LA-UR -86-3243 CONF-860990--4

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--86-3243

DE87 000157

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SUBMITTED TO: Proceedings of the Eighth Annual Participants Information Meeting, DOE National Low-Level Waste Management Program

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TECHNOLOGY DEVELOPMENT FOR THE DESIGN OF SHALLOW LAND BURIAL FACILITIES AT SEMIARID SITES

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Los Alamos National Laboratory

SUMMARY PAPER

EFFECTIVENESS OF A MOISTURE BARRIER

The purpose of capillary barrier experiments is to field-test systems that can be used to control the movement of water on top of and around shallow land burial trenches. These systems will insure the execution of the performance objectives for low-level radioactive waste disposal sites set up by the Nuclear Regulatory Commission (NRC) and by the Department of Energy (DOE). Small-scale modeling has demonstrated that capillary barriers located above porous media can protect such a medium from water exposure. Barriers are created by differences in particle size and are effective because suction predominates over gravity forces. The percolating liquid will penetrate the coarser material only after the overlying finer material nears saturation. As long as the pressure at the coarse/fine interface remains negative, water infiltrating the finer layer will not cross the interface; instead, it will flow laterally until percolation recurs where the water reaches the edge of the coarser layer. This barrier concept has sometimes been referred to as the "wick effect." The water will travel only a limited distance laterally and will be influenced by the slope of the interface (1, 2 and 3).

The permeability of waste disposal facility liners and caps, i.e., moisture barriers, is important in geotechnical engineering. Permeability is the dominant parameter in the design and implementation of waste disposal facilities. Clay is prominent among the materials usually considered to line or cap disposal pits. Foremost among the problems connected with the use of clays is cracking during periods of desiccation, although both the Environmental Protection Agency (EPA) and the Nuclear Regulatory Commission (NRC) seem to feel that clays, as barriers to water leachate migration and inflow of water, are the principal materials to be considered as liners and caps in waste disposal facilities. Clays and soils, in general, also offer by far the longest service life of any liner material.

Use of clay mixes instead of pure clays may be warranted not solely on the basis of economics; mechanical benefits may even become overriding in mandating the use of mixes. In Los Alamos, New Mexico, the use of local tuff with low amounts of bentonite appeared to be very promising in greatly decreasing hydraulic conductivity without showing any of the mechanical impairments of clays (4). Saturated Na bentonite absorbs water up to 5

times its own mass to form a gel up to 15 times its own dry volume. Besides being less expensive, a liner or cap, consisting of a mix of the local medium and bentonite clay, probably would not crack when desiccated. Cracking from desiccation can be further minimized by proper compaction (4). A low hydraulic conductivity, combined with acceptable mechanical characteristics, should be obtainable at some ideal mix of two materials, each possessing one or the other property.

PHYSICAL BASIS FOR CAPILLARY BARRIERS

At equal matrix potentials, a fine-grained medium will contain more water than a coarse-grained medium. During drainage, an initially saturated soil will drain its largest pores first, whereas in wetting a dry soil, the smallest pores will fill first and as the matric potential is allowed to increase (getting less negative), the water content increases as progressively larger pores are filled. This will be accompanied by an increase in hydraulic conductivity and lateral diversion of water in the overlying fine grained soil and promoted by the presence of a sloping interface. The coarser medium, on the other hand, with its predominantly large pores, will remain relatively dry with a low hydraulic conductivity until the matrix potential reaches zero or near zero at the interface. The system will fail when or before the matrix potential at the interface ceases to be negative. Point readings at the interface are provided through tensiometers. Proximity of the failure point to zero will be a function of abruptness and magnitude of particle size difference at the interface.

Our field experiment was designed to test the performance of a wick system emplaced in a 6-m-deep caisson with a diameter of 3 m for a wick system of known thickness (2 m), slope (10%), and slope length (2 m), and for one combination of porous medium materials [a bentonite-tuff mix having a 0.02 bentonite ratio by mass overlying Ottawa sand] subjected to a known addition rate of water.

Tensiometers are emplaced 20 mm above the mix-sand interface, which is the interface to be tested for "wick effectiveness." Two rows of five tensiometers are equidistantly emplaced along that sloping interface. Two tensiometers are located at the mix-tuff interface, one at the upper side of the wick and one at the lower side. Similarly, two tensiometers are situated above the tuff-gravel interface. Finally, two vertical rows of tensiometers are emplaced 0.30 m apart in the mix, with each one of the tensiometers located at the same height as the access tubes for neutron moisture probe (Fig. 1). Ponding of water over the bentonite mix/tuff barrier was continuous for 2 years. The moisture barrier will fail as the matrix potential nears zero. The extent to which a negative matrix potential can be maintained at the interface depends on several factors. Five of these factors will remain constant in our bentonite mix moisture barrier experiment:

1) Amount of available water.

The experimental caisson was ponded continuously for two years. Since available water amount was unlimited and the mix was not impermeable, failure at the interface was only a matter of time.

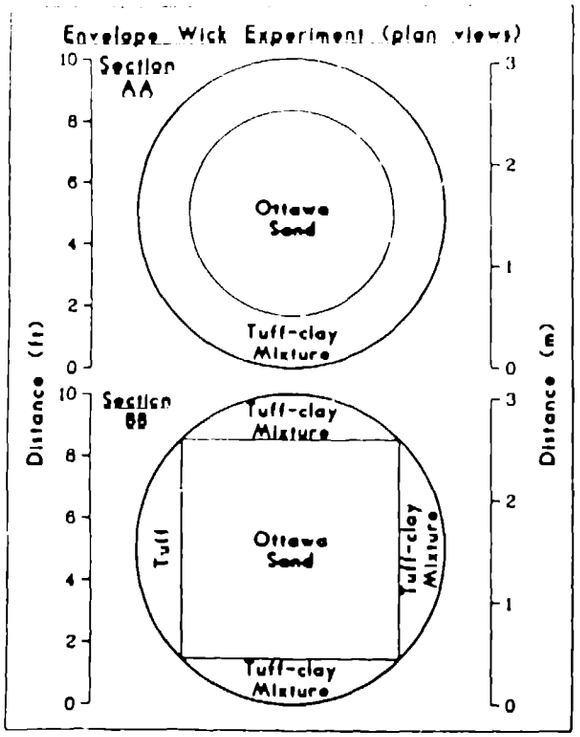

Figure 1. Caisson set-up.

2) Degree of contrast in soil moisture characteristic curves.

The soil moisture characteristic curves of the mix and sand (the two materials in contact at the relevant interface) contrast greatly. Because of that contrast, the matric potential at failure should be near zero. This only means that if the amount of water being fed to the system is unlimited, the failure would be delayed to its maximum (matric potential = 0).

3) Hydraulic conductivity of the moisture barrier (wick).

Abeele (1986) defined this as being close to $5 \cdot 10^{-9}$ (m/s). This value is proper to the composition of the mix (2% bentonite) and the degree of compaction obtained (dry density = 1.57, void ratio = 0.63 or porosity = 0.39). A low hydraulic conductivity in the wick material will obviously delay failure at the interface.

4) Thickness of the moisture barrier.

The amount of percolating water, will determine the probability of failure. Since the amount of water is unlimited, failure is inevitable. Failure retardation, however, is directly proportional to the adsorption capacity of the moisture barrier. This, in turn, will be greatly dependent on the thickness of that layer.

5) Slope of the interface.

The slope was set at 10%. The steeper the slope, the less likely early failure will occur because of less ponding at the interface and faster runoff or lateral flow.

Results show that the water content in the upper layer stabilized after around 400 days, although values differ greatly throughout the profile. Only the upper layer, located 0.5 m below the mix-tuff interface, seemed to reach anything close to satiation (30% water content by volume). At all other levels the water content by volume approximates values closer to 20 or 21% (Fig. 2). The matric potential values at the interface seem to stabilize at an earlier stage, producing only positive values once equilibrium is obtained, indicating, thereby, that saturation is reached at the interface and that the system is consequently in a failure mode. The flux from a discharge pipe at the bottom of the caisson was first being noticed 320 days after the start of the experiment. This advent is another indication of moisture barrier failure. The first discharge flux was measured at $6.8 \cdot 10^{-9}$ m/s and varied throughout the experimental period from $5.5 \cdot 10^{-9}$ m/s to $7.8 \cdot 10^{-9}$ m/s. The average flux throughout the testing period was $6.45 \cdot 10^{-9}$ m/s with a standard deviation of $0.88 \cdot 10^{-9}$ m/s or a coefficient of variation of 13.7%. Since the measured hydraulic gradient in the caisson was estimated to be varying in time from 1.42 to 1.57, the hydraulic conductivity is calculated to be $4.3 \cdot 10^{-9}$ m/s. This value is very close to the one estimated in the laboratory for the <u>saturated</u> conductivity of a crushed tuff to which 2% bentonite were added.

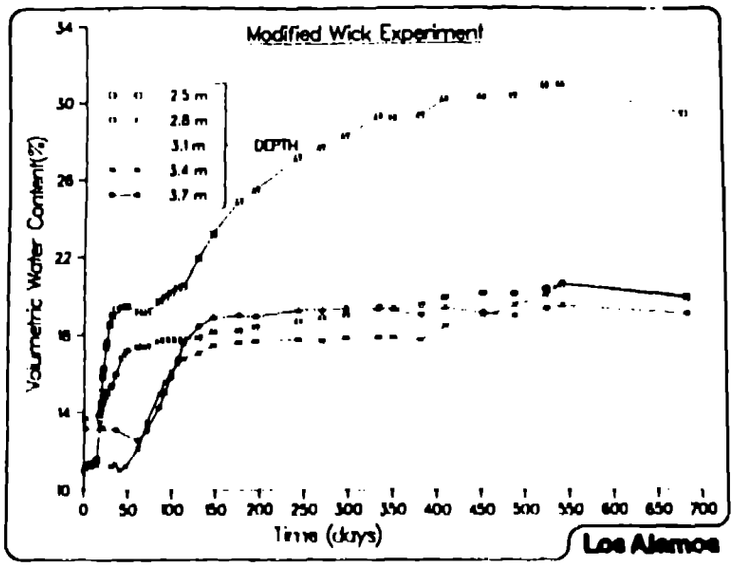

Figure 2. Water content in wick experiment.

More difficult to explain are the vagaries observed at one time or another among the tensiometric values recorded in the core of the mix. The water content values measured with the neutron moisture probe indicate that satiation is far from attained but in the uppermost measured layer of the mix. This being the case only negative pressure values are expected to prevail. Yet in the period centered around 500 days after the start of the experiment, numerous exceptions to that rule prevail, only to return to normal in the ensuing period. In conclusion, in the bentonite-tuff moisture barrier, saturation or positive (pressure) values obtained at the interface indicate the likeliness of failure which is confirmed by subsequent discharge at the bottom of the caisson. Interestingly, this state of saturation at the interface was reached through persevering unsaturated hydraulic flow which should indicate the effectiveness of the capillary barriers. However, some unexplained inconsistencies remain unsolved:

1) At intermediate levels within the core of the moisture barrier, the moisture level reached an unsaturated level which was maintained for the last 550 days of the experiment.

2) As the probable result of the invariably low moisture content prevailing in the moisture core through most of the experiment the discharge rate at the bottom of the caisson did not surpass a coefficient of variation of 13.7%. Most interestingly this constant unsaturated conductivity of $1.3 \cdot 10^{-9}$ m s^{-1} is barely lower than the one measured in the laboratory ($5 \cdot 10^{-9}$ m s^{-1}).

TRENCH CAPS DESIGNS FOR LONG TERM STABILIZATION

Trench cap designs that minimize erosion, percolation, and biological intrusion require consideration and careful selection of trench cap materials, cap materials depth, cap configuration, engineering features, including surface and layer interface slopes, and vegetation cover.

We have chosen to emphasize methods for controlling percolation and biological intrusion over those developed for runoff and erosion control in order to keep the demonstration project within manageable bounds and to provide the greatest impact for the national program and because subsurface water and biological intrusion control methods employ similar materials and designs. Results of our studies on erosion control technologies demonstrated the effectiveness of several management practices that control runoff and erosion but at the expense of increasing water infiltration into the trench cover.

Specific objectives of this demonstration will be to measure the performance of a conventional and an improved trench cover design (1) on subsurface water dynamics, (2) in limiting biological intrusion, and (3) under both natural and enhanced precipitation regimes to identify the performance limits of the two designs.

Time series measurements have been made on the relevant water balance components including precipitation input, soil moisture, soil solution, and leachate production including tracer content of the leachate and soil solution. The rate of root intrusion through the cover will also be measured by the tracer content of vegetation.

What we expect to demonstrate is that the improved trench cap design limits percolation (i.e., leachate production) and biological intrusion compared with a conventional design. In addition, we expect to define the operational limits of the two designs under enhanced precipitation. This will result in documented criteria for improved SLB design.

Research conducted by the Los Alamos Environmental Science Group over the last six years has led to an improved understanding of water dynamics and biological interaction in the SLB site environs. That research has led to the development and testing of improvements in the design of isolated components of an SLB site. The purpose of this field demonstration is to integrate some of the positive features of the isolated variable experiments into a state-of-the-science design for optimal water and biota management to minimize radionculide transport at SLB sites.

The experimental design for the integrated experiment examines the performance of standard technology for SLB compared with improved technology. The cover consists of a mixture of seeded grasses and a specified level of gravel mulch. Four 3-x-10-m plots were used for this purpose.

The unimproved technology treatment consists of the standard practice for low-level waste (LLW) disposal at Los Alamos including about 1 m of trench cap comprised of crushed tuff covered with 15 cm of topsoil, all placed over a trench filled with waste and crushed tuff backfill. The improved technology treatment from the surface downward consists of an optimal topsoil depth, which, based upon calculations and previous measurements, is about 1 m of the local sandy loam soil. Next, a cobble-gravel layer (25-cm gravel over 75-cm cobble) is used to prevent plant and animal intrusion and water flow (capillary barrier) to subsurface regions. An angle was placed on the interface between the topsoil and cobble-gravel layer to divert the vertical infiltration component into a lateral flow component using the principle of a wick system. Both the control and improved trench cover plots contain trench drains to allow for measurement of leachate production and tracer content of leachate.

Crushed tuff is used as a trench backfill material because our measurements and models have emphasized this soil matrix. Appropriate chemicals for tracing water movement including bromide, iodide, cesium, and lithium are located at specified layers in the backfill to provide a source term for evaluating chemical transport.

FY86

1) Precipitation

While the 1986 winter was in all respects a mild one, precipitation started picking up in April 1986 so that during the five months covering

April until August (last recorded month in this report), precipitation exceeded by 43% the normal precipitation occurring during an average year at Los Alamos (Table 1). Unlike in 1985, however, none of the plots leached. The reasons for this are obviously twofold:

Table 1. Average, maximum and 1986 monthly precipitation at Los Alamos

	$\bar{X}$ (mm)	X max (mm)	X 1986 (mm)
Jan	21.6	171.5	0.3
Feb	17.3	62.0	25.7
Mar	25.7	104.4	19.8
Apr	21.8	117.9	47.0
May	28.7	113.6	41.7
Jun	28.5	144.0	144.0
Jul	80.8	202.7	55.6
Aug	99.8	284.0	84.1
Sept	41.4	147.1	
Oct	38.6	172.0	
Nov	24.4	167.6	
Dec	24.4	81.6	

FY85 was an excessively wet year, with most of the precipitation occurring during the winter, a period of low evapotranspiration (5).

FY86 was not quite as wet, with the precipitation concentrated in June, a month of high potential evapotranspiration.

As a result of the heavy spring precipitation and below average summer rainfall, near satiation levels were reached near the bottom of both the control plots and one of the experimental plots while the upper layers of the experimental plots show strong signs of desiccation during the summer.

In the field of tension measurements, the attention in FY86 was mainly geared towards automation of tension readings. These achievements are described in fuller details in the section dealing with the Data Acquisition System.

Traditionally, tensiometric readings were taken with a hand-held tensiometer, whose needle was inserted in a septum that had become an integral part of the tensiometer tube.

Since a point of near saturation was never reached near the bottom of the control plots or at the biobarrier interface in the experimental plots, failure of the system never occurred and no amount of leachate was measured. No data for chemical leachate are consequently made available.

Cesium uptake by vegetation

The only tracer concentration measured is that of cesium taken up by the plot vegetation. Table 2 gives an average Cs concentration and standard deviation (n = 88 over 3 years) for 2 control plots and 2 experimental plots.

It is obvious from the results that uptake of cesium starts taking place in FY86, with at least one experimental plot showing no increase. That plot is precisely the one that showed the highest cesium concentration in its vegetation in FY84 (0.590 ppm). The high standard deviation seems to indicate that indeed this might have been a fluke. Overall, both the experimental plots show a lower cesium uptake than the control plots in FY86, tending to show the efficiency of the biobarrier under which the cesium is entrapped in the experimental plots. Even the relatively high concentration in experimental plot 2 is caused by one single measurement of 7 ppm, all others remaining well under a fraction of one ppm.

The integrity of the biobarrier remained total in experimental plot 1 where no concentration exceeding 0.13 ppm was recorded. One noteworthy fact is that experimental plot 2, with the one measurement above background (7 ppm), is also the plot where excessive amounts of water were to be found below the biobarrier, where the cesium was emplaced.

Table 2. Cs uptake by vegetation (ppm)

	FY84			FY85			FY86		
Plots	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n
Control1	0.111	0.045	12	0.071	0.039	4	5.284	8.037	6
Control2	0.119	0.069	12	0.141	0.183	4	2.483	3.720	6
Experiment1	0.590	1.499	12	0.028	0.006	4	0.077	0.027	6
Experiment2	0.069	0.024	12	0.038	0.020	4	1.244	2.854	6

Results obtained using the Data Acquisition System (DAS) show clearly the presence of an interfering factor. The periodicity of this interfering element is remarkable. To try to interpret and pinpoint the exact cause of the fluctuations in the tension measurements, calibration tensiometers were installed in buckets of water. One tensiometer, referred to on the graph as tube 125, was installed in an air conditioned trailer while the other was left exposed to the ambient (outside) temperature (referred to on the graph as tube 126). Changes in tension, or more precisely positive pressure in this case, occur in both cases (Fig. 3). The fluctuation frequency is increased during the daytime, however, when the air conditioner is most likely to switch on and off. This leads us to the inescapable conclusion that temperature is likely to influence tensiometer readings. This is even more apparent from the readings of the tensiometer located outside. While relatively stable and low at night, the readings increase and seem to fluctuate with exposure to direct solar radiation. It seems that, however small in absolute terms (pressure or tension), the highest pressure values were obtained around solar noon.

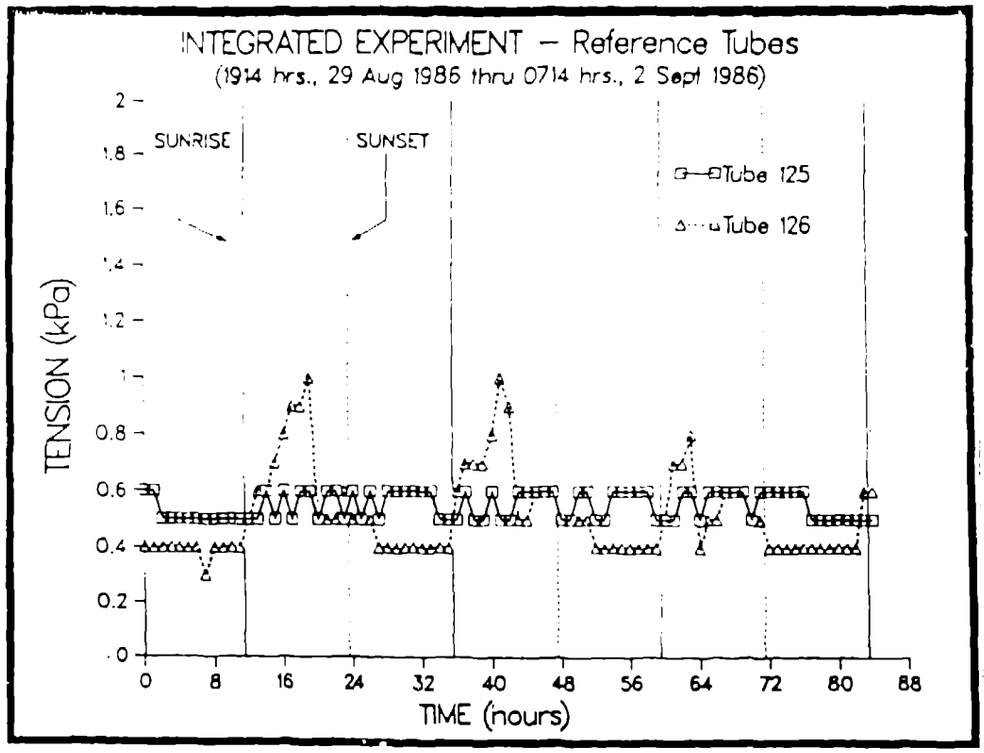

Figure 3. DAS tension readings.

If we turn our attention to the actual tensiometers in the field, the same pattern emerges with one noticeable distinction. Increases in pressure, occurring during the daytime in the calibration tensiometers, are now read as decreases in tension in the field tensiometers. It is obvious that the cause for the two parallel behaviors has the same origin.

It seems that, slowly, the automated Data Acquisition System is being debugged and that in the future, continuous tension monitoring could be applied to all our experiments.

BIOINTRUSION BARRIER TESTING

Questions concerning the performance of different types of biobarriers at various field scales and the effects of layered-rock barrier systems on the water balance are being addressed in a field experiment at a low-level waste disposal site (Area G), which will eventually be decommissioned.

Three types of 1-m-thick biobarriers are being tested in Area G experiments in 6- by 21-m plots: (1) 15-cm gravel (1- to 2-cm diam) on top of 85-cm cobble (7.5- to 12-cm diam); (2) 1-m cobble; and (3) 30-cm gravel on top of 70-cm cobble. These three treatments are being compared with the conventional trench cap treatment containing 1 m of crushed tuff without a biobarrier. Since we were trying to produce treatment effects over a short time period, we used only 15 cm of topsoil over these four field treatments to ensure that percolation of water through the biobarriers would be

detected using neutron moisture gauge techniques. A cesium chloride tracer layer was emplaced immediately beneath each biobarrier (and at a corresponding depth in the conventional cap treatment) so that the penetration of roots currently growing through the biobarriers can be detected by collecting plant samples and assaying them for their cesium content.

All of the vegetation samples collected on the control plot in the middle of the relatively wet 1986 growing season (July 1, 1986) showed above-background levels of cesium ranging from 34.9 to 163 ppm (Fig. 4). The cesium data from the plots with rock barriers generally showed below-background levels of cesium, i.e., samples collected in the plot with the 15 cm gravel/85 cm cobble treatment exhibited cesium concentrations ranging from 0.23 to 1.22 ppm. Similar data were collected on 4 out of 5 of the samples collected in the other two rock barrier systems; however, one sample from plot 3 and one sample from plot 1 were found to have cesium concentrations of 93.4 ppm and 152 ppm, respectively (Fig. 4). Although more observations are needed with time, this probably indicates that both the cobble and 30 cm gravel/70 cm cobble biobarriers are finally starting to fail at the end of the fifth growing season.

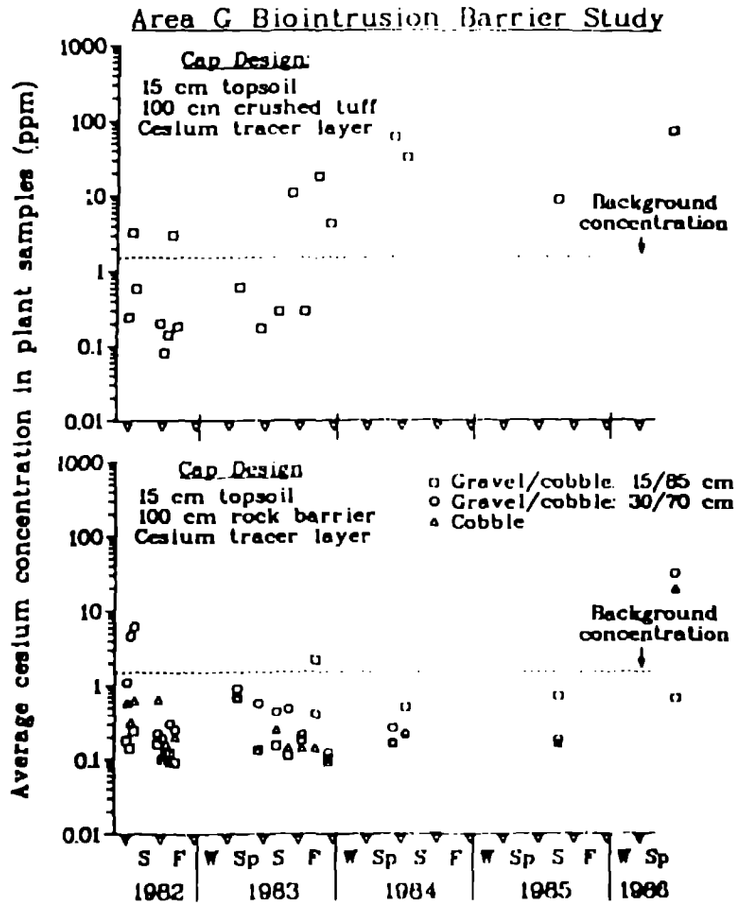

Figure 4. Cesium concentrations in plant samples collected with the Area G biobarrier plots.

In addition to our routine monitoring of the soil water content 40 cm beneath the biobarriers, we collected neutron moisture gauge data at 15-cm increments in all the Area G plots in both April and July of 1986. The data from the plot without a rock biobarrier showed the familiar pattern of an increase in volumetric water content with depth at both sampling periods. A dramatic difference was observed in the inventory of water in the 1.6 m profiles: the soil water inventories decreased by more than 50% as we proceeded from the April 1986 date (reflecting snowmelt and heavy spring precipitation additions to the trench cap) to the July 1986 date. This decrease is due to both downward drainage of water into the SLB trench, as well as evapotranspiration losses to the atmosphere, especially in the top 140 cm of the profile where there was minimal plant-available water in July 1986. The other three plots with the rock barriers demonstrated very small decreases with time in water content in the crushed tuff below the biobarrier, because plant roots were not active here (as the cesium data demonstrates in Fig. 4). This complements the pattern demonstrated for the 160 cm sampling depth, showing that the soil water content at 160 cm is usually higher under the rock biobarriers than under the crushed tuff (control) biobarrier. This observation also reflects the loss of water storage capacity in the 1 m thick layer of gravel and/or cobble that would otherwise be present in the corresponding 1 m thick layer of crushed tuff in this experiment.

JOINT DOE/NRC TRACER MIGRATION EXPERIMENT

A field experiment was designed by the NLLWMP and NRC in 1984 to evaluate leaching and transport of solutes in sandy silt backfill used in SLB operations at Los Alamos. This experiment was emplaced and performed throughout FY 1985 in caisson B (3-m diam, 6.1 m deep) at the Los Alamos Experimental Engineered Test Facility.

One of the purposes of the caisson experiments is to compare the NRC laboratory-derived parameter estimates with those derived from the caisson. This will provide unique data for evaluating the applicability of lumped coefficients in modeling solute transport under controlled conditions in the laboratory and in the large caissons. In this experiment, Caisson B received a single pulse input of bromide and iodide (conservative and nonadsorbing tracers) as well as lithium, strontium, and cesium under steady-state flow conditions. The bromide and iodide tracer data were used to determine values of D_o, τ, and γ, where D_o is the diffusion coefficient in cm^2/d, τ is a tortuosity factor, and γ is the dispersivity in cm. These values were used to estimate effective dispersion coefficients for subsequent analysis of the retardation factor (R) and the distribution coefficient (K_d) for lithium and strontium using least-squares procedures.

In caisson B, nonsorbing tracers (iodide and bromide) were used to determine coefficients for water being transported through soil, and sorbing tracers (cesium, strontium, and lithium) were used to determine retardation factors for a range of ion adsorption affinities. Flow conditions included two 6-day tracer pulses with steady-state flow conditions [about 4 cm d^{-1} (200 ml min^{-1})] and two 6-day tracer pulses with unsteady-state flow conditions. In the subsequent 70-day period following the single tracer input, soil solution samples were collected at incremental depths on a daily

basis and analyzed for tracer concentrations, outflow/inflow samples were collected and analyzed for tracer concentrations, flow rates were measured, and neutron moisture gauge data were collected as functions of depth and horizontal distance within the caisson.

The objective of our research efforts this year (6) were to (1) quantitatively evaluate the effectiveness of a one-dimensional advective-dispersive equation to predict the transport of iodide, bromide, and lithium in the unsaturated zone under steady-state flow conditions; (2) quantitatively evaluate the reproducibility of pulse experiments by comparing steady-state flow pulses; the comparison is based on the parameter predictions from the advective-dispersive equation for two steady-state flow pulses; and (3) quantitatively evaluate the feasibility of modeling unsteady-flow conditions with average steady-state flow assumptions. The word "steady" is used throughout this report to mean a pseudo steady-state or nearly steady-state flow condition.

The respective conclusions to the described objectives are the following: (1) the advective-dispersive transport model, that uses a least-squares solution (CFITM), is found to perform reasonably well under steady-state flow conditions for the conservative (iodide and bromide) and the nonconservative (lithium) solutes; larger dispersion coefficients and erratic retardation factors are estimated at depths less than 180 cm; the peculiarities at depths less than 180 cm are considered to be directly related to flow effects introduced by the multiple-point influent solution application system; (2) the flow conditions of the two near steady-state pulses are sufficiently different such that dispersion factors are estimated to be different by a factor of 2 for the two pulses; however, the predicted retardation factors are close for both pulses; and (3) the use of average steady-state flow conditions in the model to predict unsteady-state flow may be suitable to estimate "ball-park" dispersion coefficients (within one to two orders of magnitude); the approach more accurately forecasts the retardation factors. These conclusions suggest the suitability of steady-state flow models to predict solute transport in the unsaturated zone beyond a certain distance from the source of contamination (180 cm in these experiments) when flow conditions are near steady-state. As flow conditions become more unsteady, steady-state flow models become less suitable, although still appropriate for "ball-park" modeling.

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