SINGLE BOREHOLE SCENARIO FOR THE EVALUATION OF BEDDED SALT REPOSITORY SITES

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ABSTRACT

The Single Borehole Scenario is being evaluated in preparation for site comparison and licensing efforts. The preliminary calculations of this human interference scenario indicate limited exposure of waste to water because of natural physical constraints to salt dissolution at the repository horizon. As a consequence, repository system assessments using preliminary site data and conservative parameter values indicate that waste isolation and radionuclide retention are not significantly affected by this scenario. The credibility of this scenario has not yet been established and the assessment of system performance will need to take into account the siting requirements and passive controls at the site that will have a substantial impact on its likelihood of occurrence.

This paper discusses the preliminary assessments of the Single Borehole Scenario that have been conducted in the investigations of salt sites that are candidates for a geologic commercial high-level waste (CHLW) or spent fuel repository. It is, of course, premature to perform detailed performance assessments, particularly for human interference scenarios, because site investigations are still underway. However, the schedule for site characterization does require preliminary assessments at this time: (1) to establish the assessment methodology; (2) to scope the expected performance of the system; (3) to identify key parameters and data needs; (4) and to prepare for the more detailed analyses to follow.

There are several human interference scenarios currently being considered in these preliminary assessments and the Single Borehole Intrusion Scenario, illustrated in Figure 1, is representative of those in which a single flow pathway through the repository has been developed. In this case it is assumed that an exploratory borehole is inadvertantly drilled through the repository to a depth sufficient to connect hydrostratigraphic units that overlie and underlie the repository horizon. Passive controls such as widely distributed records and permanent markers constructed at the site will limit any such exploratory drilling at the site. Therefore, the probability for this scenario is also being evaluated; however, this paper reports only the preliminary consequence analyses.

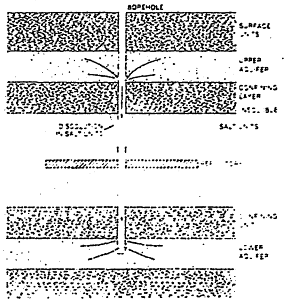

Figure 1. Single Borehole Intrusion Scenario

If such a borehole were to be drilled, a piezometric potential difference between the overlying and underlying units could induce water to flow through the borehole. In itself, this flow is not a concern for repository performance. However, the flow could dissolve the soluble host rock to expose waste and permit leaching of radionuclides. Therefore the flow, dissolution, and leaching conditions are all processes that need to be considered in the evaluations. In addition, the creep response of the salt will act to close the borehole and should be taken into account. All of these processes may be affected by the thermal conditions in the repository since the solubility of salt, the dissolution rate, and the creep rate all depend upon the temperature.

The approach to the analyses is to take these processes into account with simple models using liberal rates and extreme conditions to calculate the performance measures that are expected to bound the actual situations that could occur. The specific techniques that have been used for this scenario are illustrated here. The site considered for this illustration is a bedded salt site is the Palo Duro Basin. A location typical of Eastern Deaf Smith County, Texas, is considered here; however, this choice does not indicate any particular suitability at the present time. Details of the analyses described are given by INTERA (1984a).

BOREHOLE FLOW

The prediction of flow in the borehole depends upon the geohydrology that prevails throughout the region. However, it is important to realize that the analysis of the local flow must treat a scale that has much higher resolution than the normal regional modeling. As a result special efforts are needed to integrate the regional analyses and the local flow modelling. In this analysis, this integration is accomplished by using fixed pressure boundary conditions for the local flow modeling derived from the regional conceptualization of the flow field. The regional modeling efforts for the Palo Duro Basin are discussed by INTERA (1983 and 1984b). These reports summarize the hydrologic properties, the expected flow in the transmissive units, and the potential travel pathways in the region.

The domain modeled for the local flow at the Palo Duro Site is shown in Figure 2. The modeled repository is located in the nine blocks in the center of the 19 km x 19 km grid. The borehole is assumed to be drilled in the center grid block.

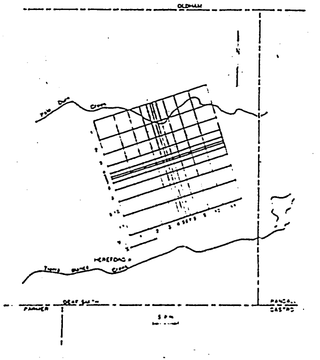

Figure 2. **Horizontal Discretization of Palo Duro Site for Single Borehole Scenario Flow Analyses**

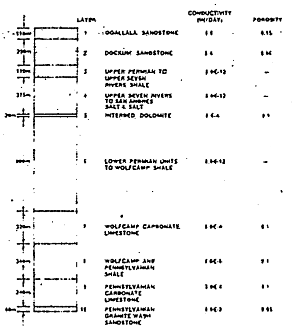

Figure 3. **Representation of Palo Duro Stratigraphy for Single Borehole Scenario Flow Analyses**

The stratigraphic unit and the properties of these units that are assumed to represent the hydrogeologic system are shown in Figure 3. This representation is based on the regional modeling for this region (INTERA, 1983 and 1984b). The repository host rock is assumed to be salt stratum within the Layer 4 confining layer. The Ogallala and Dockum units (Layers 1 and 2) represent the aquifer system that overlies the repository horizon and the Wolfcamp Carbonate (Layer 7), and the Pennsylvania Carbonate and Granite Wash (Layers 9 and 10) represent the transmissive units below the repository.

The evaluation of the steady-state flow for this system is performed with the finite-difference code SWENT (INTERA, 1982). In the calculation of the borehole flow rate, the salinity of the water in the borehole is taken into account by assuming that the water is fully saturated in the salt units. Therefore, the fluid density in the borehole is chosen to be 1250 kg/m^3 with appropriate modification to account for variation with temperature. In the Wolfcamp and the units below, a density of 1080 kg/m^3 is assumed.

The conductivity of the borehole is uncertain and depends on the material that fills the borehole. The flow is therefore evaluated for a spectrum of possible borehole conductivities using Darcy's law to represent the flow through this material. If the borehole resistance is decreased, the flow in the borehole should increase. This trend should continue until the resistance in the borehole becomes negligible relative to that in the transmitting and receiving units. For large enough borehole conductivity, the flow into the lower units should be independent of the borehole resistance. This result represents an upper bound to the rate of flow in the borehole and can be used to estimate extreme conditions. The results in Figure 4 verify this concept. This figure shows the total flow calculated for the borehole and the amount of this flow going into the various units as a function of borehole conductivity. When the borehole resistance becomes negligible relative to that in the upper and lower aquifers, the flow becomes indistinguishable from that of an open borehole. In this case the flow rate is divided among the various receiving units roughly in proportion to their relative transmissivities. The maximum borehole flow rate is predicted to be about 3800 m^3/day with 5 percent going into the Wolfcamp and 92 percent going into the Pennsylvanian Granite Wash.

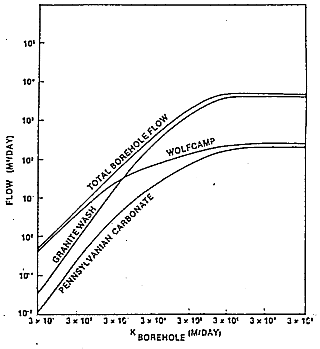

Figure 4. Calculated Borehole Flow Rate for Palo Duro Basin

These results represent upper bounds to the borehole flow rate and not necessarily the flow that would actually occur. For example the flow rate is affected by the size of the grid block used to represent the borehole. When the resistance of the borehole is decreased to negligible values, the flow rate calculated for a borehole block of about a 200 m radius will be about a factor of 3 greater than that calculated for a borehole block of about 0.1 m radius which is typical of actual borehole sizes.

In addition, the calculated flows over estimate the flow rate because it is assumed that the pressures from the regional modeling are not changed significantly at the boundaries of the model even when flow occurs through the borehole. If the boundaries are too close to the borehole or if there is insufficient water available in the transmitting units to maintain the flow in the borehole, drawdown effects could be important.

CREEP AND DISSOLUTION OF SALT IN THE BOREHOLE

A simple approach to the evaluation of borehole growth is illustrated in Figure 5. In this simple model, creep of the salt is neglected and it is assumed that dissolution occurs uniformly in all salt layers preceeding and including the repository horizon. In this model, the dissolution rate at the repository horizon is determined only by the amount of salt in the formation, the borehole flow rate, the salinity in the incoming water, and the solubility of the salt.

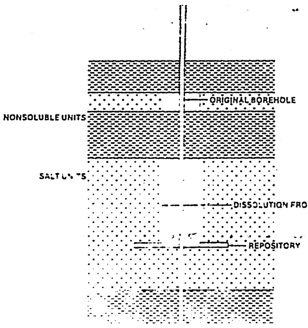

Figure 5. Simple Model of Salt Dissolution by Borehole Flow Based on Uniform Dissolution Versus Depth

A somewhat more realistic view of the processes in the borehole is illustrated in the sketch in Figure 6. For example, most of the salt dissolution will occur in the salt layers initially encountered by the flow. As the water becomes saturated downstream, less dissolution occurs. The dissolution at the repository horizon may therefore be substantially reduced below the crude estimate in the simple model. The calculation of the dissolution of salt at the repository horizon therefore requires explicit evaluation of the dissolution all along the borehole. This evaluation is complicated by the fact that solubility of salt is temperature-dependent so that the natural geothermal conditions and temperature changes induced by the repository waste heat must be taken into account. In addition, the creep property of the salt, particularly in the deep units may need to be considered since the increase in borehole radius due to salt dissolution may be compensated by creep closure of these salt layers. If the hole closes due to creep, the flow will decrease or cease altogether, effectively closing off release in this scenario.

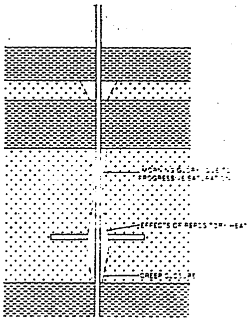

Figure 6. Improved Model of Dissolution by Borehole Flow Considering Progressive Saturation of Borehole Flow, Thermal, and Creep Effects

The conceptual model for the borehole is suggested in Figure 7. The borehole is represented as a sequence of discrete cells. The difference equations involve couplings between the cells due to transport across the top and bottom cell faces and source terms within each cell due, for example, to salt dissolution in the cell. Therefore, a coupled set of difference equations is solved.

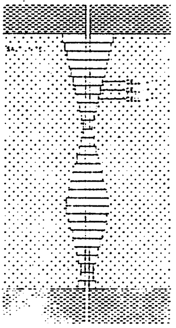

Figure 7. Conceptual Model for Borehole Dissolution and Creep Analyses

The representation for a single cell in this code is shown in Figure 8. In each cell, the one-dimensional equations for mass and energy transport are given with source terms representing the lateral transfer of heat and mass from the walls of the cell.

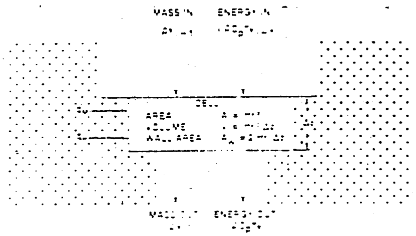

Figure 8. Conceptual Model for Borehole Cell

This approach is incorporated into the BORHOL code (INTERA, 1984c) and this code is used in the analysis. However, even with this code precise analyses are not possible because site-specific data are not yet available. As a result extreme, bounding rates are used.

The dissolution occurring in the salt units due to the flow in the borehole is estimated using phenomenological salt dissolution rates. The salt creep is estimated assuming a steady-state creep law and using preliminary site data for the parameters in this law. For both processes, the effects of temperature in the rock and heat in the repository and the dependence on depth are taken into account.

Calculations have been made for the open borehole taking into account flow, creep, salt dissolution and precipitation, and thermal effects. The first result is shown in Figure 9 where the temperatures in the rock and in the fluid have been analyzed. The in situ rock temperatures tend to increase with depth. In addition, these temperatures are modified by the heat generated by the radioactive waste. This modification is expected to be most important in the vicinity of the repository and could affect the temperature of the fluid in the borehole passing through the repository. Figure 9 shows the predicted temperatures 1000 years after waste emplacement. Although the fluid temperature does reflect some dependence on the rock temperature, this dependence is weak and the temperatures are largely determined by the thermal conditions in the transmitting aquifer. Because of this weak dependence, transient effects due to the decrease in the waste heat generation rate with time will apparently not have a strong impact.

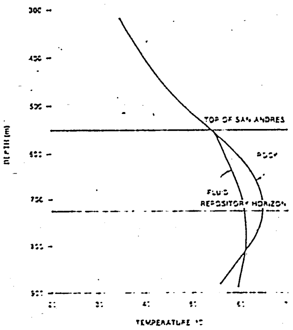

Figure 9. Calculated Fluid and Rock Temperature with Depth

The calculated borehole radius is shown as a function of time in Figure 10. In the deeper layers, the hole grows until dissolutions ceases because of salt saturation. At later times the hole even begins to close due to salt creep. At the top of the salt, the hole continues to grow in the model in the time frame shown.

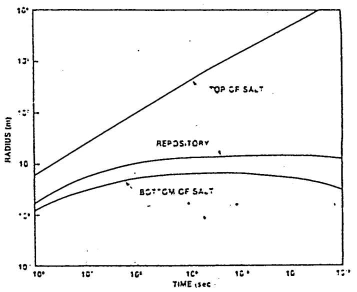

Figure 10. Calculated Radius of Borehole Versus Time

The differing rate of growth of the borehole is a reflection of the fact that, as the flow becomes saturated with salt, less dissolution of salt can take place. At the top of the salt, the fluid is only partially saturated; but, as the flow proceeds downward, the degree of saturation increases. At the repository horizon, much less dissolution can take place as a result. The calculated degree of saturation as a function of depth and time in indicated in Figure 11. It can be seen that the flow at the top of the salt is more than 90 percent saturated within 10 years after the borehole is drilled. At the repository horizon the flow is nearly saturated after only one year. Deeper in the salt, saturation occurs after only a few months of flow. Thus, the salinity of the flow at the lower depths is high due to the dissolution occurring in the upper salt layers.

The shape of the borehole in this idealized model is shown for selected times in Figure 12. The "morning glory" shape of the hole characteristic of the progressive saturation effect is evident. At the repository horizon, the maximum size of the borehole is predicted to be about 10 m for the dissolution parameters utilized. For variations in the dissolution rate parameters or other material properties, this maximum size could very well be different; however, it is clear that total salt dissolution and exposure of waste will be limited.

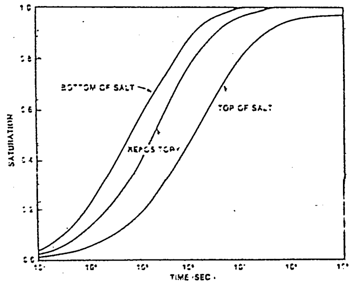

Figure 11. Calculated Progressive Salinity of Borehole Flow

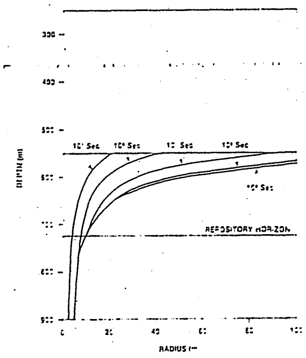

Figure 12. Calculated Borehole Radius with Depth

RELEASE OF RADIONUCLIDES

The dissolution rate of salt at the repository horizon serves as the basis for the evaluation of the rate of exposure of the waste to the borehole flow. The release of radionuclides to this flow then depends upon the waste package and the waste form performance and the solubility of the radionuclides as well as the salt dissolution rate. In this scenario the waste package containment is ignored because the performance of the waste package under these conditions has not yet been evaluated. Future assessments will take the waste package integrity and degradation rate into account.

Underground Facility Performance

The peak rate of dissolution of the borehole wall occurs in the first year because the salinity of the water is lowest then. As suggested in Figure 12, the dissolution rate rapidly decreases from this peak value and soon becomes negligible. Thus, any release of radionuclides from the host salt is expected to be limited to the first few years after drilling the borehole.

The rate of release of radionuclides for the repository can be calculated from the waste exposure rate due to salt dissolution and waste form and waste package performance are determined. The rate of release for a model in which the waste package and waste from are neglected is shown in the solid curves in Figure 13. The rates are different for salt dissolution in the CHLW portion of the repository than in the spent fuel portion because the distribution of waste is different in each case. From Figure 13, the calculated fractional release rate in this simple model is less then one part in 100,000 per year after the first two years of dissolution.

When the waste form leach rate is taken into account the initial short term peak is eliminated. For example, the effect of the glass waste form leach rate for the CHLW case is also shown in Figure 13. In this case a leach rate of 1.0E-7 gm/cm^2-day has been used resulting in a fractional leach rate of 2.2E-5 parts per year. The integration of the waste form release rate and the waste exposure rate results in the dotted curve in Figure 13.

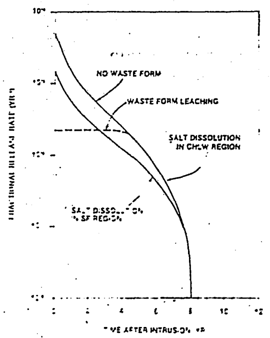

Figure 13. Calculated Fractional Release Rate from Underground Facility for Palo Duro Basin

Release to the Accessible Environment

It is assumed that radionuclides release from the waste form are transported instantaneously by the borehole flow to the lower aquifer units. No retardation of this portion of the transport is taken into account. It is assumed that the borehole flow is added to the ambient flow in the receiving unit. Therefore the radionuclides are transported in the ground-water flow in this unit and the flow is determined from the local modeling of the system including the borehole.

For an open borehole, the local flow patterns in the receiving units could be strongly influenced by the borehole flow. In fact, the flow in these units is calculated to be essentially radial out to a distance of at least 10 km. In this circumstance, the transport is calculated for a one-dimensional, radial flow field and is evaluated using an axially-symmetric discharge velocity that varies as the inverse of the distance from the borehole. The releases are calculated at the 10 km radius and are the sum of all those around the 62 km perimeter at the time of interest. The small amount of mechanical dispersion due to the ambient flow field is neglected.

This transport problem can be modeled directly with standard migration codes. The code used here is SWENT (INTERA, 1982) in which radionuclide chain decay and daughter production are taken into account. Hydrodynamic dispersion and radionuclide retardation can also be in included in the calculations using this code. In the one-dimensional model, hydrodynamic, dispersion transverse to the direction of flow is not taken into account, consistent with the evaluation of total flow across the 10 km boundary. Longitudinal (radial) dispersion is taken into account with a dispersivity of 100 m. Retardation factors appropriate for the flow in receiving units are not well known at present. However, bounding values have been determined for the salt sites by Muller et al (1981) and these are used here. The values are summarized in Table 1.

These evaluations are for the case of a source term due to flow in an open borehole. The results are shown for release to the Granite Wash in Figures 14 to 18. These figures show the releases for the most important radionuclides, all others having curie release rates at the 10 km boundary less than 1.0E-30 Ci/yr.

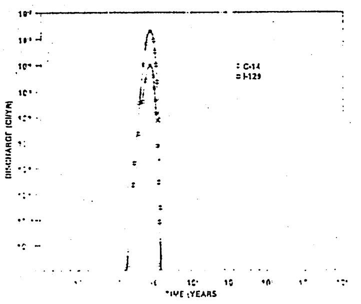

Figure 14. Calculated Release Rate to Accessible Environment Palo Duro Basin-Granite Wash (I-129; C-14)

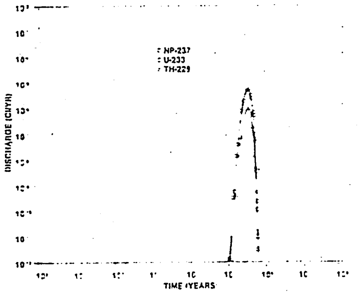

Figure 15. Calculated Release Rate to Accessible Environment Palo Duro Basin-Granite Wash (Np-237 ⟶ U-233 ⟶ Th-229)

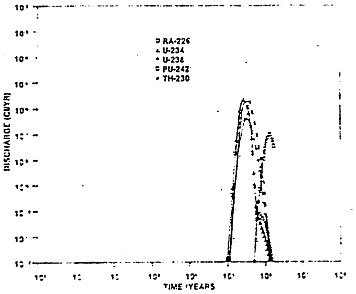

Figure 16. Calculated Release Rate to Accessible Environment Palo Duro Basin-Granite Wash (Pu-242 ⟶ U-238 ⟶ U-234 ⟶ Th-230 ⟶ Ra-226)

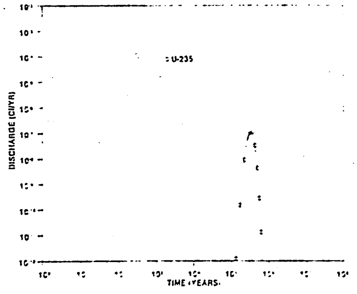

Figure 17. Calculated Release Rate to Accessible Environment Palo Duro Basin-Granite Wash (U-235)

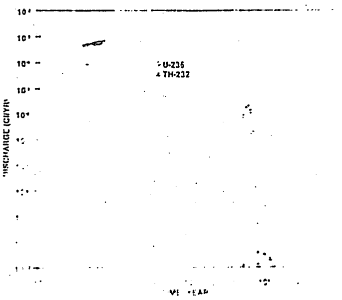

Figure 18. Calculated Release Rate To Accessible Environment Palo Duro Basin-Granite Wash (U-236 ⟶ Th-232)

TABLE 1

Preliminary Calculation of Peak
10,000-Year Integrated Release
10 km Repository

Radionuclide	Assumed Retardation Coefficient (ml/gm)	Peak 10,000-Yr Release (Ci)
C-14	0	1.0
Tc-99	5	21.
Sn-126	5	.019
I-129	0	.98
Pu-239	50	--
U-235	10	.001
Np-237	10	.068
U-233	10	.054
Th-229	50	.011
Pu-240	50	--
U-236	10	.023
Th-232	50	--
Pu-242	50	.004
U-238	10	.021
U-234	10	.033
Th-230	50	.0044
Ra-226	10	.022

As can be seen in the figures, all releases are quite low and even a factor of 1.0E+4 increase would not produce a significant result. The results are summarized in the Table.

CONCLUSIONS

The calculated release rates for the open borehole flow situation are quite small and below currently-proposed regulatory standards. It may be argued that the criteria may not be applicable to the scenario in the way presented. For example, the EPA criteria for system release may not be applicable to the radial flow problem since the release evaluation involves contributions as far as 20 km from each other. Likewise, it may not be appropriate to compare the fractional release rates from the repository horizon due to the dissolution with the criteria for release from the engineered barrier subsystem. Nevertheless, this illustration provides an initial effort to define the approach that may be used in the future assessments.

Analyses for this scenario have been conducted for a bedded salt site (NRC, 1983; Pepping et al, 1983; Cranwell et al, 1982) and the predicted releases are somewhat larger than those given here. However, these analyses used simple models for the salt dissolution and did not attempt to take into account the physical constraints to the release due to the dissolutioning occurring in salt layers upstream of the repository nor were realistic salt dissolution rates used in these analyses. Therefore, the present study provides a useful contrast to the earlier work and demonstrates the constraint due to well-understood physical phenomena upon the release rate in this case.

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