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SHALLOW LAND BURIAL TECHNOLOGY - HUMID[1]

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ABSTRACT

Applying engineered modifications to present shallow land burial (SLB) practices is one method of ensuring safe operation and improving overall disposal-site performance. Two such engineered modifications, trench lining and grouting, are being demonstrated and evaluated at the Oak Ridge National Laboratory (ORNL) Engineered Test Facility (ETF), using nine 28-m^3 experimental trenches containing compacted low-level waste (LLW). Concurrent to this field demonstration experiment, two finite-element hydrologic models have been developed to model water movement and solute transport at a waste disposal site. This paper covers progress made in these two areas during FY 1984.

Though the economic analysis of the two trench treatments favored Hypalon lining (lining costs were 33% lower at this demonstration scale), results of field experiments examining waste hydrologic isolation favored the cement-bentonite grout treatment. Data from water pump-out and water pump-in tests, combined with observed intratrench water-level fluctuations, suggest that the original goal of constructing watertight liners in three experimental trenches was not achieved. In addition, trench-cover subsidence of ∿2% of the total trench depth has been measured over two of the three lined trenches but has not occurred over any of the three grouted or three control (untreated) trenches. The evaluation of the two trench treatments is continuing. However, results indicate that the cement-bentonite treatment, implemented at a cost of \$160/m^3 of grout, provides a degree of waste isolation not afforded by the lined and control trenches and should be considered for use at SLB sites with water-related problems.

[1]Supported by the Office of Defense Waste and Byproduct Management, U.S. Department of Energy, under Contract No. DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc. Publication No. 2434, Environmental Sciences Division, ORNL.

INTRODUCTION

Shallow land burial (SLB) is, in most cases, an effective disposal method for low-level radioactive solid waste. The operation of such disposal areas requires the management of surface runoff and groundwater in ways that prevent water from contacting buried waste and possibly leaching and transporting radionuclides to unrestricted areas. Although site selection is the most powerful technique to avoid such environmental contamination problems, all present and future sites will likely have either subareas with marginal geohydrological characteristics for waste disposal or classes of wastes with a sufficient inventory of radioactivity that the degree of isolation provided by the geologic formation may not provide adequate assurance that site performance objectives can be met. For either of these situations, engineered modifications of these burial areas, or wastes, could provide the necessary assurance for acceptable site performance. Two such engineered modifications, trench lining and trench grouting, have been under investigation as part of the Shallow Land Burial Technology Task performed at the Oak Ridge National Laboratory (ORNL) for the Department of Energy (DOE) Low-Level Waste Management Program.

Problems identified as potentially compromising the performance of SLB sites include groundwater intrusion, trench-cover subsidence and resulting surface runoff intrusion, plant and animal intrusion, and radionuclide migration to unrestricted areas. In theory, either grouting or lining of trenches can reduce all of these problems. However, a field demonstration of their effectiveness is required before either technique can be advocated as standard practice for existing or future disposal operations. Thus, the focus of the SLB Technology study has been a field demonstration of trench grouting and lining techniques that can be used, not as a remedial measure, but during waste disposal operations as a possible improvement to present practices.

Of the many grouts and liners that are commercially available, two specific treatments were selected for demonstration: a Portland cement-bentonite grout applied as a trench backfill (grout cost = \$160/m^3) and an impermeable Hypalon fabric liner placed in a trench so that it surrounds the waste on all four sides, top, and bottom (liner cost = \$8.30/m^2). For evaluation purposes, the performances of these two trench treatments were compared with the performances of untreated trenches typical of current SLB disposal operations. A complete description of the experimental objectives, along with liner and grout emplacement techniques at the study site, can be found in earlier reports by Davis, Spalding, Lee (1983), and Boegly and Davis (1983).

An economic analysis of the two treatments being investigated favored the trench lining procedure (\$1055/experimental trench, materials, and installation) over cement-bentonite grouting (\$1585/experimental trench, materials, and installation) by a total of \$530 per trench (33% lower cost for lining). This cost differential becomes even greater, in favor of lined trenches in the movement from the 28-m^3 experimental trenches considered in this study to 170-m^3 trenches typical of those used at ORNL. In this latter case, the cost differential is estimated at \$11,520 per trench: \$13,850 estimated cost required to grout an ORNL trench and

$2330 estimated cost to line a similar-sized trench. Thus, from an economic standpoint, lining waste disposal trenches offers considerable cost savings over trench grouting. The crucial question, however, is whether the two treatments offer the same degree of hydrologic isolation.

The purpose of this paper is to highlight FY 1984 activities of the SLB Technology Task that fall into two categories: (1) experimental demonstration burial [carried out at the ORNL Engineered Test Facility (ETF)] and (2) hydrologic model application to waste disposal sites. The first of these activities involves an in-depth evaluation of the hydrologic isolation capabilities of the two trench treatments being studied at the ETF. Particular emphasis has been placed on an evaluation of the three Hypalon-lined experimental trenches. The second activity has involved construction and validation of two finite-element models, one for modeling water flow through aquifers and the second for modeling solute transport. Both models are briefly described and will be of value in predicting water and solute movement at the ETF site.

EXPERIMENTAL DEMONSTRATION BURIAL

Background

The site selected for the experimental demonstration of cement-bentonite grout and Hypalon liners is a 0.3-ha tract of land located within Solid Waste Storage Area Six (SWSA 6) at ORNL. Nine 28-m^3 experimental trenches were excavated at the site in a 3 by 3 matrix with three trenches selected for lining, three selected for grouting, and three serving as controls (untreated trenches). The ETF has been the subject of an extensive disposal site characterization study (Vaughan et al. 1982, Davis et al. 1984, and Newbold and Bogle 1984), which was a major part of the overall project activities during FY 1982 and 1983. Figure 1 presents a plan view of the ETF study site within SWSA 6, showing the location of the experimental trenches, monitoring wells, rain gauge, and surface water sampling stations (Parshall flumes).

Evaluation of the two trench treatments centers on their ability to keep the waste dry and to remain intact for an extended time. A total of six tests are being conducted to examine these two criteria (Table 1): four dealing with water-waste contact, one dealing with strength and durability of materials, and one addressing the question of trench-cover subsidence. In some cases the results of a particular test are evaluated between the three classes of trenches (lined, grouted, and control); however, certain tests (such as the water pump-out tests) apply only to the lined trenches and would have little or no meaning if applied to grouted or control trenches.

Presence of Water in Intratrench Wells

An obvious indicator of water-waste interaction in disposal trenches is the presence or absence of standing water in intratrench wells. For purposes of such a survey, shallow wells were placed in each of the 9 experimental trenches, and depth of water was measured periodically for

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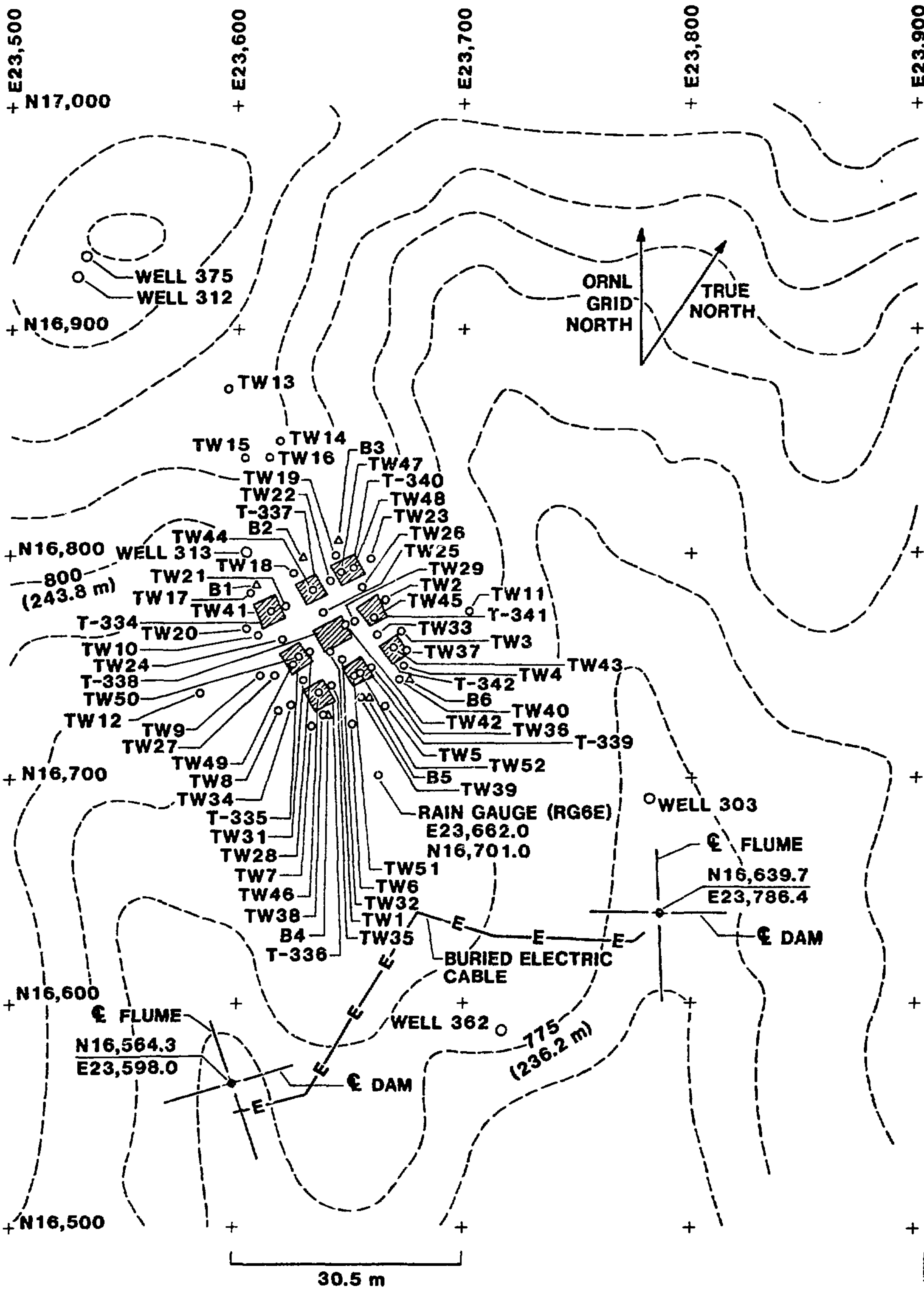

Fig. 1. Plan view of the ETF site.

TABLE 1. METHODS USED IN EVALUATING THE ABILITY OF THE LINER AND GROUT TREATMENTS TO PREVENT WATER-WASTE CONTACT

Evaluation Method	Applicable Trench Treatment		
	Control	Lined	Grouted
1) Presence of water in intratrench wells	*	*	*
2) Water pump-out tests		*	
3) Water pump-in tests		*	
4) Hydraulic conductivity of waste-backfill mixture	*		*
5) Strength and durability of materials		*	*
6) Presence of trench-cover subsidence	*	*	*

* = Evaluation method applies to this type of trench.

16 months, beginning in January 1983. Figure 2 summarizes the data for three of the trenches (lined trench 338, control trench 337, and grouted trench 335).

The intratrench water level in trench 338 was typical of the three lined trenches and was observed to fluctuate seasonally. Highs of ∿1.5 m occurred in the winter months, and lows of ∿1 m of standing water were present in the summer. If these water levels had remained stationary, it could be argued that water from preclosure infiltration was trapped within the liner and could not drain from the trench. Even small increases (on the order of a few centimeters) in water level following a storm could possibly be explained by increased soil moisture conditions around the trenches exerting an inward squeezing force on the liner, resulting in a slight rise in trapped water. However, the large seasonal variation exhibited in two of the three lined trenches suggests that water is entering and leaving these trenches, perhaps through tears or open seams in the Hypalon fabric.

Like the lined trenches, wells in the three control trenches showed signs of intratrench water, but only for brief periods of time. The majority of the time, these wells were observed to be dry, indicating that no trapped water was present. In the case of trench 337 (Fig. 2), intratrench water would reach a maximum depth of 0.84 m, and it was noted that these periods were all preceded by 5-d periods when rainfall totaled between 3 and 38 mm (average = 25.3 mm). In contrast, on dates when the

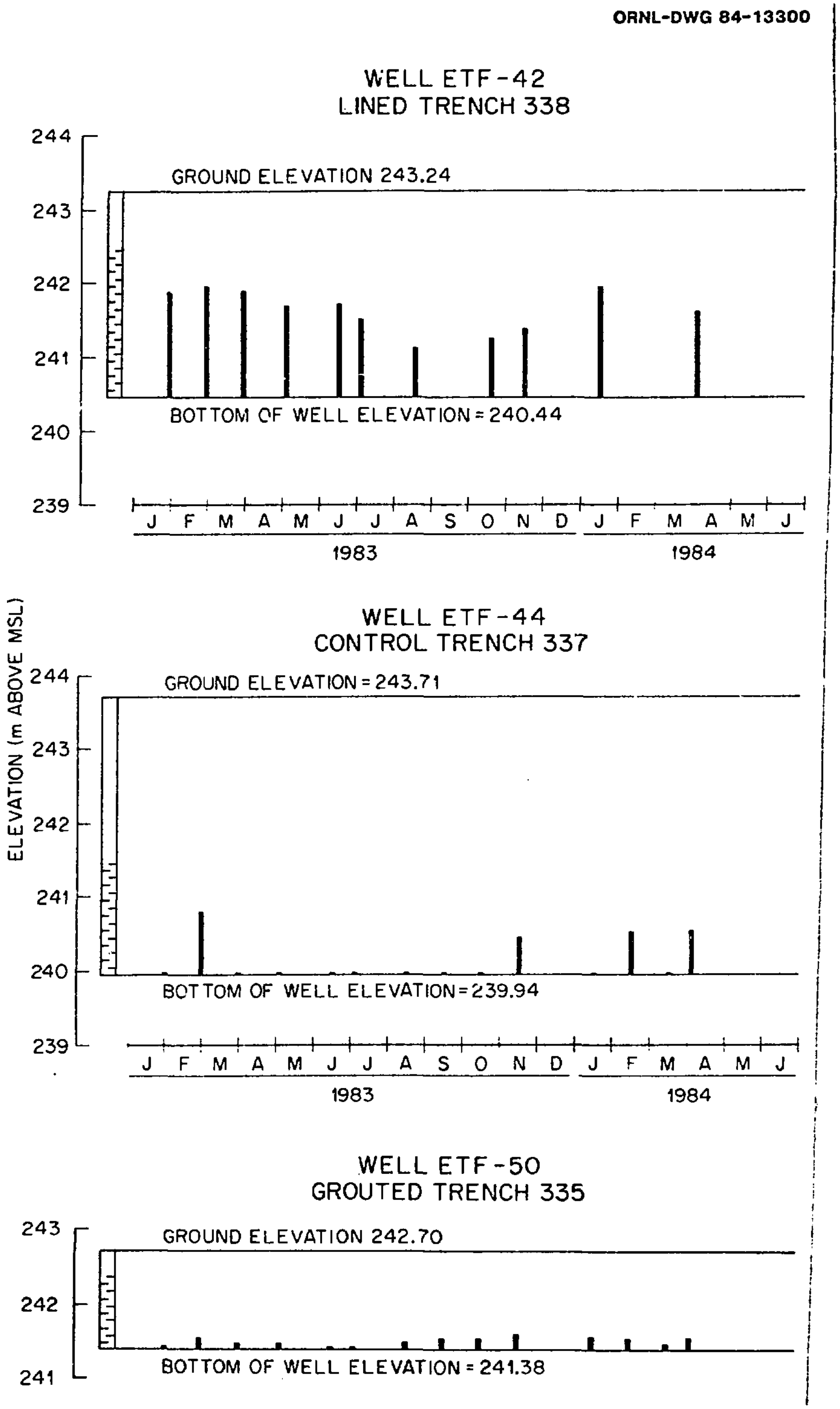

Fig. 2. Summary of water levels in three ETF experimental trenches.

wells in the control trenches were observed to be dry, the total rainfall for the preceding 5 d was considerably less, ranging from 3 to 19 mm (average = 5.6 mm). This suggests that water is entering the control trenches as surface infiltration and remaining for several days until drainage to the underlying groundwater can occur. No seasonal variation is evident, but, rather, the water appears to be transient and directly related to individual precipitation events. This situation will likely continue to expose the waste to wetting and drying cycles, which is the case for a number of waste disposal trenches at ORNL (Spalding 1984, Arora et al. 1981, Davis and Stansfield 1984).

Intratrench water levels taken in shallow auger holes installed in the three grouted trenches suggest a different pattern than that of the lined and control trenches (Fig. 2). A majority of the time, a minimal amount of water (5 to 10 cm) was trapped in the bottom of each well. There is certainly no evidence that water levels are fluctuating within these trenches, which is the case with the Hypalon-lined trenches, and there were no instances of high water-level measurements that could be correlated to periods of heavy rainfall. Based on these intratrench water-level data, the grout treatment appears to represent an improvement over the control trenches because it does not allow the waste to experience fluctuating intratrench water levels resulting from rainfall infiltration.

In summary, intratrench water has been detected in all nine experimental trenches at the ETF, but to differing degrees. This detection of water in intratrench-monitoring wells does not necessarily indicate that a particular treatment has failed or is allowing large quantities of water to leach the waste and transport radionuclides. It simply gives an indication of the presence or absence of perched water in the trenches and how it might be fluctuating over an annual cycle.

Water Pump Out Tests for the Lined Trenches

To determine if the intratrench water in the three lined trenches is either trapped or transient in nature, as the seasonal fluctuations might suggest, a water pump-out test was conducted on each trench. The tests were conducted with the assumption that if the water was trapped and could not exit the impermeable liner, the trenches should be able to be pumped dry over a period of several weeks and should thereafter remain dry. On the other hand, if the trenches were drained and then began to collect infiltrating water after pumping stopped, there would be strong evidence that the liner system is leaking. To determine which of these two cases applied, draining of the lined trenches was initiated in January (1984), a seasonally wet month.

Figure 3 summarizes the results of the water pump out-test for lined trench 338 by showing the cumulative volume of water removed during the test, the response of the intratrench water level to pumping, and the daily rainfall totals for the duration of the test. Similar tests performed on the other two lined trenches indicate that water levels in trenches 342 and 338 steadily increased after pumping stopped and actually exceeded the initial (prepumping) water levels. The third trench (trench 334) maintained a rather steady water level after being pumped until the first

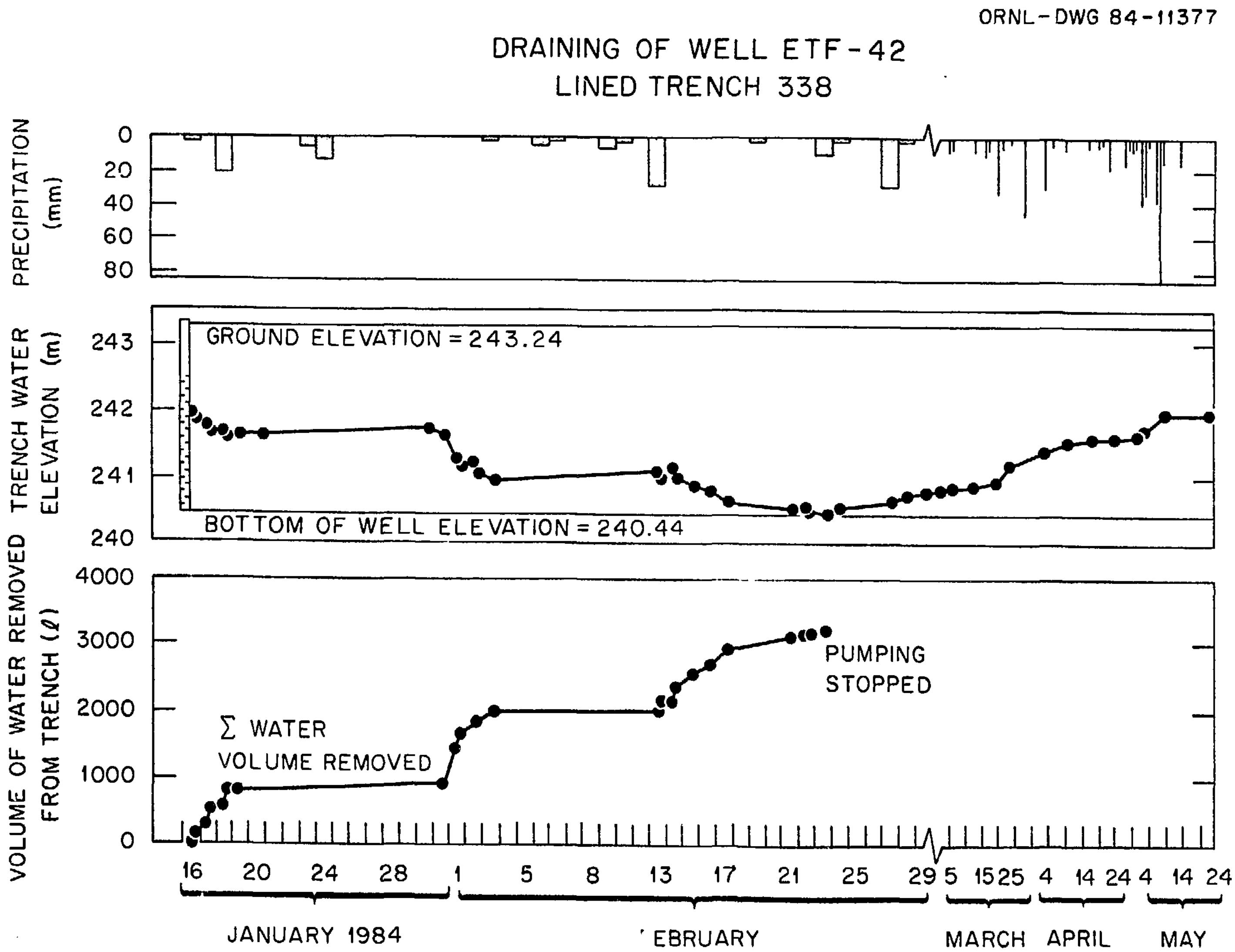

Fig. 3. Water elevations during draining of lined trench 338.

week in May, when it increased to a level ~0.75 m above the trench bottom. This observed increase in intratrench water levels can be directly related to the site precipitation, which is obviously responsible for the large increase noted the first week in May.

Results of these lined trench pump-out tests suggest that the intratrench water observed is not merely trapped as a result of infiltration prior to cover emplacement but, rather, is transient and infiltrates through holes in the liner during periods of precipitation. The tests are not extensive enough to form any solid conclusions about the extent or spatial distribution of holes in the liner; they do, however, suggest that the lined trenches are not watertight as initially planned.

Water Pump-In Tests for the Lined Trenches

A final evaluation of the integrity of the three lined trenches was carried out through water pump-in tests. If the three lined trenches were indeed watertight, it should be possible to fill each trench with water over a period of several days, and the water level measured in the intratrench well should remain constant at an elevation at, or near, the top of the trench. On the other hand, if the liner is leaking, it may be impossible to fill the trench as the water level continually drops with leakage. If this latter case exists, it may actually be possible to observe an increase in water levels in monitoring wells surrounding the trenches.

To conduct these water pump-in tests, water was delivered to the ETF site using a 5670-L tanker truck. From the truck, a 2460-L head tank (located ~5 m higher in elevation than the experimental trenches) was repeatedly filled and used as a source of water. It was estimated that each trench would take on the order of 7600 L (7.6 m^3) to fill the void within the liner, and this volume of water could be delivered to each trench in ~2 working days.

On June 11, 1984, filling of trench 342 began with the delivery of water at a rate of 28 L/min from the head tank, using a 5-cm-diam water hose. On June 12 (one day later) a total of 6624 L of water had been delivered, and filling of trench 338 began. A total of 7191 L were added to trench 338 on June 12 and 13, and then, on June 14 and 15, 11,809 L were added to the third lined trench (trench 334, which was the deepest of the three lined trenches).

Immediately after water delivery to each trench was completed, a record of the water level within the intratrench well was taken for a period of time. Figure 4 summarizes the water level recovery observed for each of the lined trenches and shows that within one day after water delivery ceased, the water elevations in the intratrench monitoring wells had returned to near the pretest water elevations. In the case of trench 342, the water elevation stabilized at 241.5 m, 1.47 m above the trench bottom; water in trench 338 stabilized at 242 m, 1.57 m above the trench bottom; and water in trench 334 stabilized at 240.6 m, 0.74 m above the trench bottom. These rapidly decreasing water elevations suggest that the liners are indeed leaking water and may have a tear or puncture at these respective elevations.

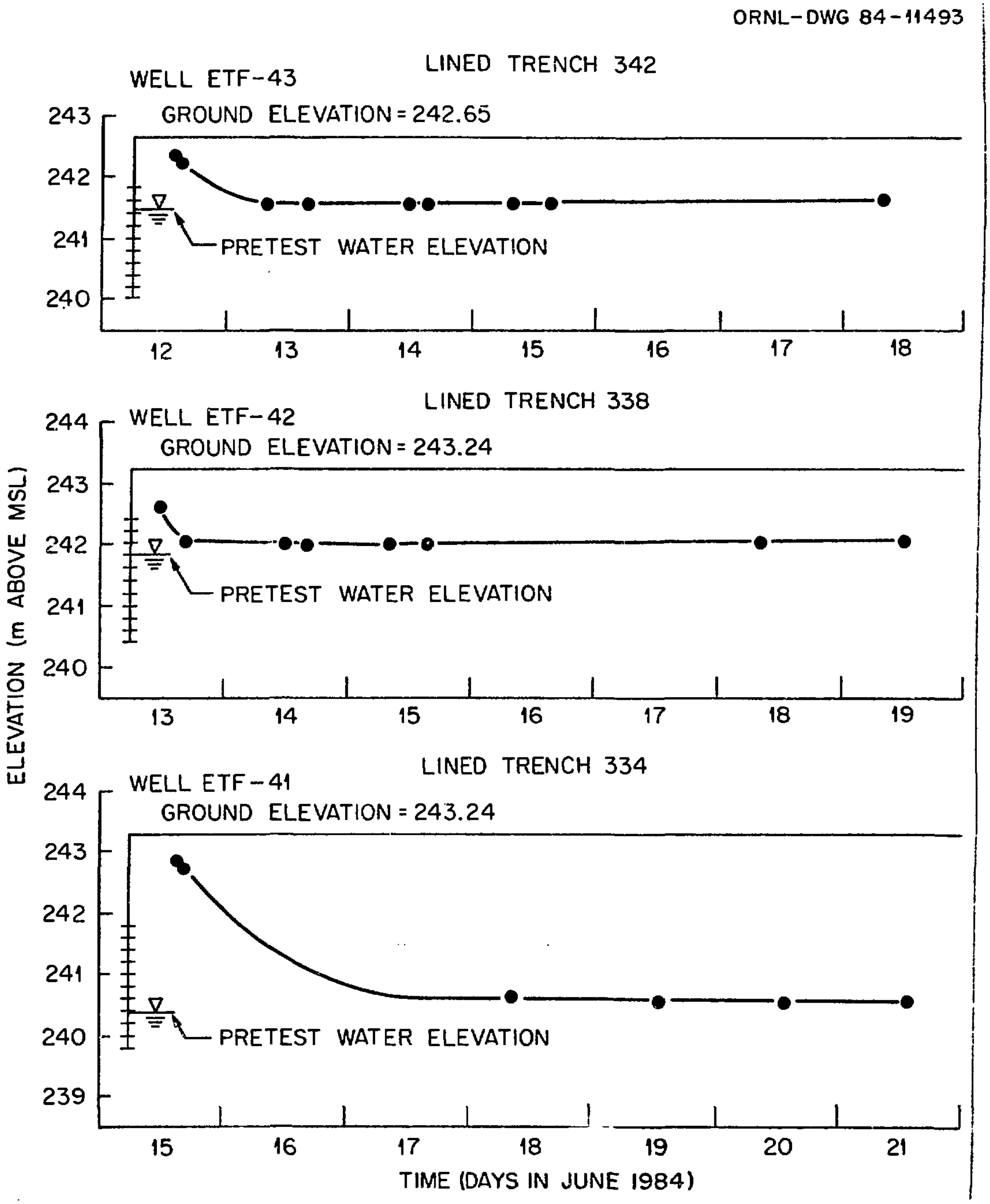

Fig. 4. Water elevations in lined trenches during water pump-in tests.

In addition to monitoring the water levels in the intratrench wells, water levels were recorded in 12 wells (4 around each lined trench) located around the experimental trenches (Fig. 1). If water was confined to the lined trenches, these surrounding wells should maintain a constant water level throughout the pump-in test. Results indicate that within several hours of commencing the pump-in test, water in these monitoring wells began to rise to an elevation between 0.31 and 2.55 m higher than the pretest levels. In general, the pair of wells to the west and east of the trench being filled (wells ETF -36, -37, -28, -29, -20, and -21) showed the greatest response to the pump-in tests; this probably results from the similar orientation of the geologic strike (N50°E) and the higher transmissivity in this direction (Vaughan et al. 1982).

In summary, all tests designed to evaluate the performance of the three lined trenches indicate that they are not watertight. Although the intratrench wells will accept water at a rate of ~28 L/min, the water is not contained within the liner but is exiting the trench and causing water elevations in surrounding wells to increase through the duration of the test. For these reasons lining of waste disposal trenches using methods developed in this demonstration project cannot be recommended as an improvement to present SLB practices. The source of the leaks (e.g., holes in the liner or tears in the seams) should be determined and the liner installation procedure modified accordingly before trench lining can be considered an improved disposal technique for low-level waste (LLW).

Strength and Durability of Materials

An important question in the evaluation of trench grouting and lining, as carried out in this field demonstration, is the strength and durability of the materials used. In the case of the grout, the expected reductions in cover subsidence and hydrologic isolation of the waste are of little value if the properties of the set grout are such that it lacks the necessary strength to withstand the environmental conditions (temperature, precipitation, and mechanical stresses) likely to be encountered with extended storage at LLW disposal sites. Likewise, a material used to line a trench must retain its shear strength, resistance to puncture, and impermeability if it is to serve its intended purpose of waste isolation in future years. This assurance of durability for extended periods of time will certainly be an important factor in public acceptance of any type of material used for improved SLB.

To investigate the question of durability of the two materials (cement-bentonite grout and Hypalon fabric) being tested at the ETF, grout and liner aging studies were initiated in February 1984. An important engineering property of the cement-bentonite grout, and the one selected for examination in this study, is the unconfined compressive strength (ASTM C 109-80) of the set grout. If this strength, measured as the force per unit area required for breakage of a cylindrical grout specimen, decreases significantly with time, then the grout is gradually losing its strength and will likely form cracks and fissures as the result of natural stresses. A decreasing compressive strength would obviously not be a desirable grout property. For the Hypalon-liner evaluation, shear strength (ASTM D 751-79) and puncture resistance were selected as the two engineering properties to examine. These two properties are thought to best characterize the resistance of the fabric to puncture or tearing from waste packages, the most likely cause of treatment failure.

To carry out the aging study, 100 samples of cement-bentonite (7-cm-high cylinders with a radius of 2.75 cm), along with 200 2.5- by 20.3-cm strips of Hypalon fabric, were prepared for testing. The Hypalon-strip samples were taken from a piece of the fabric leftover from the trench lining operations that took place in the summer of 1982. Thus, the specimens can be considered representative of that used to line the ETF trenches. The cement-bentonite grout samples were not collected from the delivery trucks that actually filled the three trenches selected for grouting but, instead, were made up at a later date according to identical specifications.

After sample preparation a total of 9 subsets (1 subset consists of 10 randomly selected grout cylinders and 20 randomly selected liner strips) were buried at a depth of 30 cm at the ETF just west of the experimental trenches. This depth does not represent the worst-case scenario (which might be burial in the saturated zone), but it does allow exposure to freezing and thawing and facilitates sample recovery. To date, one set of samples, those corresponding to the subset to be tested after 4 months, has been retrieved and tested (Table 2).

Results indicate that a significant increase in the strength of the grout specimens has occurred, probably resulting from the increased curing time. The samples in subset 0 were tested after 7 d of curing while the samples in subset 1 aged 4 months in the field before being tested. This increase in grout strength (final strength over early strength) is typical of cement chemistry (Smith 1976). Table 2 also indicates that for the Hypalon fabric samples there was little difference in the mean tensile

TABLE 2. PRELIMINARY RESULTS OF THE GROUT AND LINER AGING STUDY

Aging Time (Months)	Subset Number	Grout Compressive Strength (kPa)	(psi)	Liner Tensile Strength (kg)	Liner Puncture Resistance (kg)
0	0	x=1190 sd=317	x=177 sd=48	x=64.4 sd=6.8	x=11.7 sd=0.97
4	1	x=4160 sd=1060	x=602 sd=152	x=67.6 sd=8.2	x=12.5 sd=0.86
Significant difference in means[a]		yes		no	no

[a]Tested at the 5% level of significance.

strengths and puncture resistances between subset 0 and subset 1, and no statistical difference could be detected at the 5% level of significance. Thus, no apparent change has occurred in these two liner properties with 4 months of weathering in the field.

These preliminary results of the grout and liner aging study indicate that no significant deterioration in selected engineering properties has taken place between subset 0 and subset 1. This is obviously a tentative conclusion based on the results of limited storage time and will be evaluated further as additional specimen subsets are retrieved and tested in the future.

Trench Cover Subsidence

The final treatment performance evaluation involves the presence or absence of trench-cover subsidence. For this purpose three reference transects were established at the site, each to pass over a subset of three of the nine experimental trenches (Fig. 5). Three subsidence surveys were conducted along the transects over a 13-month period between March 1983 and April 1984. Each survey consisted of using a surveyor's level to determine the surface elevation at 30-cm intervals along each of the three transects. In this manner comparisons of elevations between surveys could be made, and subtle differences that may have been missed by a visual site survey could be detected. The timing of the surveys makes them an excellent indicator of rapid trench-cover subsidence caused by initial settlement of waste bales or water-induced movement of cover material into trench void space; however, they are limited because they do not serve as an indicator of long-term subsidence caused by general waste degradation.

The surface profiles resulting from the three surveys are summarized for one of the three transects in Fig. 6, which is plotted with a 13-to-1 vertical-to-horizontal distortion. The data indicate that there has been no catastrophic trench-cover failure and actually very little settlement of the soil cover across the entire site. The largest amount of settlement (on the order of 5 to 8 cm) occurs in two regions: between 3 and 6 m along transect 1 (Fig. 1) and between 15 and 19 m along transect 3. These regions of highest soil settlement correspond to the cover material directly over two of the three Hypalon-lined trenches (trenches 334 and 342). The settlement of cover material over these two trenches was an unforeseen result and may have resulted from the following conditions. Waste bales placed into trenches 334 and 342 were dumped in a random manner, which resulted in a very irregular top surface. Many jagged edges and ends of waste bales, with accompaning large void spaces, were then covered by the Hypalon trench liner. With time, the Hypalon liner stretched under the weight of the soil cover and conformed to the shape of the top surface of the waste. This stretching and molding of the Hypalon cover have resulted in a gradual settlement of the overlying soil that could be detected in the subsidence surveys.

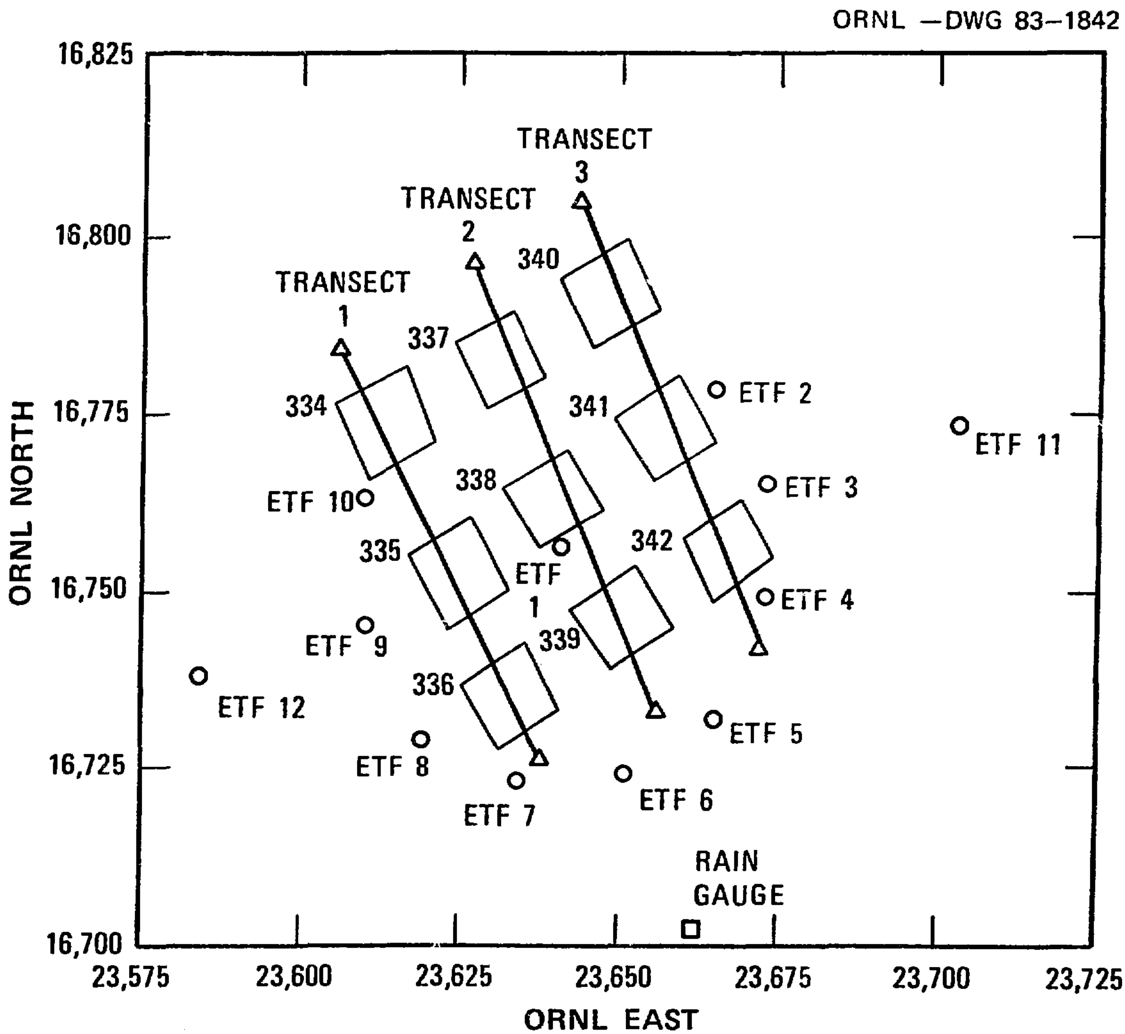

Fig. 5. Trench-cover subsidence transects.

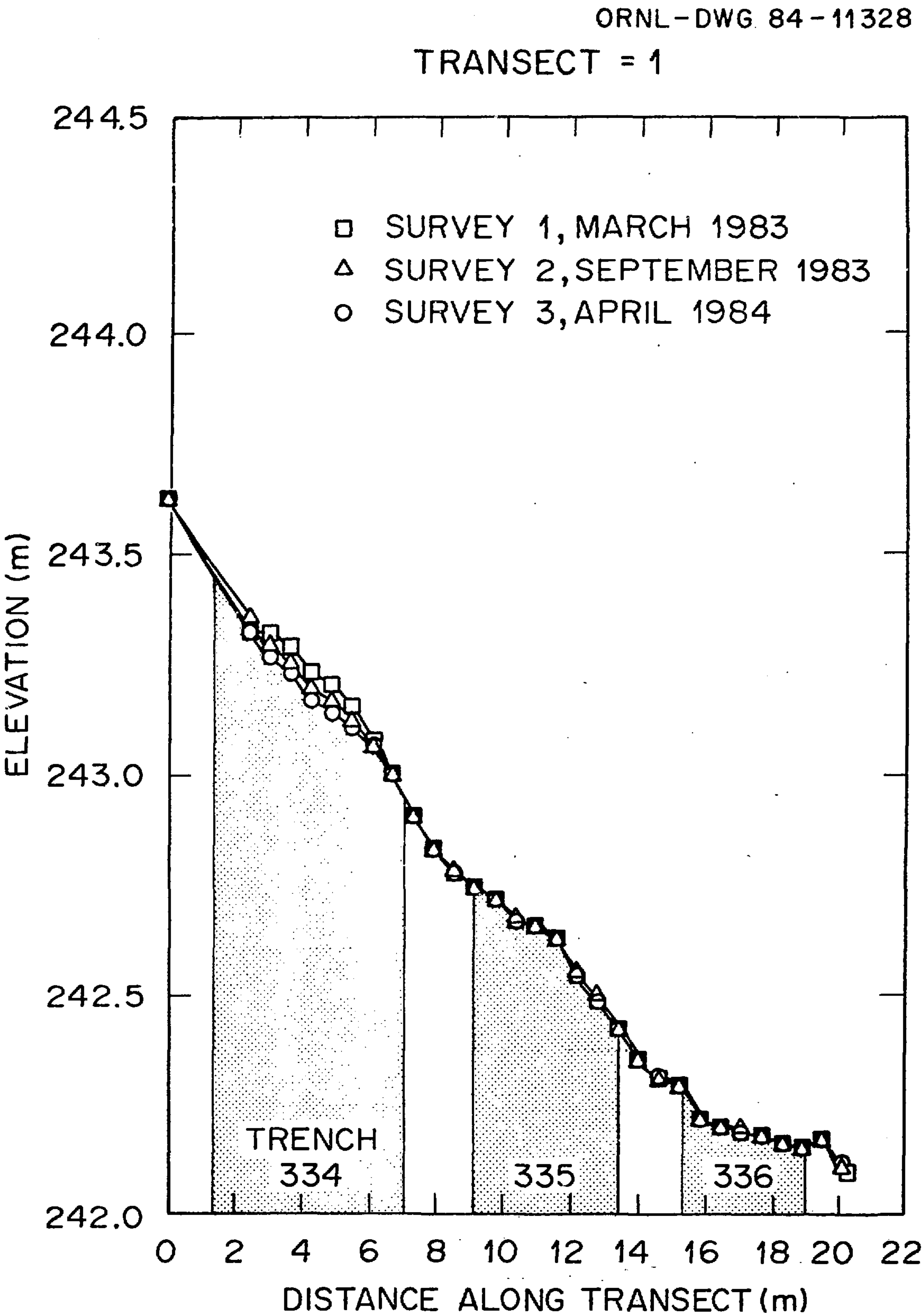

Fig. 6. Subsidence along ETF Transect 1.

In an attempt to quantify the subsidence that has taken place over these two trenches, the average depth of settlement was expressed as a percentage of the total trench depth (3.05 m). In this manner it was calculated that trenches 334 and 342 have both exhibited ∿2% settlement during the 13-month observation period. No detectable settlement, either visual or as a result of the surveys, could be detected over the remaining seven trenches.

HYDROLOGIC-MODEL APPLICATION

Background

Concurrent to the experimental demonstration burial experiments that have been carried out at the ETF, the SLB Technology Task has addressed two additional topics of concern to LLW disposal in humid regions: disposal-site characterization and hydrologic-model development and application. The first of these (disposal-site characterization) was completed in FY 1983 (Davis et al. 1984), and data were used to determine background environmental conditions at the ETF (i.e., conditions before waste burial) and to supply the necessary data to calibrate finite-element hydrologic models for the site. The second task (hydrologic-model development and application) has resulted in construction of two finite-element models [a finite-element model of water flow through aquifers (FEWA) and a finite-element model of material transport through aquifers (FEMA)] that are currently being set up and calibrated for use at the ETF experimental site. A complete description of both computer codes can be found in Yeh and Huff (1983, 1984).

Summary of the Computer Model FEWA

The purpose of this code is to model the effects of natural and artificial disturbances on the piezometric head distribution and groundwater flow in a system of aquifers. The program computes and predicts the temporal-spatial distributions of piezometric head and water flow velocity on an area-wise two-dimensional (2-D) plane. The system may consist of as many types of aquifers as desired, and each aquifer may be completely confined, completely unconfined, or partially confined and partially unconfined. Each aquifer may be inhomogeneous and anisotropic in material properties. Important processes included in the model are sources/sinks, pressure and gravity forces, aquifer leakage, consolidation, and compressibility of water.

The vertically integrated groundwater-flow equation in this code is solved with the Galerkin finite-element method, subject to appropriate initial and boundary conditions. Twelve numerical schemes were included to ensure convergent solutions for as wide a range of inputs as possible. Both quadrilateral and triangular elements are used to facilitate the discretization of the region of interest.

The input to the code can be divided into eight categories: (1) geometry in terms of nodes and elements and boundaries in terms of nodes and segments; (2) number and types of aquifers; (3) spatially varying thickness (in the confined portion) or bottom elevation (in the unconfined portion) of all aquifers considered; (4) hydraulic conductivities or transmissivities, compressibilities of water and media, effective porosity, specific yield, and viscosity of water for each aquifer type; (5) spatially-dependent initial conditions of piezometric heads, either from field measurements or from model simulations; (6) spatially-distributed or point sources/sinks to represent natural infiltration/evaporation or artificial recharging/pumping; (7) piezometric head on Dirichlet boundaries normally adjacent to surface water bodies (such as streams, rivers, lakes, impoundments, and coastal waters) and prescribed fluxes through open boundaries normally with adjacent aquifers; and (8) leaky characteristics of the confining aquitards (beds), represented by leakage coefficients and transient heads above or below the beds. The input in items 6-8 can be time-dependent or constant.

The output from the code is in the following form: (1) piezometric head distribution over a 2-D grid at any desired time, (2) rate and amount of water through all types of boundaries at any desired time, and (3) rate and amount of water accumulated in the aquifer system and transported through confining beds at any desired time. This code has been applied to the ETF experimental site and two additional hazardous waste disposal sites for which water elevation data were available and has simulated water table elevations under steady state conditions. The next step is to test the code's predictive capabilities under transient (storm) conditions.

Summary of the Computer Model FEMA

The purpose of this second code is to model the effects of natural or artificial disturbances on the distribution of waste concentration and waste fluxes in a system of aquifers. The program computes and predicts the temporal-spatial distributions of waste concentration and waste fluxes on an area-wise 2-D plane. The system may consist of as many types of aquifers as desired, and each aquifer may be completely confined, completely unconfined, or partially confined and partially unconfined. Each aquifer may be inhomogeneous and anisotropic in material properties. Important processes included in the model are sources/sinks, advection, dispersion, linear and/or nonlinear isotherm sorption, decay, degradation, effect of consolidation, and leakage through confining beds to upper or lower aquifers.

The vertically integrated advection-dispersion equation, modified to include sources/sinks, leakage, decay, sorption, degradation, and consolidation, is solved with either the Galerkin or upstream finite-element method, subject to appropriate initial and boundary conditions. Twenty-four numerical schemes are included to ensure a convergent solution for as wide a range of inputs as possible. Both quadrilateral and triangular elements are used to facilitate the discretization of the region of interest.

The input to the code is in many ways similar to that of FEWA and also can be divided into eight categories: (1) geometry in terms of nodes and elements, boundaries in terms of nodes and segments, and number and types of aquifers; (2) thickness and/or bottom elevations for each aquifer type; (3) bulk density, dispersivities, decay constant, effective porosity, compressibilities of water and media, molecular diffusion coefficient, tortuosity, degradation rate constants through dissolved and absorbed phases, respectively, and distribution coefficients for linear isotherm equilibrium or Freundlich coefficients and power index (or Langmuir equilibrium constants and maximum absorbed concentration for each aquifer type); (4) initial waste concentration distribution, either from field measurements or from model simulations; (5) flow velocity and piezometric head as a function of time and space, either from field measurements or from FEWA outputs; (6) spatially-distributed or point sources/sinks; (7) waste concentrations at Dirichlet boundaries or amount of waste flow into the region through adjacent aquifers; and (8) leaky characteristics of the confining aquitards (beds), represented by leakage coefficients and transient heads and contaminant concentration above or below the beds. The inputs in items 5-8 may be time-varying or constant.

The output from the code is in the following form: (1) distribution of waste concentration over a 2-D grid at any desired time, (2) rate and amount of waste through all types of boundaries at any desired time, and (3) rate and amount of waste accumulated in the aquifer system in dissolved and absorbed phases, radioactive decay, degradation in dissolved and absorbed phases in the system, and waste transported through confining beds at any time. Application of this model to the ETF experimental site is an FY 1985 planned activity.

SUMMARY AND CONCLUSIONS

The purpose of the SLB Technology Project has been to examine two improved burial practices: trench grouting prior to soil cover emplacement and trench lining, using a synthetic, impermeable lining material. In 1981 and 1982 nine experimental trenches were excavated, filled with bales of low-level compacted waste generated at ORNL, and treated (or not) according to the ETF experimental plan (Boegly and Davis 1983). This paper summarizes the observed performance of the two trench treatments and, where possible, makes a comparison with the untreated control trenches. In all cases the treatment evaluation experiments have been designed to investigate the ability of the improved practices to prevent water-waste contact. Although the project is not completed at the present time, the following conclusions have been reached as a result of project activities in FY 1984.

1. Standing water was observed in all nine experimental trenches (both treated and control); however, depth of water and water-level fluctuation patterns differ considerably, according to the type of treatment. For example, intratrench wells in the three grouted trenches contained only a small amount of water, and no fluctuation pattern was apparent. At the other extreme, the three lined trenches contained up to 1.5 m of standing water that appeared to fluctuate seasonally, being highest in the winter months. The three control trenches were observed to contain water on several occasions, and this intratrench water seemed to be directly correlated with the previous 5-d precipitation totals, indicating that the water was probably transient in nature and rapidly drains from the trench. Thus, none of the intratrench wells remained absolutely dry over the monitoring period.

2. Water pump-out tests conducted on the three lined trenches did not support the original hypothesis that the liners were watertight. Within three months of being pumped dry of intratrench water, all three trenches collected water to a level at or above the pretest elevation. In addition, there was a very noticeable increase in intratrench water levels resulting from the heavy storm activity that occurred the first week in May 1984.

3. Water pump-in tests conducted on the three lined trenches indicated that the liner was leaking. After delivery of 6624, 7191, and 11,809 L of water to lined trenches 342, 338, and 334, respectively, the intratrench water levels rapidly subsided to the pretest elevations, thus indicating leakage. In addition, nearby monitoring wells (within 2 m of the trench sidewalls) were observed to show a rapid increase in water elevation, further supporting the leaking-liner scenario.

4. The unconfined compressive strength of the grout specimens showed a significant increase between subset 0 (7-d curing time) and subset 1 (4-month curing time) and has been attributed to the increased curing time. Testing of liner tensile strength and puncture resistance indicated that no significant (5% level) changes have occurred in these engineering properties with an initial 4 months of field weathering. Additional sampling during FY 1985 will enable a more extensive evaluation of any rapid changes in grout and liner properties with age.

5. Trench-cover subsidence surveys indicated that only two trenches (lined trench 334 and lined trench 342) have exhibited cover subsidence. The subsidence was on the order of 5 cm and represented a settlement of ∿2% of the total trench depth in a 1-year period. The reason for the subsidence over these particular trenches was believed to be the stretching of the Hypalon over the irregular top surface of the waste. Only continued monitoring will determine if subsidence over these two trenches will continue or cease as the fabric conforms to the shape of the waste. None of the remaining seven trenches have shown any indication of cover subsidence.

6. Two finite-element computer models have been developed, one to examine water flow through aquifers (FEWA) and one to predict solute transport (FEMA). Both codes have been documented and verified, and the FEWA code has been applied under steady state conditions to the ETF experimental site and two additional hazardous waste disposal sites. Project activities for FY 1985 will focus on documenting and continuing these modeling activities both at the ETF and at selected disposal sites in humid regions of the country.

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