in the Transport of Mineral Substances in the Soil," Pegobiologia 12:261-266 (1972).

28. V. I. Maslov, K. I. Maslova, and I. N. Verkhouskaya, Characteristics of the Radioecological Groups of Animals and Birds of Biogeoceonosis with High Natural Radioactivity. Radioecological Concentration Processes, Pergamon Press, London (1967).

29. R. M. Chew, "Consumers as Regulators of Ecosystems: An Alternative to Energetics," Ohio J. Science, 74(6):359-370 (1974).

30. R. M. Chew, The Impact of Small Mammals on Ecosystem Structure and Function, Proc. Populations of Small Mammals Under Natural Conditions, Pymatuning Laboratory of Ecology, Special Publ. No. 5 (May 1976).

31. T. E. Hakonson and J. L. Martinez, "Disturbance of a Low-Level Waste Site Trench Cover by Pocket Gophers," Health Phys. (in press).

32. H. L. Gunderson, Mammalogy, McGaw-Hill (1976).

33. L. Ellison, "The Pocket Gopher in Relation to Soil Erosion in Mountain Ranges," Ecology, 27:101-114 (1946).

34. H. K. Buechner, "Interrelationships Between the Pocket Gopher and Land Use," J. Mammal., 23:346-348 (1942).

35. J. Thorpe, "Effects of Certain Animals That Live in Soils," Scientific Monthly, 68:180-191 (1949).

36. E. F. Hooven, "Pocket Gopher Damage on Ponderosa Pine Plantations in Southwestern Oregon," J. Wild. Mgmt., 35:346-352 (1971).

37. W. E. Grant, "The Functional Role of Small Mammals in Grassland Ecosystems," Ph.D. Thesis, Colorado State University, Fort Collins, Colorado (1974).

38. R. M. Hansen and M. J. Morris, "Movement of Rocks by Northern Pocket Gophers," J. Mammal, 49:391-399 (1968).

39. G. D. Tierney and T. S. Foxx, Floristic Composition and Plant Succession on Near-Surface Radioactive Waste Disposal Facilities in the Los Alamos National Laboratory, LA-9219-MS (March 1982).

40. J. F. Cline, K. A. Gano, and L. E. Rogers, "Loose Rock as Biobarriers in Shallow Land Burial," Health Phys., 39:497-504 (1980).

41. G. R. Cox, Mitigation of Plant Intrusion and Subsequent Uptake of Buried Radioactive Waste Through the Use of Herbicides, RHO-SA-213, IAEA-SM-257/45P (July 1981).

42. T. E. Hakonson, G. C. White, and E. M. Karlen, "Evaluation of Geologic Materials to Limit Biological Intrusion of Low-Level Waste Site Covers," ANS Topical Meeting, Richland, WA (April 1982).