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RAPID SEEPAGE OF CONTAMINANTS THROUGH THE HIGHWALL OF A URANIUM MILL TAILINGS PIT

by
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ABSTRACT

A computer code (MIGRAT) is used to quantify the migration of moisture and multiple retarded contaminants in the unsaturated zone and assess the impact of open mine disposal of uranium mill tailings. The model is applied to a generic uranium mill tailings pit constructed with a clay-lined bottom and steep unlined sidewalls. The migration of a two contaminant system is modeled assuming that neither contaminant decays and only one contaminant is retarded. This study shows the anticipated result that moisture and contamination migrate slowly through the bottom clay liner and that, in this migration, concentrations of the retarded contaminant significantly lag the unretarded contaminant. This study also shows that the major pathway from the pit to the underlying water table is through the sidewall and that the time scales for this pathway are much shorter than those associated with the clay liner. More importantly, this study reveals that due to the strong nonlinear character of the hydraulic properties of unsaturated soils, concentrations of the retarded contaminant may only slightly lag the nonretarded contaminant through this pathway and contamination of the uppermost aquifer by the retarded contaminant may occur shortly after contamination by the nonretarded contaminant.

INTRODUCTION

Disposal of waste in open subgrade areas has recently attracted considerable attention. In some cases, a bottom clay liner was installed on the floor of the disposal area to inhibit the vertical seepage of contaminants and prevent the rapid development of a mound of contaminated groundwater beneath the disposal area. Conventional one-dimensional vertical analyses show that the time required for a retarded contaminant to migrate vertically through the liner and reach the water table can be lengthened by tens of years when liners are constructed with several feet of compacted materials with very low permeability. In some cases, however, due to an unsaturated flow phenomenon, aquifer contamination by nonretarded and retarded contaminants may be recorded in the near vicinity of such disposal areas at very early times after

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initiation of the disposal process. This study uses a numerical model to identify and describe this phenomenon which is shown to lead to the rapid leakage of water from disposal areas and which provides an explanation for the apparently rapid migration of retarded contaminants. By showing the phenomenon, it draws attention to the possible mitigation actions to be taken to minimize leakage from disposal areas. The simulated disposal area consists of a typical open mine pit excavated in a uniform geological medium and equipped with a clay liner. The bottom of the pit is assumed to be 8 ft. (2.4 m) above a flat water table. The gradual disposal of the contaminated wastes in the pit is assumed to take place over a period of 1 year and is simulated by the addition of discrete layers of waste material in the pit at regular time intervals. The wastes are assumed to be initially saturated with water that contains dissolved contaminants. The model simulates the migration of moisture, retarded and nonretarded contaminants throughout the geological medium. An overview of the model equations and numerical methods can be found in Ref. 1.

DESCRIPTION OF THE SIMULATED DOMAIN

The numerical simulations are made on a two-dimensional vertical cross-section of a typical disposal area 17.5 ft. (5.25 m) deep and 400 ft. (120 m) long. Because of symmetry, calculations are only performed on the left half of the cross-section. A thin clay liner 1.5 ft. (.45 m) thick covers the bottom part of the disposal area. The tailings are assumed to be placed in the pit at a rate of 1.25 ft/month (.38 m/month), in a discrete series of 6 layers, each 2.5 ft. (.75 m) thick. During the first year of simulation, the mesh is thus revised every two months to incorporate a new layer of tailings. The simulation of the gradual disposal of the tailings is important because the phenomena leading to short time migration of contaminants are generated during the filling period and are influenced by the height of the tailings in the pit. The tailings are assumed to be discharged under a fully saturated state without excess water so that no ponded water accumulates above the tailings. This situation represents the ideal method for the disposal of saturated tailings since it minimizes the volume of water available to transport contaminants out of the pit.

Three materials, tailings material, a sandstone type material for the host material, and clay for the liner, are used in the simulations. The moisture characteristic data chosen to represent the unsaturated properties of these materials are taken from Ref. 2. These are typical data for materials to be found in a tailing disposal area environment. Isotropy of the materials is assumed since this assumption does not play a major role in this generic study; the phenomena we want to present would have been qualitatively similar, had the horizontal hydraulic conductivities been assumed larger than their vertical counterpart.

Two nondecaying contaminants are considered in the simulations. Contaminant 1 is taken as a non-retarded contaminant with a constant distribution coefficient equal to 0 in all materials. This contaminant constitutes a marker for the moisture fronts created by leakage from the tailings area and a tracer for the migration of contaminated water through the unsaturated zones. Contaminant 2 is given a constant distribution coefficient of 3 in all materials. Equivalently, its retardation factor ($Rd = 1 + P_sKd/n_eSP_w$, where R_d is the retardation factor, P_s is the soil bulk density, Kd is the distribution coefficient, n_e is the effective porosity, S is saturation and P_w is the fluid density) is about 18 (at saturation) or higher (in unsaturated state) in the sandstone and about 13 (at saturation) or higher (in unsaturated state) in the clay liner. To emphasize and better show the role and consequences of both the advective transport and the non-linear retardation phenomena in unsaturated media, the constituents are assumed non-dispersive. This assumption has no effect on the pressure field or the moisture migration pattern. Its effects are on the patterns of concentration only, mainly in the frontal zones of contaminant migration, and remain small compared to the retardation phenomenon effects. In a quantitative field modeling study, this assumption in fact corresponds to the worst (undesirable) but still probable case of advective transport through channelized areas with no or little dispersive capacity. The contaminants are leaching out of the tailings with a uniform concentration C_0. No initial contamination is assumed to exist in the host material or in the saturated zone below the water table. The results can thus be conveniently displayed in terms of the non-dimensional concentrations, C/C_0.

The boundary of the domain of computation is represented with a dashed line in Figure 1 and following figures. A dashed line is also used to show the separation between the different materials. Note that on these figures, the vertical dimension has been exaggerated by a factor of about 8. The bottom boundary simulates an impermeable layer located 1.5 ft. (.45 m) below the reference altitude ($Z=0$). Boundary nodes which define the calculation and plotting boundaries are placed at the reference altitude. The upper boundary is defined by the topography of the host unit and the surface of the tailings. No flow, such as infiltration or evaporation has been assumed through the upper boundary. The right boundary is the axis of symmetry and is treated with the condition of no normal flow. The left boundary is open to the external environment and is treated with a prescribed potential condition. This condition is acceptable as long as the boundary is placed far from any active transient flow area so that no significant head gradients develop in its vicinity, which will be the case in these short time simulations. The water table is chosen initially flat and laying at an elevation of 3./5 ft. (1.13 m). Infiltration and evapotranspiration are not considered and the undisturbed host unit is assumed in equilibrium with its water table at a uniform potential of 3.75 ft. (1.13 m). Each new layer of saturated tailings will be added to the system with a uniform potential corresponding to its elevation.

NUMERICAL SIMULATIONS

As previously described, tailings are emplaced in an initially empty pit in six equal layers with an additional saturated layer being emplaced every 60 days until the pit is filled. Numerical simulations begin when the first layer of tailings is emplaced (simulation day 0). Figure 1 shows the pattern of isocurves of relative concentration for the nonretarded contaminant (thereafter denoted as C1) after 300 days. At this time, moisture has progressed vertically through the liner into

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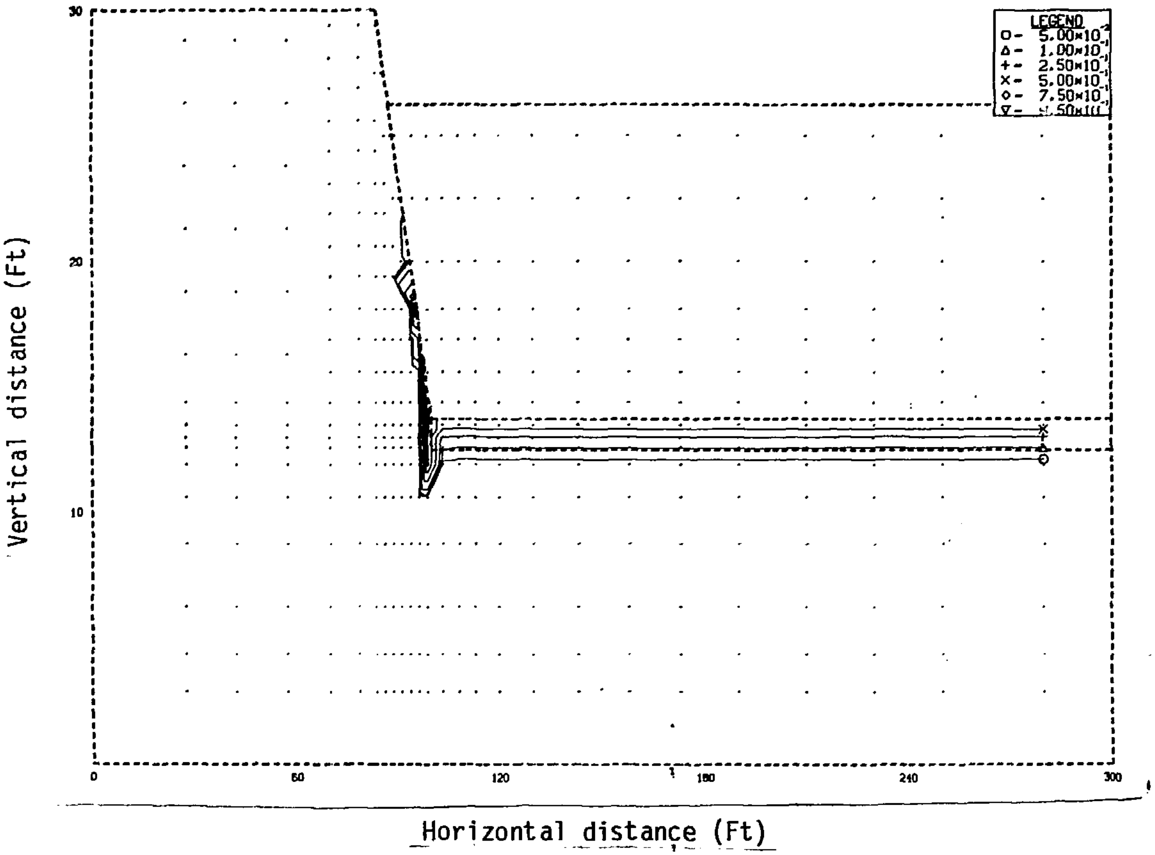

Fig. 1. Pattern of isocurves of relative concentration at time t=300 days for a nonretarded contaminant.

the sandstone below. The nonretarded contaminant has followed the water through the liner into the initially unsaturated sandstone below. Values of relative concentration directly under the liner do not exceed .1 at this time. In the sidewall region, moisture has migrated horizontally from the tailings into the sandstone due to differences in potential between the two materials, saturating a small region in the sandstone at the bottom of the sidewall. A wetting front and an associated contamination front have been created and have moved radially from this saturated area into the surrounding sandstone. The fronts which originated at the bottom of the sidewall have in fact progressed an equal distance in the horizontal and vertical directions but the exaggeration of the vertical dimension by a factor of about 8 on the plots, emphasizes the vertical migration around the edge of the liner. It is important to note that due to the saturation of a very narrow region at the bottom of the sidewall, water and contamination now bypass the liner. This area will subsequently be referred to as the bypass region. Also important is the fact that the ratio of the flow rates per unit areas of bypass and of liner is equal to the ratio of the vertical saturated hydraulic conductivities of the host material (sandstone) and of the compacted clay. This ratio commonly ranges between 10^2 and 10^5 in the field, implying that for a typical circular pit 400 ft. in diameter and a saturated bypass region only 2 ft. wide, the total amount of water that may potentially leave the pit through the bypass is 1 to 1000 times the amount leaving the pit through the entire liner. In this study, an upper bound of 3×10^5 was chosen for the ratio of conductivities to accentuate the bypassing phenomenon. As seen in Fig. 1, the front of nonretarded contamination is very sharp and concentrations greater than 0.95 are observed over the entire bypass region. After 300 days concentrations for the retarded contaminant (thereafter denoted as C2) are still less than 0.05 in the liner (Fig. 2). In the sidewall region, however, the larger flow rate of water through the saturated bypass region results in concentrations of C2 reaching 0.25 in the sandstone. Unlike C1, for which migration is limited by the advance of the moisture front in the dry material, C2 is transported through sandstone areas already saturated by water flowing with high flow rates. It thus advects [illegible] solute in saturated porous media and its transport is not affected [illegible] low values of unsaturated hydraulic conductivities. At time t = 368 days the arrival of C1 at the water table is coincidental with the moisture front arrival (Fig. 3). The concentration of C1 at the water table exceeds 0.9. In this case, little dilution is taking place because the flow rate of contaminated water is large compared to the aquifer flow rate. (An inclined water table would provide more dilution of the contaminants.) Shortly after the arrival of C1 at the water table, large values of concentration and a pressure response corresponding to the groundwater mound should be expected in guard wells located near the edge of the pit. Figure 4 shows the pattern of concentration of C2 at time t = 368 days. No sharp front of contamination has been created because of the retardation phenomenon, but C2 is seen to have progressed through the bypass region around the edge of the liner. Five-hundred days after the initiation of the tailings disposal (Fig. 5), the retarded contaminant C2 has reached the water table in the region located directly below the sidewall. Contamination of neighboring guard wells by C2 should therefore be recorded shorthly after that time (1.5 years). As seen in Fig. 5, the water moving vertically

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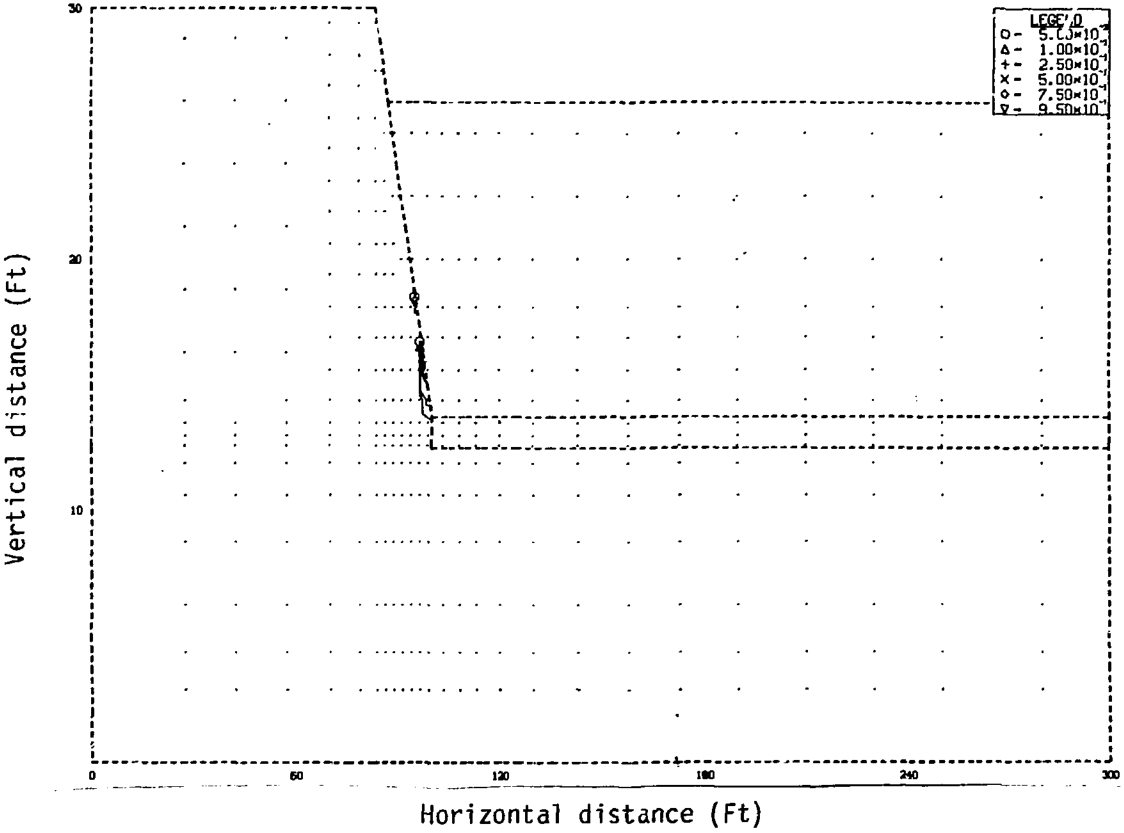

Fig. 2. Pattern of isocurves of relative concentration at time t=300 days for a retarded contaminant (Kd=3).

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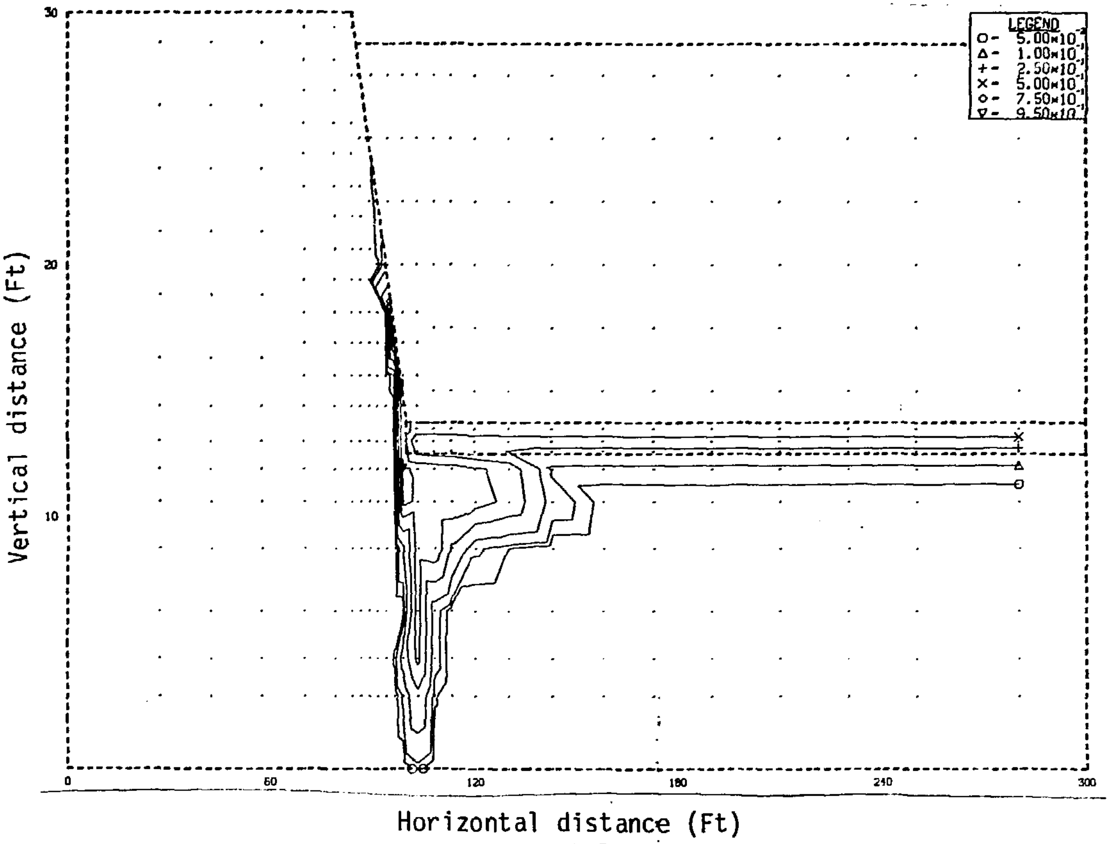

Fig. 3. Pattern of isocurves of relative concentration at time t=368 days for a nonretarded contaminant.

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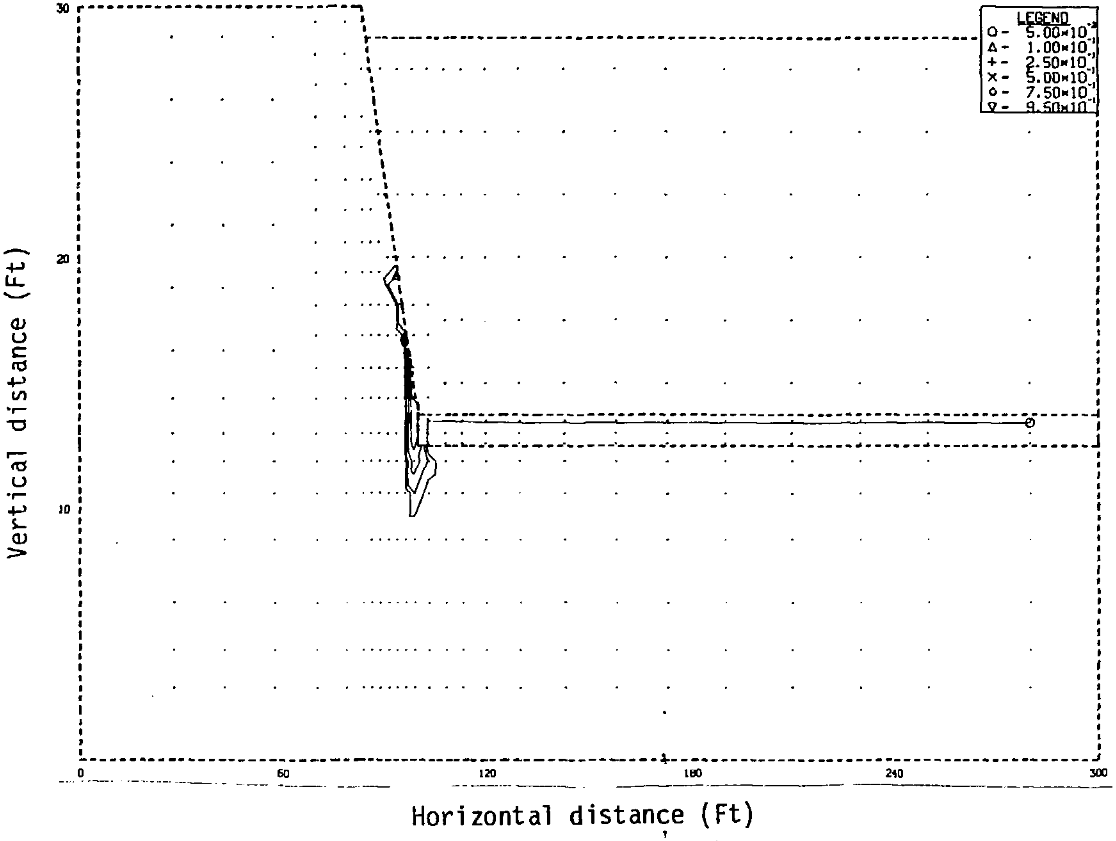

Fig. 4. Pattern of isocurves of relative concentration at time t=368 days for a retarded contaminant (Kd=3).

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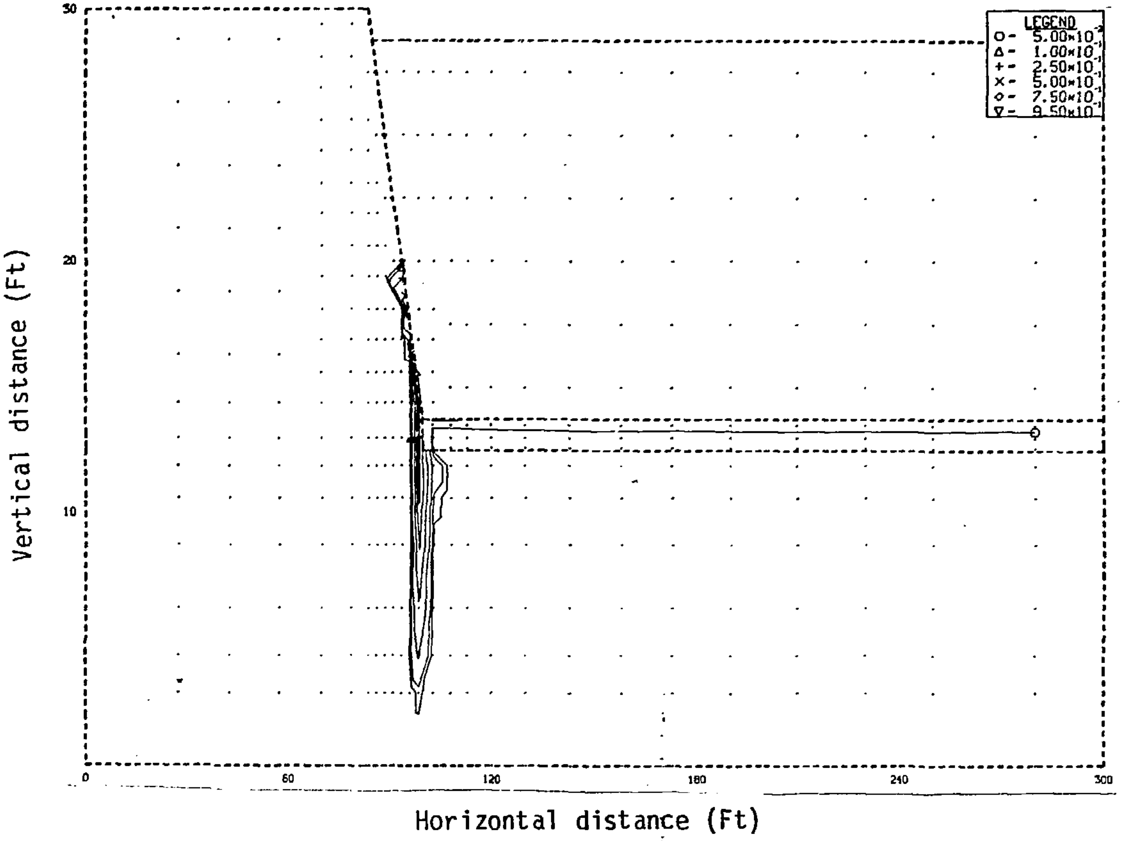

Fig. 5. Pattern of isocurves of relative concentration at time t=500 days for a retarded contaminant (Kd=3).

through the liner has transported C2 only a small distance in the liner and with low values of concentration. A simple vertical one-dimensional analysis would predict this migration of C2 over a small distance in the liner but would overlook the overall impact of the disposal process. A two-dimensional analysis is necessary to show the rapid contamination of groundwater by tailings solution contaminants bypassing the liner.

CONCLUSIONS

The results of the simulations indicate that rapid leakage of contaminated water can occur through the sidewalls of subgrade disposal areas equipped with bottom clay liners. The contaminated water is shown to bypass the liner through a narrow region in the sidewall area, progress rapidly through permeable host materials and reach the water table at early times after initiation of the waste disposal process.

The difference between the potentials of the saturated wastes and the dry host material is the cause for the initial horizontal migration of moisture through the sidewall and the saturation of a narrow region in the host material. Due to the nonlinear character of the unsaturated properties of the geological materials, a moisture front is created which propagates in the host material around the edge of the liner.

A non- or little-absorbed contaminant follows wetting fronts in the geological medium. Its advance is limited by the advance of the fronts and therefore its time of arrival at the water table strongly depends on the unsaturated hydraulic conductivity of the host materials. This emphasizes the need for precise moisture characteristic data for site specific transport modeling studies to be conducted.

The retarded contaminant (distribution coefficient Kd = 3) is seen to lag only little behind the non-retarded contaminant and to reach the water table shortly after the moisture front (1.5 years compared to 1 year in this case). This apparently surprising result is due to the fact that in unsaturated media, the migration of a retarded contaminant occurs in "ideal" conditions compared to the migration of a non-retarded one. It is transported in post frontal regions where moisture contents and therefore hydraulic conductivities and flow rates are high. Its advance is not limited by the moisture fronts or the low values of unsaturated hydraulic conductivities.

Because of the difference in saturation of the medium in which they are transported, very little information about the value of the distribution coefficient of contaminants can be gained in field or laboratory experiments involving, even partially, unsaturated flow conditions. Saturated media represent the best environments for a determination of distribution coefficients.

The phenomenon leading to rapid leakage through the side wall has been shown to be onset by the difference of potentials between the waste and the host material at the sidewall and to develop because of the high permeability and flow capacity of the materials in the sidewall region. Decreasing the difference of potential between waste and host unit by partial dewatering of the waste prior to disposal is not thought to be cost effective and practical for very large volumes of waste. A solution to the rapid leakage through the sidewall should therefore aim at decreasing the flow capacity of the sidewall region. Several alternatives, such as synthetic sidewall liners, underdrains, or capillary barriers may be considered. When studying these alternatives, however, additional parameters such as the effect of ponded water topping the wastes, the distribution of the waste material in the pit, or the relative placement of the underdrains have to be taken into account. Companion studies specifically dealing with these parameters and alternatives are currently being pursued.

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