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CONSULTING MINING AND GEOTECHNICAL ENGINEERS

THIRD REPORT
DEVELOPMENT OF SITE SUITABILITY
AND DESIGN PERFORMANCE DATA BASE
FOR A HIGH LEVEL NUCLEAR WASTE REPOSITORY
FOR
LAWRENCE LIVERMORE LABORATORY
P.2 9197703

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SUMMARY

THIRD REPORT DEVELOPMENT OF SITE SUITABILITY AND DESIGN PERFORMANCE DATA BASE FOR A HIGH LEVEL NUCLEAR WASTE REPOSITORY FOR LAWRENCE LIVERMORE LABORATORY

GENERAL

This report presents the results of our mining and geotechnical studies provided to the Lawrence Livermore Laboratory (LLL) as support for the development of a technical data base suitable for the generation of a regulatory framework governing high level nuclear waste disposal. The work was performed in accordance with our unsolicited proposal to LLL dated November 9, 1977 and authorized by University Purchase Order 9197703. The primary purpose of our effort was twofold: expand appropriate areas of site suitability described in our previous reports (Golder Associates, Inc. (GAI) 1977a, 1977b), and review a conceptual design in bedded salt. The work presented in this report supplements and expands the work presented in our previous reports (GAI 1977a, GAI 1977b). This current report should be reviewed in conjunction with those reports.

SITE SUITABILITY DATA BASE

MODEL EVALUATIONS

The site suitability data base developed by GAI has been integrated into a site suitability repository model or Long Term Risk Model (LTRM) developed for this study (TASC 1977a, 1977b). The specific information presented in this report relating to the LTRM modeling effort is discussed below.

1. Flow Path Model Refinements

Several flow path model refinements have been developed in this cycle. The basic flow path model is discussed in various reports (TASC 1977a, 1978a) and pertains only to a generic model in salt or shale. These refinements include a nonpoint source depository model, evaluation of the potential depressurization of the lower aquifer, and depository recharge time coupling.

Cycle I and Cycle II LTRM models treated the depository as a point source for cases considering backfill deterioration or fracture zones around the tunnels and shaft. That is, all nuclides were assumed to enter the flow system at a single node representing the depository. A computer model, called REPFLO, was developed which incorporates the spatial distribution of waste canisters within the depository, calculates the proportion of flow contributed by various areas of the depository and the time it takes that flow to reach the depository exit. The results of the REPFLO computer model can then be directly used in the LTRM model. The use

of the model will shorten the transit times for the waste close to the depository exit point. Except for extremely high backfill tunnel fracture permeabilities (at least six orders higher than the surrounding rock), most of the nuclides exiting via the shafts and associated fracture zones originates from waste areas near the depository exit. Thus, this refinement may significantly affect the computed doses for certain backfill/fracture zone cases. Regardless of the conditions, the model better accounts for the complex flow paths within the depository backfill.

The depository water recharge time after decommissioning is highly dependent on the initial properties of the host media and man-induced and/or naturally induced changes. In the initial models, the recharge time was introduced as an independent variable. To be more realistic, we have developed a relationship between recharge time and general depository characteristics.

Due to the effects of flaws (such as the depository backfill and surrounding fracture zones, failed boreholes, changes in original fault zone characteristics, development of breccia zones (in salt), and other phenomena) the pressure gradient between the upper and lower aquifers may be locally reduced. It is important to consider these effects. As discussed in this report, any flaw which extends only to the depository depth and not through to the lower aquifer will have a limited impact on depressurization. Flaws which extend through to the lower aquifer can depressurize the lower aquifer if they have sufficient size and/or permeability. Based on simple computations, it appears that depressurization may be significant for faulting, breccia zones and certain borehole cases. Future LTRM models should incorporate these considerations.

2. Preliminary Evaluation of Selected Phenomena

Consistent with our previous work (GAI 1977a, 1977b), GAI has continued to perform preliminary scoping evaluations of selected phenomena. The problems considered in section 3.0 of this report include gas transport, lateral groundwater flow, multi-aquifer systems, and impermeable faults.

Based on a simplified upper bound solution and ignoring radiolysis, hydrolysis, and gas solubility it does not appear that gas pressure will cause a breach in waste containment. Computations are presented of predicted gas pressures as a function of depository size, depth, backfill characteristics and recharge behavior.

The initial Cycle I and Cycle II sedimentary basin models (TASC 1978a) analyzed idealistic flow path configurations which assumed strictly vertical flow in the rock surrounding the depository layers, strictly horizontal flow in the aquifer layers, no lateral dispersion effects, and discharge of nuclides into the biosphere occurred along a single infinitely long body of water. In our opinion, these are reasonable assumptions for the preliminary generic model analysis, which emphasized parametric sensitivity studies. However, there are several site conditions which may require lateral flow and lateral dispersion to be more rigorously evaluated. These conditions are discussed along with procedures for evaluating the effects and anticipated results. These include:

1. Multi-shaft locations spaced over the depository.
2. Horizontal flow dominating within the depository and barrier layers.

3. Multi-discharge points.
4. Multi-aquifer systems.
5. Nuclide release through wells.

The current LTRM model evaluates faults that have a higher permeability than the surrounding rock. Thus, any new fault or reoccurring movement along an old fault would produce a permeable pathway to the overlying aquifer. In addition, the model assumes that flow along the fault will disperse into the upper aquifer. This type of fault flow behavior was chosen for the initial model for simplicity and because it represented a relatively adverse case. However, as discussed in our previous reports (GAI 1977a, 1977b), there are several other scenarios which may be more realistic. These might include impermeable faults and impermeable faults with associated permeable fractured zones. This report discusses these other cases and presents a methodology for their evaluation.

3. Simplistic Preliminary Flow Path Models

In our November report (GAI 1977b), we presented a preliminary data base for basalt, salt domes and crystalline formations. This work included simple geologic/hydrologic generic models which were summarized in Section 3.4 of that report. These models were intended to be simple enough to be synthesized into a generic nuclide transport model (such as the LTRM model) while enabling realistic geologic and hydrologic conditions to be evaluated. In this report we develop preliminary flow path models for the generic geologic/hydrologic models. These flow path models are consistent with the capabilities of the current LTRM models. The purpose of these flow path models is to develop a framework for future LTRM model evaluations and provide sufficient insight to more intelligently plan future work.

Generally only the unflawed flow path models were developed and discussed. However, general comments on flaw pathways are also presented for each formation type.

4. Simplistic Model Evaluations

A procedure has been developed under this contract for approximating the radiation dose release for very simple flow path networks (TASC 1978). Although the numerical results of the analysis are only crude approximations and could even be misleading, the results probably represent a reasonable approximation of the more rigorous LTRM model.

The integrated population dose is a measure of the total dose release to mankind over the life of the repository. Assuming a single release pathway to the biosphere, the integrated population dose is essentially constant for all repository performance conditions provided no waste escapes for at least 420 years. As compared to background radiation dose rates, the longer the period over which the waste is released, the smaller the impact compared to background. In general, a well-designed unflawed repository in a sedimentary basin corresponds to an integrated population dose rate on the order of 0.1 percent of background. For detailed definition of different dose computations see TASC 1978a.

The results of the current LTRM model for sedimentary basins indicate that two dominant geometric barriers to nuclide release exist: the thick, impervious depository rock layer (salt or shale) and the overlying aquifer. In section 5.0 of this report we present the results of lumped parameter evaluations of two single barrier models. First we consider

only a shale (or salt) barrier discharging into a river; and second we consider an aquifer barrier discharging into a river. The following model evaluations are presented:

1. Dose release into the river through an unflawed depository layer (shale, salt).
2. Dose release into the river through the overlying aquifer.
3. Dose release into the river through a flaw in the depository layer (shale, salt).

5. Loss of Administrative Control

In our November report (GAI 1977b), we presented a preliminary data base for the evaluation of Loss of Administrative Control (LOAC) and the impact of a repository on future natural resource development. In this report we present a methodology consistent with the general LLL approach for evaluation of the risks associated with LOAC. The methodology presented involves an event tree with associated probabilities and consequences. It is expected that the probabilities generally increase gradually with time while the consequences decrease with time.

The general categories of LOAC events considered include:

1. Initial Conditions: Following decommissioning, the performance of the repository will be carefully monitored and evaluated.
2. Repository Performance: The repository either performs as designed or it does not.
3. LOAC: Loss of Administrative Control either occurs or it does not.
4. LOAC Increases Release: LOAC either affects the performance of the repository or it does not.

The final states or termination points of the event tree for cases without LOAC include:

1. Repository Performs Adequately: There are no unacceptable releases.
2. Repository Does Not Perform Adequately: The monitoring program will determine if an unacceptable level of radiation release occurs. Under such conditions, active and/or passive action (such as increasing the buffer zone) could be taken to reduce the radiation to acceptable levels.

The final states for cases with LOAC include:

1. Repository Performs Adequately and LOAC Does Not Affect Performance: There are no unacceptable releases.
2. Repository Performs Adequately but LOAC Affects Performance: There may be a certain level of release depending on the nature of the breach in containment and the time of LOAC after decommissioning.
3. Repository Does Not Perform Adequately: Depending on when LOAC occurs, there may be curtailed level of release; due to LOAC the release would not be detected.

For an unacceptable release to occur, a combination of low probability events must occur. Although these probabilities may increase with time, the consequences of release decrease with time (significantly so after about 400 years).

DESIGN PERFORMANCE DATA BASE

This part of the report presents an evaluation of repository design concepts based on our review and interpretation of existing repository conceptual design data. The evaluation considers:

1. A review of the underlying design assumptions.
2. The interaction between major design features.
3. General design criteria.

The scope of work under this contract includes only repository designs for bedded salt, which are documented in two reports:

1. Waste Isolation Facility Description - Bedded Salt, by Parsons, Brinckerhoff, Quade, and Douglas, Inc. (1976a).
2. Waste Isolation Pilot Plant Conceptual Design Report, by Sandia Laboratories (1977a).

As we have not been able to obtain access to the data or to discuss the design assumptions with the authors, we are unable to present an in-depth review of the detailed engineering contained in these designs. They appear, however, to be quite competently and thoroughly engineered in many respects. However, the procedures for monitoring and verifying design performance, and the decision points that should exist in the transition from pilot plant to operational phase, are not clearly presented. These procedures and subsequent evaluations may be essential to provide an increased level of confidence that the data on which the design is based adequately represents

the range of conditions actually experienced. As a minimum, they would provide a solid factual base on which to support decisions concerning waste retrieval or decommissioning.

We have classified repository design factors that affect radiation hazards into two categories, those that affect presealing performance and those that affect postsealing performance. As the repository design must include consideration of all geologic and hydrologic factors, it is considered essential that studies concerned with design performance criteria and site suitability criteria be closely interfaced. The general hydrologic transport model would be used to evaluate the contribution to radioactive release from postsealing factors. Presealing factors require an alternative methodology for evaluating their radioactive hazard.

Some of the more important factors identified for prime consideration and discussed under site design performance are:

1. Waste storage capacity of the repository and design dimensions.
2. Shaft design and shaft sealing.
3. Borehole sealing.
4. Waste retrieval.
5. Thermal effects.
6. Ventilation requirements.
7. Backfilling (decommissioning).

The interaction of these factors is discussed in detail in Section 8.0 of this report. Based on this discussion, some comments on preliminary site design performance are presented.

The purpose of LLL's work for NRC is to provide a defensible set of technical data on which to base regulatory decisions. Engineering barriers may, in some instances, be

required to satisfy the defense-in-depth requirements postulated by NRC, where a credible set of natural barriers to radioactive release cannot be defined.

1.0 PURPOSE AND SCOPE

This report presents the results of our mining and geotechnical studies provided to the Lawrence Livermore Laboratory (LLL) in support for the development of a technical data base suitable for the generation of a regulatory framework governing nuclear waste disposal. The work was performed in accordance with our unsolicited proposal to LLL dated November 9, 1977 and authorized by University Purchase Order 9197703. The primary purpose of our effort was twofold: expand appropriate areas of site suitability described in our previous reports (Golder Associates, Inc. (GAI) 1977a, 1977b), and review repository design concepts for bedded salt. The site suitability information is to be integrated into the Site Suitability Repository Model (LTRM). This model is described in detail in various reports (TASC 1977a, 1977b) and will not be described in this report. The conceptual design data reviewed was contained in "Waste Isolation Pilot Plant (WIPP) Conceptual Design Report" by Nuclear Waste Engineering Division 1142, Sandia Laboratories, Albuquerque, New Mexico, June 1977 (Sandia 1977a). The report "Waste Isolation Facility Description" by Parsons, Brinckerhoff, Quade and Douglas, Inc., September 1976, was also used as a reference document.

The scope of our work involved literature research; further evaluation of geotechnical and mining site suitability and design performance factors; development of specific descriptors and coefficients relating to generic depositories in basalt, salt domes, and crystalline rock; flow path modeling refinements; review of a conceptual repository design; and geotechnical and mining guidance to the overall LLL waste management program. In addition to the work presented in this report, we attended

numerous working project meetings involving LLL and their other consultants, attended monthly Waste Management Coordination meetings at NRC, attended portions of the American Nuclear Society's meeting in San Francisco on November 29, 1977 relating to Sandia's WIPP effort, and visited several salt and potash mines.

The work presented in this report supplements and expands the work presented in our previous reports entitled "Development of Site Suitability Criteria for the High Level Waste Repository for Lawrence Livermore Laboratory" submitted in June 1977 (GAI 1977a) and "Second Report Development of Site Suitability Criteria for the High Level Waste Repository for Lawrence Livermore Laboratory" submitted in November 1977 (GAI 1977b). This current report should be reviewed in conjunction with those reports. In addition to our work for LLL, we are currently under contract to The Analytic Sciences Corporation (TASC) as the prime subcontractor on an NRC contract entitled "Definition of Design Performance Criteria for a Geologic Waste Repository," Basic Ordering Agreement NR-02-77-81.

2.0 FLOW PATH MODEL REFINEMENTS

2.1 GENERAL

Several flow path model refinements were developed as part of the overall program development. The basic flow path model is discussed in various reports (TASC 1977a, 1978a) and pertains only to a generic model in salt or shale. These refinements include a nonpoint source depository model, evaluation of the potential depressurization of the lower aquifer, and depository recharge time coupling.

2.2 NONPOINT SOURCE DEPOSITORY

2.2.1 Previous Treatment of Depository Flow

Cycle I and Cycle II LTRM treated the depository as a point source for cases considering backfill deterioration or fracture zones around the tunnels and shaft. That is, all nuclides were assumed to enter the flow system at a single node representing the depository. The length of the flow path representing flow within the depository was set equal to one-half the total length of the depository. This preliminary pipe analog treatment of flow within the depository did not account for the spacial distribution of waste within the depository and the resulting time-dependent release rates. Thus, in the preliminary models, no nuclides were released from the depository until flow had traveled the distance representing one-half of the depository length, after which nuclides from the entire depository were assumed to be released into the corridors leading to the shafts. It is apparent for the Cycle I and Cycle II models that nuclides from canisters located very near to the exit of the depository will leave the depository much sooner than those from canisters located at greater distances from the exit.

A relatively simple computer model, called REPFLO, has been developed which incorporates the spacial distribution of waste canisters within the depository and calculates the proportion of flow contributed by various areas of the depository and the time it takes that flow to reach the depository exit. The results of the REPFLO computer model can then be directly used in the LTRM model. In this report we present the basic REPFLO model and the results of the model for a specific set of conditions. The conditions analyzed represent a depository geometry similar to the Parsons, Brinckerhoff, Quade, and Douglas, Inc. conceptual design (Parson, Brinckerhoff, Quade, and Douglas, Inc. 1976b) with a pervious backfill. Future model runs might include fracture zones around depository openings, multi-shafts, and/or different depository geometries.

2.2.2 Description of REPFLO Program

A schematic of the situation to be modeled is shown in Figure 2-1. Flow is upward from the lower aquifer into the depository. A proportion of the flow continues through the depository and upward through the overlying formation to the upper aquifer. The remainder of flow travels along pathways formed by fracture zones or deteriorated backfill within the depository and eventually exits via the connecting tunnels and shaft to the upper aquifer.

REPFLO treats the depository as a series of nodes connected by pipes as shown in Figure 2-2. Flow within the pipes is one-dimensional and steady state. The pipes themselves are oriented in three dimensions. Referring to Figure 2-2, flow within the depository is in the x and y directions, whereas flow from the lower aquifer to the depository and from the depository to the upper aquifer via the formation and shaft is in the z direction.

The rationale for the nodes and connections comes from the mine master plan from Parsons, Brinckerhoff, Quade and Douglas (1976).

reproduced in Figure C-2 of our November report (GAI 1977b). Connections from node 4 to node 29 represent the main corridors running down the central axis of the depository with node 29 representing the depository exit. Node 30 represents the bottom of the shafts. Nodes connecting to the main corridor from the side represent the HLW storage rooms. Because of the symmetry of the depository, branches off only one side of the main corridor were needed and the areas attributed to the connections and nodes were doubled to account for the other side. The nodes representing the HLW storage rooms were connected by pipes (not shown in Figure 2-2) to the lower and upper aquifers in the model. None of the main corridor nodes were connected to aquifers with the exception of node 30 (bottom of shaft) which was connected to the upper aquifer only. The three shafts were combined into an equivalent single shaft (i.e., equivalent to the existing LTRM model).

The flow to/from a node i to/from a node j can be solved by using Darcy's Law:

$$Q_{i-j} = \frac{KA}{L} (H_i - H_j) \quad (1)$$

where Q_{i-j} = flow

K = permeability of flow path

A = area of flow path

L = length of flow path

H_i = head at node i

H_j = head at node j

Note that flow into node i ($H_i < H_j$) will be negative and flow out from node i positive ($H_i > H_j$). For steady state conditions the inflow to node i must equal the outflow. Thus, the sum of all flows to node i from connecting node j must equal zero.

$$\sum_{j=1}^n Q_{i-j} = \sum_{j=1}^n \frac{KA}{L} (H_i - H_j) = 0 \quad (2)$$

where n is the number of connections to node i.

The REPFLO program through an iterative process solves for heads at all nodes and adjusts them until the conditions of equation (2) are met. Instead of setting equation (2) equal to zero, the program actually tests for when equation (2) is less than or equal to some small number greater than zero at which convergence is assumed.

After each iteration cycle, if the convergence criteria are not met, the head at each node is adjusted by adding ΔH_i , which is defined as:

$$\Delta H_i = \beta \frac{\sum_{j=1}^n \frac{KA}{L} (H_i - H_j)}{\sum_{j=1}^n KA/L} \quad (3)$$

The parameter β can be varied to find a value which causes the convergence criteria to be met in the fewest iterations. A β value of 1.50 was used in our analyses. Two additional criteria for convergence (other than the allowable value for Q) were established. These consisted of a maximum allowable ΔH_i for all nodes, and a maximum allowable Root Mean Square defined as:

$$RMS = \sqrt{\sum_{i=1}^m (\Delta H_i)^2} \quad (4)$$

where m is the number of nodes.

2.2.3 Program Inputs

The input data to the REPFLO program included:

1. Nodal connections: Nodal connections follow from Figure 2-2. Connections included node to node and node to reservoirs.
2. Connection types: Five connection types were considered. They included: (1) reservoir to nodes representing

storage room area; (2) node to node in storage room area; (3) node to node along main corridor; (4) node to node along connecting tunnel (node 29 to node 30); (5) node to reservoir along shaft.

3. Areas, lengths, permeabilities and porosities:
These parameters are defined for each connection type. They were based upon the mine design plan (areas and lengths) and the range of expected permeabilities and porosities.
4. Reservoir data: The heads within the upper and lower reservoir were set constant.
5. Initial nodal heads: The initial head of each node was set at an arbitrary value between the two reservoir heads.
6. Convergence criteria: The parameters defining the convergence criteria were set at arbitrarily small values.

2.2.4 Program Outputs

The program outputs included:

1. Final heads: The heads after convergence at each of the depository nodes were calculated. If convergence criteria were not met in a specified number of iterations, a message was given and the final values of head were then printed.
2. Transit times: The travel time between adjacent nodes was calculated. These times would then be summed to give total transit times from the various regions within the depository to the exit (node 29).

3. Net nodal inflow: The net gain in water flowing towards the depository exit was calculated for each node with reservoir connections. The net gain is the difference between the inflow from the lower aquifer to the node and the outflow from the node to the upper aquifer.
4. Total flow: The total flow entering (and leaving) the depository was calculated.

2.2.5 Discussion of Results

The REPFLO program was utilized in analyzing the effects of backfill deterioration. A number of computer runs were made, varying the permeability of the formation surrounding the depository, K_D , and the permeability of the backfill, K_B , each time. K_D was assumed equal to the equivalent permeability of all layers between the aquifers. Thus,

$$K_D = \frac{L_D}{\frac{L_1}{K_1} + \frac{L_2}{K_2}}$$

where: L = thickness of layer or flow path

K = permeability

From these runs nodal heads as illustrated in Figure 2-3 were determined, for a given ratio of K_B to K_D . Figure 2-4 is a plot of the head at several locations in the depository (as a percentage of the total head drop between the aquifers) versus the ratio K_B/K_D . The curve labeled H_s represents the head at the bottom of the shaft, node 30; the curve labeled H_c the head at the depository exit (node 29); and the curve H_A the "average" head within the depository. The actual head in the depository varies from node to node (see Figure 3-3). The "average" head

is the head which, when coupled with the LTRM model analog and the appropriate pipe characteristics, will yield the same inflow to the depository as calculated in the REPFLO model. Figure 2-4 shows that for K_B/K_D ratios greater than about 10^5 , most of the head drop between the aquifers occurs before flow enters the depository.

Figure 2-6 is a plot of the ratio of the contaminated flow exiting the depository outlet at any given time to the final contaminated flow as a function of the ratio of K_B/K_D . With larger K_B/K_D ratios, a larger proportion of the flow exits via the shaft. At large K_B/K_D values, lateral inflow and the effects of horizontal gradients may be important. The current REPFLO model does not account for these but could be expanded to include these effects.

Figure 2-6 plots the percentage of flow up the shaft carrying nuclides as a function of a factor, α , defined as:

$$\alpha = K_B (H_{\text{total}}) t$$

where H_{total} is the total head drop between aquifers and t is the time since resaturation of the depository. By assuming a value for K_B/K_D , K_B , and H_{total} , the release of nuclides as a function of time since resaturation can be found. The resulting release rates can then be incorporated into the LTRM model. These curves assume no nuclide retardation.

The use of the nonpoint source depository model (REPFLO) will shorten the transit times for the waste close to the depository exit point. Since most of the flow through the shaft originates from waste areas near the depository exit, REPFLO refinement

will significantly affect the computed doses for high K_B/K_D ratios. For low ratios (less than 10^4 or 10^5) or long resaturation times (greater than 300 to 400 years), the refinement will have a limited effect. Regardless of the conditions, REPFLO better accounts for the complex flow paths within the depository backfill. Thus, Figure 2-5 is a better representation of the flow split up through the shaft and rock.

Although the current use of REPFLO was confined to the evaluation of a particular depository geometry and flow path system, the model has potential for better modeling many of the aspects of both site suitability and site design.

2.3 DEPRESSURIZATION OF LOWER AQUIFER

Due to the effects of flaws (such as the depository backfill and surrounding fracture zones, failed boreholes, changes in original fault zone characteristics, development of breccia zones in salt, and other phenomena) the long-term pressure gradient after decommissioning between the upper and lower aquifers may be locally reduced. For more realistic modeling, it is important to consider these effects. Otherwise, the model may overestimate the effects of certain flaws by erroneously maintaining the initial high vertical pressure gradients along these flaws.

The following table presents the theoretical increase in flow or leakage in the depository area between the upper and lower aquifers. The computations are based on the generic shale model (TASC 1977a, GAI 1977a) and assume the pressure in the lower aquifer is maintained. In all cases, the preferred geometry of the depository and formation were assumed.

<u>Case</u>	<u>Assumptions</u>	<u>Increase in Leakage</u>
1. Unflawed	Preferred values (GAI, 1977a)	0%
2. Backfill Deterioration	Preferred: $K_B = 10^{-3}$ cm/sec Upper Limit: $K_B = 10^{-1}$ cm/sec	66% 100%
3. Boreholes Seal Failure		
a. Shallow (40 holes, only to depository level)	Preferred: $K_B = 10^{-4}$ cm/sec Upper Limit: $K_B = 10^{-2}$ cm/sec	less than 5% 90%
b. Deep (10 holes, to lower aquifer)	Preferred: $K_B = 10^{-4}$ cm/sec Upper Limit: $K_B = 10^{-2}$	less than 5% 500%
4. Shaft Fracture Zone	Preferred: $K_B = 10^{-4}$ Upper Limit: $K_B = 10^{-2}$	9% 100%
5. Permeable Faults	Preferred: $K_B = 10^{-5}$ Upper Limit: $K_B = 10^{-4}$	500% 5,000%

From inspection of the above, for this specific simple model any flaw which extends only to the depository depth and not through to the lower aquifer will have a limited impact on the overall leakage. This is obvious since the upper limit effect of such a flaw is to double the gradient through the rock below the depository. Thus, these flaws (backfill deterioration, shaft fracture zone, shallow borehole seal failure) probably will not cause any significant depressurization of the lower aquifer and the effect can probably be ignored in the generic models. Flaws which extend through to the lower aquifer can depressurize the lower aquifer if they have sufficient size and/or permeability. Based on the simple computations presented above, it appears that depressurization may be significant for faulting, breccia zones, and the worst borehole cases.

Future models should incorporate these considerations. The appropriate relationship between shale (or salt) and aquifer properties, initial vertical gradients, flaw characteristics and resulting depressurization is a complex problem which cannot be rigorously solved for the generic model. Section 5.2.6 of our second report (GAI 1977b) discusses a similar problem relating maximum credible vertical gradients with formational hydrologic properties. Simplistic analytical solutions or two-dimensional flow models could be used to consider depressurization in future flow path models.

2.4 RECHARGE TIME COUPLING

The depository water recharge time after decommissioning is highly dependent on the initial properties of the host media and man-induced and/or naturally induced changes. In the initial models, the recharge time was introduced as an independent variable. For more realistic modeling, it is important to incorporate this dependence.

Based on equations developed in our second report (GAI, 1977b Section 3.2.1.6), the following relationship is derived:

$$t = \frac{A}{Q_0} (Len + 2DS_S H)$$

where t = recharge time

Q_0 = time average recharge flow rate

A = depository area

L = height of depository rooms

e = depository extraction ratio

n = porosity of depository backfill material

D = distance from depository to aquifers (half the thickness of layer L-4)

S_S = specific storage of rock mass

H = initial total pressure head at depository level

In addition, the recharge flow rate, Q_o , can be related to the long-term steady state flow rate after decommissioning, Q_s , by the following equation:

$$Q_o = Q_s \left(\frac{H_o}{\Delta H_1} + \frac{H_o}{\Delta H_2} + \frac{\Delta H_1}{\Delta H_2} + 1 \right)$$

where Q_s = long-term steady-state flow rate

H_o = depth of depository below the groundwater table

ΔH_1 = long-term, steady-state average total head difference
between the depository and the upper aquifer

ΔH_2 = long-term steady-state average total head difference
between the depository and the lower aquifer

This equation is valid for cases involving flow up flaws (shafts, faults, etc.) provided Q_s , ΔH_1 , ΔH_2 reflect these flaws.

These relationships should be used in future shale or salt generic repository models provided the same basic geometry and two aquifer systems are maintained.

SCHEMATIC DEPOSITORY MODEL

Figure 2-1

H_A = Average depository head

H_O = Head at depository outlet

H_S = Head at base of shaft

↑ Indicates direction of flow

Connection vectors
for nodes 25, 26,
27 and 28.

NOTE:

Node 29 represents depository outlet.
Node 30 represents bottom of shaft.

Golden Associates

PARAMETERS

$K_B / K_D = 10^5$

$K_B = 0.864 \text{ m/day}$

$K_D = 0.864 \times 10^{-5} \text{ m/day}$

Total Head Drop = 61m; Total Flow into Depository = 5.26 m³/day

EXPLANATION

Node number } Head, m } Net flow, m³/day

NOTE

For definition of Net Flow see text.

EXAMPLE COMPUTER RUN

Figure 2-3

VALUES OF HEAD FOR VARIOUS $\frac{K_B}{K_D}$ RATIOS

Figure 2-4

EXPLANATION

K_B = Permeability of Backfill

K_D = Equivalent permeability of all formation between aquifers.

H = Head at some point ($H=0$ in upper aquifer is taken as datum)

H_T = Total Head drop between aquifers

H_A = Average Head in depository

H_D = Head at depository Outlet

H_S = Head at base of Shaft

TOTAL FLOW EXITING THROUGH THE SHAFT

Figure 2-5

EXPLANATION

K_B = Permeability of Backfill

K_D = Equivalent Permeability of all layers between aquifers.

$Q_{dep.}$ = Flow up shaft

$Q_{tot.}$ = Total flow into depository

WASTE FLOW FROM DEPOSITORY TO SHAFT

Figure 2-6

3.0 PRELIMINARY EVALUATION OF SELECTED PHENOMENA

3.1 GENERAL

Consistent with our previous work (GAI 1977a, 1977b), GAI has continued to perform preliminary scoping evaluations of selected phenomena. The primary purpose of these evaluations is to determine the relative significance of a phenomenon and the need for more detailed evaluations. These evaluations are the Tier 1 models referred to in "SSC Residual Uncertainty Management Framework" (LLL 1978).

The problems evaluated below include gas transport, lateral groundwater flow, multi-aquifer systems, and impermeable faults.

3.2 GAS TRANSPORT

3.2.1 General

This section presents a simplified, upper-bound solution for evaluating potential transport problems induced by gas pressures. The analysis is primarily for fuel rods and assumes that no gas escapes (maximum pressure buildup).

3.2.2 Sources

Gas can originate from several sources within the repository. These include: (1) gas contained originally in waste; (2) gas produced as decay products; (3) gas produced by corrosion of canister; (4) gas produced by radiolysis and hydrolysis. The types, rate of production, and total volumes of gas are dependent

upon the type of waste, type of canister, rate of canister dissolution, resaturation time, type of ionic species in water or brine, and gas solubilities, among other factors.

Through discussions with members of the project we understand the following factors about fuel rods. Fuel rods, when removed from the reactor, will contain Kr, Xe, I, and ^3H . These gases will not occur as a single gas phase but will be trapped within the uranium pellets in fuel rods and within the cladding. Breaching of the canisters may release some gas but pulverization or dissolution of the spent fuel rods is needed for complete release. Reprocessed waste will not contain these gases as they will be reclaimed during reprocessing. Thus, this section is applicable to spent fuel only unless the gas obtained during reprocessing is also placed in the repository. We understand it is possible to at least partially immobilize these gases by various methods. It is assumed in this preliminary analysis of gas transport that all gases are present as a continuous gas phase.

Several gases decay themselves or are decay products. This is true of ^{85}Kr , $^{220,222}\text{Rn}$, $^{129,131}\text{I}$, and ^3H . In general, the quantities of these gases are relatively small when compared to gases already present at burial. One gas, he, does build up in substantial quantities after very long times but is relatively unimportant for the first few thousand years. Tables 10-1 and 10-2 from TASC (1978b) list gases either present originally in the waste (spent fuel rods) or produced by decay.

In addition to the two processes explained above, gas can be produced by corrosion of the waste canister and by radiolysis and hydrolysis. Corrosion can produce H_2 , from reaction of the canister with water. Species including H_2 , HCl , NO_2 , and O_2 are produced through radiolysis (and hydrolysis) of encapsulated fluids (such as brine contained in inclusions in salt) or of free-flowing

solutions (Table 4 - Jenks 1972). The quantity and rate of production has not been estimated for this preliminary gas transport study. Studies by Jenks (1972) of radiolysis and hydrolysis in salt mine brines were made primarily during the mine operating phase. Long-range production rates and volumes are not given. No studies of corrosion and radiolysis and hydrolysis in shale environments have been found. It is necessary to examine corrosion and radiolysis and hydrolysis more carefully before making any final statements regarding the importance of gas transport.

The remainder of this section looks at pressure buildups due to gas produced by the first two processes listed above and examines potential gas release pathways from the repository.

3.2.3 Gas Pressures

3.2.3.1 Dry Repository

The pressure increase due to gas release in a dry repository can be estimated by Boyle's Law which gives partial pressures exerted by the various gas species.

$$PV = nRT$$

where P = partial pressure of gas

V = volume (in this case, assuming a backfill porosity of about 30 percent, the void volume of a dry repository estimated to be $2 \times 10^6 \text{ m}^3$ based upon the design by Parsons, Brinckerhoff, Quade, and Douglas, Inc. (1976)).

n = moles of gas

R = Boltzman constant

T = absolute temperature of gas ($^{\circ}\text{K}$)

It is assumed for this analysis that all gas contained within the fuel rods is released immediately upon repository closure. This assumption is conservative since most gas is not free to

flow out of the canisters until pulverization or dissolution occurs. It is further assumed that no gas escapes from the depository. This is also a conservative assumption but not wholly unrealistic due to the potential high air entrance values of the surrounding rocks (Bradley and Corey 1976).

The estimated pressure increases (over ambient) are plotted as a function of time in Figure 3-1. These pressures relate to fuel rods and include the effects of the heat produced by the waste. Pressures are for 6×10^6 MWe-year of waste and are given for each individual gas and for the total gas produced. Table 3-1 and the temperature profiles in Figures 3-20 and 3-21 of GAI, 1977b, were used together with Boyle's Law to estimate these pressures. It is assumed that at closure of the repository the temperature is 37°C and pressure is atmospheric (1.0×10^5 Pa).

The total gas pressures (canister gas plus atmosphere) as shown on Figure 3-1 are well below hydrostatic pressure at the depths considered for repository location. Virtually all the gas pressure is caused by heating the original air. Thus, there would not be sufficient pressure to force gas into the surrounding formation. The only release pathway would be up a partially saturated or dry shaft containing a continuous air phase to the surface. Steady state gas flow rates were estimated by Darcy's Law using the calculated pressure difference between the depository and the surface and converting permeability of the backfill from that of water to that of gas. Assuming a backfill permeability (to water) of 10^{-3} cm/sec in the tunnels and shaft and using the preferred values for shaft length and area, the maximum calculated gas discharge rates at the surface would be $8.6 \text{ m}^3/\text{year}$ for a salt repository and $11.7 \text{ m}^3/\text{year}$ for a shale repository. Most of this gas would be the original atmosphere in the repository pressurized due to the temperature increase with only a small proportion consisting of waste gases. The radiation impact of this gas leakage was beyond the scope of this study.

The existence of a continuous gas phase in the shaft from the repository to the surface is highly unlikely in repositories with an overlying aquifer zone. It would require deterioration of the backfill to obtain high permeability without saturation of the backfill caused by invasion of water from the aquifer. Thus, the shaft lining would have to remain intact through the aquifer zone. The most likely scenario involving a dry shaft would occur in a repository with no overlying aquifer zones.

3.2.3.2 Repository With Resaturation

The pressure exerted by gas in a repository during resaturation will increase as the volume of water in the repository increases. A plot of pressure versus percent of the repository filled with water (for a repository void volume of $2 \times 10^6 \text{ m}^3$) is shown in Figure 3-2. Hydrostatic pressure at the assumed repository depth (approximately 600 meters) is also indicated. It demonstrates the slow buildup of gas pressure until most of the repository is filled with water. Hydrostatic pressure is not exceeded for this case until over 98 percent of the repository is filled with water.

When the gas reaches hydrostatic pressure, it may begin flowing into the surrounding formation depending upon the air entrance value of the repository host rock. The air entrance value constitutes an additional pressure over hydrostatic which is needed to overcome capillary forces within the host rock. Air entrance values of $1.4 \times 10^5 \text{ Pa}$ or more over hydrostatic pressure may be needed to initiate gas flow out of the repository. If the shaft ends somewhat below the mine level, little or no gas will reach the shaft to flow towards the surface. It will instead be trapped in the mine level. (See Section 3.2.1.6 of GAI 1977b for example of air entrapment in a flooding mine.)

The depth of the repository, since it affects the hydrostatic pressure, is an important parameter to consider for gas release. The repository depth is plotted versus the ratio of the gas pressure, P_g , to the hydrostatic pressure, P_s , in Figure 3-3 for various gas volumes. When P_g/P_s equals 1.0, the gas will begin flowing after the additional air entrance pressure is met. It is apparent from Figure 3-3 that gas release is less likely in deeper repositories than in shallow ones.

For the above upper-bound analysis of gas release in a repository filling with water conservatively assumes none of the gas is dissolved in water. This will not be true unless the water filling the repository is saturated with gas. A preliminary analysis shows that most or all of the gas within the repository will dissolve in water at pressures less than 1.4×10^6 Pa. Thus, at moderate repository depths no gas phase will exist after repository resaturation is complete. Gases dissolved in water will not be released until the water flows near enough to the surface to allow the gas to come out of solution.

3.2.4 Conclusions

The preliminary analysis of gas transport considers gases originally contained within fuel rod canisters and gas produced by radioactive decay. It does not consider gases produced by corrosion or radiolysis and hydrolysis, nor does it consider thermal convection effects. More information and study is needed before the latter effects can be considered.

It is difficult to foresee circumstances in which gas release from the two sources considered will be a significant problem. In a "dry" repository the flow of gas is small due to the relatively low pressure gradient towards the surface. In a repository being resaturated with water, the gas pressures must overcome hydrostatic pressure plus the air entrance value of the host rock before flow out of the repository will occur. In relatively deep reposit-

ories located well below an aquifer, the possibility of gas overcoming hydrostatic pressure before it is completely dissolved in water appears negligible. Most or all of the gas will be dissolved in water at pressures of approximately 1.4×10^6 Pa (some 140 meters below the groundwater table).

Thus, provided gas produced by radiolysis and hydrolysis is not significant, gas production does not appear to be a problem.

3.3 LATERAL FLOW AND LATERAL DISPERSION

The initial Cycle I and Cycle II sedimentary basin models (TASC 1978a) analyzed simplistic flow path configurations which included, in our opinion, the following assumptions:

1. Strictly vertical flow in the layer around the depository and barrier bedrock layers (Layers L-3, L-4 and L-5).
2. Strictly horizontal flow in the aquifer layers (Layers L-2 and L-6).
3. No lateral dispersion effects, i.e., only one-dimensional dispersion in the direction of flow.
4. Discharge of nuclides into the biosphere occurred along a single infinitely long body of water, i.e., all nuclides essentially exited at the same point.

In our opinion, these are reasonable assumptions for the preliminary generic model analysis, which emphasized parametric sensitivity studies. If applied to specific sites, these simplifying assumptions, coupled with the existing models, might result in errors in the magnitudes of the computed dose (or concentrations). However, in a generic model, these model-induced uncertainties are acceptable provided they: are small compared to the parameter-induced uncertainties; do not alter the general implications of a sensitivity or uncertainty analysis; and/or, do not result in a misrepresentation of a potential release mechanism.

There are several site conditions which may require lateral flow and lateral dispersion to be more rigorously evaluated. These include:

1. Multi-shaft locations spaced over the depository:
The horizontal gradients within the upper aquifer might result in flow into the up-gradient shafts, through the depository, and exiting out the down-gradient shaft.
2. Horizontal flow dominating within the depository and barrier layers: Figure 3-4 indicates the general relationship between flow path direction and vertical to horizontal gradient and permeability ratios. For high horizontal to vertical permeability ratios and/or low vertical to horizontal gradient ratios, the groundwater flow direction may be essentially horizontal. This would result in a significant increase in the flow path distance and possibly a change in the final nuclide discharge location. Lateral dispersion may become a significant factor with the shortest release pathway being through vertical dispersion along horizontal flow lines.
3. Multi-discharge point: Many site conditions would result in nuclides reaching the biosphere at several locations. These might include releases through various flaws and/or into several different bodies of water. In order to credibly evaluate this type of problem, lateral dispersion must be incorporated into the analysis.
4. Multi-aquifer systems: see Section 3.4 below.
5. Nuclide release through wells: this problem is discussed in TASC (1978b) and GAI (1977b).

In general, the problems of lateral flow can be examined for specific problems with simple two-dimensional numerical flow models and/or with closed-form solutions. These results could then be incorporated into the general flow path analog as deemed appropriate. The general problem of lateral dispersion may be far more complex. Although there are certain closed-form solutions to dispersion problems, the solutions generally require too many assumptions to have much meaning in a multi-layer system. Thus, numerical mass transport models would probably be required to reliably assess the modeling errors associated with ignoring lateral dispersion and to develop a technique for reducing the errors in the LTRM model. Generally, ignoring lateral dispersion is conservative and will lead to an overestimation of the radiation effect.

3.4 MULTI-AQUIFER SYSTEMS

The current LTRM model only considers a single aquifer overlying the depository. This aquifer discharges the nuclides directly into surface waters. In general, as discussed in Section 2.4 of our initial report (GAI 1977a), a depository located in a sedimentary basin will probably be overlain by several aquifer zones. These aquifers are often at different piezometric levels, have different discharge points, contain water at different salinities, and may even be flowing in different directions. This may be particularly important since the aquifer immediately overlying the depository may be saline. The first potable aquifer would be separated from this saline aquifer by one or more aquitard barriers. Thus, the nuclide release behavior may be very complex with several discharge points and release times resulting from the nuclides dispersing upward toward the biosphere through a complex hydrologic system. Ignoring the effects of the multi-aquifer conditions results in overestimating the dose (or nuclide concentration).

In our opinion, in a generic model study it may be very difficult in the time available to attempt to model all the detailed complexities of possible sites. However, certain generalized examples of multi-aquifer systems should be evaluated. Of particular interest is a model which includes a shallow, freshwater aquifer and a deeper saline aquifer overlying the depository. This appears to be a relatively common occurrence and might have significant implications concerning wells and loss of administrative control.

3.5 IMPERMEABLE FAULTS

The current LTRM model evaluates faults that have a higher permeability than the surrounding rock. Thus, any new fault or reoccurring movement along an old fault would produce a permeable pathway to the overlying aquifer. In addition, the model assumes that flow along the fault will disperse into the upper aquifer. This type of fault flow behavior was chosen for the initial model for simplicity and because it represented a relatively adverse case. However, as discussed in our previous reports (GAI 1977a, 1977b) and below, there are several other scenarios which may be more likely. These might include impermeable faults and impermeable faults with associated permeable fractured zones.

A new impermeable fault or movement along an old fault which decreases its permeability can produce a barrier to groundwater flow. Under certain conditions, this may effectively dam the normal groundwater flow and actually result in the groundwater surfacing on the up-gradient side of the fault. Examples of this include Whitewater Canyon and Seven Palms Valley in southern California, which may

be near-surface phenomena. This could be evaluated in the LTRM model by describing three conditions:

1. Initial flow path model with no fault.
2. Transition flow path model after faulting which accounts for the time required to reach a steady state condition with the fault barrier.
3. Final flow path model.

In general, the model would probably indicate that impermeable faults had an impact considerably less than the previously assumed permeable fault. However, under certain conditions with rapid waste transport times after faulting and/or for depositories with flaws (such as backfill deterioration, fracture rock flow, etc.), the impermeable fault scenario may be more critical since it might eliminate the long flow time in the upper aquifer.

Impermeable faults with associated permeable fracture zones represent flow barriers perpendicular to the fault surface and flow paths parallel with the surface. Multi-fault systems with fracture zones can effectively trap water between the faults, evidenced by experience dewatering pressurized water-bearing zones between faults in mine excavations. This general faulting scenario could be evaluated by the LTRM model by combining procedures similar to that for the initial permeable fault and that proposed above for the impermeable fault. These cases might include:

1. Fault not acting as an effective dam to ground-water flow: this model would be very similar to the initial permeable fault model. However, since the fault zones tend to trap the water within the associated fractured zones, nuclides

being transmitted along the fractured zones might not disperse into the upper aquifer. Depending on the pressure within the zone, the nuclides might actually travel to the surface. Clearly this would be a more serious scenario than the permeable fault scenario.

2. Fault acts as an effective dam to groundwater flow: This is effectively identical to the condition discussed above for impermeable faults but with an additional pathway of flow along the fault fracture zone. This scenario could also be more serious than the permeable fault scenario.

NOTES

1. Individual gas pressures are in terms of ;
2. Total depository pressure includes deposes
3. Rn and ³H are insignificant.
4. Total waste is assumed to equal 6×10^6 .
5. Total pressure in a shale depository will greater at the period of maximum temper

PRESSURES EXERTED BY DEPOSITORY ATMOSPHERE AND CANISTER GASES IN A SALT DEPOSITORY

Figure 3-1

of partial pressures.
pository atmosphere (air) plus canister gases.

6 MWe-year.

will be approximately 2 psi (1.4×10^4 Pa)

perature.

6. Gases produced by corrosion or radiolysis and hydrolysis not included.

7. Assumes about a 30% backfill porosity.

8. See text for explanation of curves.

9. Solubility effects ignored.

VARIATION OF GAS PRESSURE WITH PERCENT OF DEPOSITORY FILLED WITH WATER

Figure 3-2

NOTES

1. Hydrostatic pressure for a depository located 600 meters below the water table or piezometric surface
2. Curve developed for gas pressures produced during the initial 1000 years.
3. Solubility effect ignored.
4. See text for explanation and assumptions.

THE EFFECT OF DEPTH BELOW WATER TABLE ON THE P_g/P_s RATIO

Figure 3-3

REFRACTION OF FLOW PATHS IN A 3-LAYERED MODEL Figure 3-4

IN WHICH

K_{H1}, K_{V1} = Horizontal and vertical permeability in layer 1.

I_{H1}, I_{V1} = Horizontal and vertical gradient in layer 1.

L_D = Length of depository.

L_1 = Thickness of layer 1.

L_{F1} = Length of flow path in layer 1.

A_1 = Area of flow path in layer 1.

EQUATIONS

$$\theta_1 = \tan^{-1} \left(\frac{K_{H1} I_{H1}}{K_{V1} I_{V1}} \right)$$

$$K_1 = \left(\frac{(K_{H1} I_{H1})^2 + (K_{V1} I_{V1})^2}{I_{H1}^2 + I_{V1}^2} \right)^{\frac{1}{2}}$$

$$A_1 = L_D^2 \cos \theta_1$$

$$L_{F1} = \frac{L_1}{\sin \theta_1}$$

4.0 PRELIMINARY FLOW PATH MODELS FOR BASALTS, SALT DOMES AND CRYSTALLINE ROCKS

4.1 GENERAL

In our November report (GAI 1977b), we presented a preliminary data base for basalt, salt domes, and crystalline formations. This work included simple geologic/hydrologic generic models which were summarized in Section 3.4 of that report. These models were intended to be simple enough to be synthesized into a generic nuclide transport model (such as the LTRM model) while enabling realistic geologic and hydrologic conditions to be evaluated.

In this section we develop the preliminary flow path models for the generic geologic/hydrologic models. These flow path models are consistent with the capabilities of the current LTRM models. The purpose of these flow path models is to develop new base line cases by expanding LTRM model evaluations into new media.

Since the basic generic geologic/hydrologic models were discussed in our November report (GAI 1977b), they will not be presented here. In order to develop the flow path models, it was necessary to analyze a smaller scale geologic/hydrologic model than presented in the November report. These new models are shown on Figures 4-1 to 4-4.

Generally only the unflawed flow path model was developed with appropriate comments on the more significant flaws which need to be evaluated.

4.2 BASALTS

4.2.1 General

In GAI's November 1977 report, the geology and hydrology of thick basalt sequences are described in some detail. Briefly, however, these thick basalt sequences consist of complex inter-layering of dense but strongly jointed basalt and clays, sands, and gravels. Therefore the basalts may be expressed to have fracture permeability and the sands and clays interstitial permeability.

Some layers of basalt are significantly less fractured and the depository would presumably be placed in one of these. As well, some of the interlayered clay beds can be of low permeability and these can result in a complex flow regime. Figure 4.1 shows the geologic/hydrologic generic basalt model used to develop the flow path model based on equivalent thicknesses.

4.2.2 Unflawed Flow Path Model

It is not practical at this time to model each of the numerous, rather thin basalt flows and interbeds found within a thick basalt sequence. Instead, equivalent thicknesses of rock layers are used. These equivalent thicknesses are based upon the estimated percentages of four types of hydrologic units existing in basalt sequences. They are:

1. Dense, relatively unfractured basalt.
2. Fractured and weathered basalt.
3. Coarse-grained interbeds and volcanic rubble.
4. Fine-grained interbeds.

Two additional layers are considered, including:

1. Very dense basalt (repository layer).
2. Surficial sediments (these can be separated into a series of aquifers and confining layers).

The rationale for using equivalent thicknesses is shown in Figure 4-5. Although the flow path the water takes within the four equivalent layers is different from that it would take in a basalt sequence with numerous basalt and interbed layers, the total distance traveled and total travel time remains the same in both cases as long as the horizontal gradients are constant. The condition of constant gradient is probably rarely met in natural hydrologic systems in basalts, but it is probably a reasonable approximation for the purposes of this study.

The hydrologic parameters such as horizontal and vertical permeability, porosity, thicknesses, and gradients of each of the five layers mentioned above are considered in the following section. The actual lengths, areas and directions of flow paths must be determined using the hydrologic parameters and the lateral flow analysis presented in Section 3.3. A diagram of the unflawed Generic Basalt Model is shown in Figure 4-6, along with a possible flow path model of the flow through the formation and up the shaft.

Flow path analogs for various flaws (faults, wells, mines, etc.) will require some modification of the basic generic model since these flaws can "short-circuit" the flow and make the use of effective thicknesses for the entire basalt sequence inappropriate. Flow analogs for the various flaws (other than those involving the fracture zone around the shaft and tunnels and deteriorated backfill) will probably have to be developed and analyzed on a case-by-case basis.

Table 4-1 presents preliminary descriptors for the flow path model shown on Figure 4-6. This data was based on the data base information presented in our November report (GAI 1977b) and a review of several deep boreholes (Atlantic Richfield Hanford Co. 1976). The preferred values related to a depository depth of 850 meters.

4.2.3 Flawed Flow Path Model

The model outlined above represents an unflawed situation. It is appropriate to investigate a variety of other conditions that are likely or possible and which represent potential pathways for the release of depository contents. The following is a partial listing of conditions which require consideration in the flood basalt model:

1. Depository Induced or Related Conditions

- a. Fracture zones around openings: The high strength of basalt will probably necessitate excavation by drilling and blasting, which may result in an extensive fracture zone. This could be modeled in a procedure similar to that used in the sedimentary model. The effect of fractures around the shaft would be to transmit waste to overlying layers, reducing the transit time and possibly changing the waste discharge location. It would also reduce the resaturation time. It may be possible, by placing the repository in a zone dominated by downward flow (such as in the regional recharge area), to minimize the effects of fracture zones around the shaft.

- b. Shaft backfill and shaft sealing: The shaft is a potential problem, both in reducing the resaturation time and in becoming a pathway for nuclide release. The problem would be modeled in a similar procedure to that used in the sedimentary model. Due to the numerous permeable layers and fractured character of the basalt, shaft sealing may present significant construction problems. The effect of poor shaft backfill performance may be minimized as discussed above by placing the depository in an area of downward flow. Multishafts spread out over the depository area should also be examined. With sufficient horizontal gradients and very permeable backfill, water may tend to flow down one shaft, through the depository, and exit out another shaft.
- c. Fracturing of depository layer: Thermally induced stresses and/or stresses induced by the depository opening may result in increased fracturing of the depository basalt layer. This would increase the permeability of the layer, causing a decrease in resaturation time. It most likely also decrease the nuclide transit time in the layer.
- d. Thermally induced groundwater flow: The thermal gradients around the depository, under certain conditions, will develop small convection cells. The magnitude and extent of these gradients will be relatively small and may be insufficient to affect flow on a large scale. To date the predicted thermal gradients (GAI 1977b; Sandia 1977b; Parsons, Brinckerhoff, Quade and Douglas, Inc. 1976b) have

been based only on heat conduction in the geologic formations. The inflow of groundwater during resaturation and the potential movement of heated water away from the depository may significantly reduce these gradients. It is also important to consider the relatively short duration of the peak thermal gradients (probably on the order of 100 to 200 years). The potential for thermally induced convection flow involving multishifts and failed boreholes needs to be examined. Long recharge times and/or long canister dissolution times will minimize the consequences of thermally induced flow. Should analysis indicate that thermally induced flow is important, it could be modeled by temporarily increasing the vertical gradients leading away from the depository. The probably result would be to reduce the transit time to the overlying layers. If there is a long unbreached aquifer before the nuclides can discharge to the biosphere, the effects of thermal gradients on the predicted dose would be small.

2. Existing Geologic Conditions

- a. Faults: The effects of existing faults need to be examined. Due to the brittle nature of basalt, the faults will probably be permeable although faults through the interbeds may not be. The modeling of the fault would be similar to that in the sedimentary model. However, since the ranges in vertical gradients are quite small for the data examined to date, the effect of the fault may be minor.

- b. Geothermal effects: Some naturally heated water may be withdrawn from wells proximal to fault lines such as occurs in the Columbia River basalts. The influence of these geothermal zones on the general groundwater flow patterns and on the performance of a depository need to be examined. Due to these effects and the potential resource value, sites in close proximity to geothermal zones may be unsuitable for a depository.
- c. Fracturing: Basalt flows are generally highly fractured and quite permeable, although there are relatively unfractured layers which are much less permeable. Potential undetected fractured zones within the depository layer may lead to a decrease in resaturation time and early breach of the layer. This could be modeled with additional "flow paths" placed at varying locations within the depository layer.
- d. Dikes: Dikes (lava-filled cracks) may be more or less permeable than the enclosing strata. Their occurrence can be modeled like faults.

3. Future Geologic Changes

- a. Faulting and tectonically induced changes in fracturing: The suitability of the layered basalts may depend upon maintaining the integrity of the low permeability strata among which is the depository layer itself. Relatively thin beds of brittle rock will fracture rather than bend when subjected to differential loading or tectonic forces. These effects could be modeled with

additional "flow paths" (as in the sedimentary model) and/or by increasing the permeability of the layers.

- b. Volcanism: While, for the data examined to date, the vicinity of several feeder systems are known, undetected feeders may exist. There is a possibility that a new fissure could invade the depository and bring selected contents to the surface. This would probably be modeled independently of the LTRM model since the effect of intrusion does not lend itself to a flow path evaluation.
- c. Glaciation: The Columbia River basalts, for example, are adjacent to regions covered by glaciers during the Pleistocene. Glaciation significantly alters the hydrology of the entire area.

4. Man-Induced Pathways

- a. Wells: The aquifers within a basalt sequences examined to date tend to contain fresh water, and, as the basalts studied to date are in a desert environment, sources of fresh water are likely to be tapped eventually. A water well may intercept the hydrologic regime of the repository. Thus, the potential release of waste through wells is a critical factor in the suitability of basalts.
- b. Undetected boreholes and failed borehole seals: In basalt sequences there are similar problems to sedimentary models. In general due to small vertical gradients, the effects may be minor. In our opinion

the probability of undetected deep boreholes is also less likely than in sedimentary basins.

- c. Economic minerals: Placer deposits of economic grade may occur in ancient stream channels between basalt flows. At present we have no exploration technology for locating them. Additionally, potential ore zones may exist in the rocks underlying the basalt which we are presently incapable of finding save by a random drilling program. Thus, problems associated with current and future mines and wells (except for water) are considered, in our opinion, to be less than for sedimentary basins.

4.3 SALT DOMES

4.3.1 General

There are more than 300 salt domes distributed throughout the Gulf Coast area as shown on Figure 3 of our June report (GAI 1977a). Salt domes have many of the advantages of bedded salt; i.e., the salt is plastic, has a very low (if any) permeability, and excellent thermal properties. In addition, domes tend to be composed of purer salt than bedded salt, be more uniform, and not as far as we are aware underlain by potential artesian aquifers.

In our previous reports (GAI 1977a; GAI 1977b) we discuss the geology and hydrology of salt domes. In general, salt domes are vertically oriented cylindrical plugs of salt that have pushed up from great depth through interbedded sands and shales.

Thickening of sediments near the Gulf Coast indicates that down-warping is occurring. The East Texas area, however, is more stable being a zone of erosion. Domes apparently consist of several spines of salt that may have moved independently of each other. These movements have characteristic effects on the surrounding sediments, forming traps for oil and gas, and influencing the surrounding groundwater regime. Figure 4-2 shows the geologic/hydrologic generic salt dome model.

4.3.2 Unflawed Flow Path Model

Our current data indicates that there would be essentially no flow paths out of an unflawed repository in a salt dome. This is due to the extremely low permeability of the salt (available data indicates it may be effectively zero), and the lack of any significant driving hydraulic gradients within the dome. Thus, no unflawed flow model has been developed. The primary concerns at a salt dome repository relate to the potential flow pathways such as those through multi-shafts, those caused by thermal gradients, and those caused by salt dome solutioning, etc. These problems are discussed below in Section 4.3.3.

Table 4-2 presents preliminary descriptors for the generic salt dome model shown on Figure 4-2. This information would be used to evaluate the flow pathways.

4.3.3 Flawed Flow Path Model

The model outlined above represents an unflawed situation. It is appropriate to investigate a variety of other conditions that are likely or possible and which represent potential pathways for the release of depository contents. The following is a

partial listing of conditions which require consideration in the salt dome model.

1. Depository-Induced or Related Conditions

- a. Fracture zone around openings: As with bedded salt (GAI 1977a), fracturing around the salt is expected to be relatively minor and will probably heal with time.
- b. Shaft backfill and shaft sealing: Similar to the bedded salt model.
- c. Density effects of canisters: As with bedded salt, the canisters may migrate through the salt and ultimately reach a structure that increases the rate of waste release. Preliminary studies (Sandia 1977c) indicate that the magnitude of movement will be small (less than a few inches in 1,000 years). Thus, it is doubtful that this effect will be a problem.
- d. Depository heat-induced diapirism: The heat generated by the waste might affect the balance of forces and initiate movement of the salt dome. Considering the size of the salt domes and the great depth of the source of the salt, it seems doubtful, in our opinion, that the relatively small heat source of the depository applied near the top of the dome would induce diapirism. However, due to the present lack of understanding about salt dome diapirism, it may be difficult to prove that the depository heat is not a problem. This effect would probably be best evaluated independently from the flow path model.
- e. Fluid inclusion migration: Inclusions of brine and possibly gas will migrate toward the heated depository

and potentially become a source of water and pressure. Based on the limited available volumes of water and the probable slow rate of migration, it is doubtful that brine migration would be a significant factor over the long term. Future analyses are required to evaluate this problem. Inclusions of brine reaching the depository could be modeled by periodically introducing a finite volume of water into the flow path model and determining the dose release out of the shaft backfill. Large brine cavities in dome salt tend to occur in the boundary shear zones and are less frequent than inclusions in bedded salt. Effects of brine migration on viscosity and solubility should be examined.

- f. Thermally-induced groundwater flow: This is similar to the problem discussed in Section 4.2.3, item 1d. Since there is probably no effective source of water within the salt dome, a convection cell would have to develop with inflow down one pathway (such as a shaft) and up another pathway. Such a convection cell also may have a serious impact since the incoming fresh water would dissolve the salt. However, since incoming fresh water would quickly become saturated brine, the small thermally-induced gradients may be insufficient to overcome the density gradients. The process, however, leads to solutioning.
- g. Solutioning: Fresh water flowing from aquifers may cause significant solutioning of the salt, particularly around shafts and boreholes. This could lead ultimately to the aquifer coming in direct contact with the waste. Also during resaturation of the depository, the pillars may dissolve, leading to collapse of the roofs and

possibly large scale deformations above the depository. Data have been developed by Sandia (1977b) and others to examine the rate of solutioning. Data from solutioning around oil and gas wells may also be useful in evaluating the problem. The problem could be analyzed in the flow path model with a major "flow path" connecting the depository with the overlying aquifers. The "flow path" would remain closed until sufficient time has passed to affect the solutioning of the salt.

2. Existing Geologic Conditions

- a. Boundary shear zones: These more permeable zones within the dome may be difficult to detect until they are encountered. Such a zone may exist in close proximity to the repository facilities, and could be evaluated with a "flow path" at some distance from the edge of the depository. Water could then flow down (or up) a shaft, through the depository, through a small thickness of salt, and hence up (or down) the boundary shear zone.
- b. Limits of the dome: Salt domes are complex structures. Perhaps the best way of visualizing the characteristics of the structure is Kupfer's analogy of drawing a table napkin up through a ring. The external surface is deeply convoluted. For the salt dome, these convolutions are filled with shear clays, salt, and other sedimentary debris. The repository proximity to these features, or to the boundary shear zones separating different spines of salt within the dome may be difficult to locate, with existing technology, in advance of actually encountering them in the workings. This problem may be modeled with "flow path" similar to that described above for boundary shear zones. The consequence of being too close to the edge of the

dome could be serious as it might lead to an immediate discharge of nuclides to the adjacent aquifers. The heat and potential deformation around the depository could disturb the salt between the depository and the edge of the dome and lead to further deterioration of the seal. Ideally, the site investigation both prior to and during depository construction will minimize this problem.

- c. Gas, oil and brine-filled voids: These will occasionally be encountered during the mining and are usually associated with boundary shear zones.

3. Future Geologic Conditions

- a. Solutioning: Some salt domes are imperfectly isolated from circulating groundwater. Such domes gradually dissolve, and a "salt plume" is detectable in the groundwater downstream. However, it may be difficult to prove that a specific salt dome is not dissolving now nor will be in the future. Clearly estimates of the potential range in rates of solutioning is critical and will put the problem in perspective. The problem could be modeled similar to that described above for boundary shear zones and limits of the dome. Recent studies (Smith 1976) of solutioning of salt domes in northeast Texas indicate that less than 30 meters of salt would be removed from the top of the dome in 250,000 years. Thus, natural solutioning may not be a serious problem.
- b. Movement: Salt domes represent structures formed by the movement of salt. Some domes are possibly

still moving. New spines may be developing adjacent to existing domes. Data on the rate of movement and the potential for movement reoccurring after the dome has stabilized are very limited. Currently investigations of this problem at a specific salt dome in Louisiana (Thoms, et al. 1977) concluded "...tectonic movement of the dome may be so small that crustal movements due to other natural effects may tend to dominate." Based on very limited information, it appears that the rate of movement might be too slow to affect the depository during at least its most critical period, some 400 years.

c. Changes in sea level at near coastal sites.

4. Man-induced Pathways:

- a. Oil and gas wells: Salt domes form traps for oil and gas in the sediments surrounding the dome. These traps are the target of our energy companies and the search for them will continue.
- b. Mining: Salt is a mineable commodity. Possibly a future salt mine will encroach upon the repository.
- c. Undetected boreholes: For better than a century salt domes have been the focus of a degree of economic activity for salt, sulfur, oil and gas. Many holes have been drilled in search of such resources and only some percentage of these have been recorded and/or plugged. Surface evidence of the holes may have been long since concealed and there is, therefore, a certain probability of the repository encountering or just missing an undetected borehole. The consequences of this require consideration. In the case where the borehole was encased in the salt for some depths and material properties the hole may be partial or totally closed by creep. Conversely the hole may be enlarged due to solutioning.

4.4 CRYSTALLINE ROCK

4.4.1 General

In our November report (GAI 1977b, Section 3.4), two generic models were proposed as representing crystalline rock in a batholithic and a piedmont context. Shield areas are incorporated in the piedmont model. Future study may indicate that a separate model would be required where the sediments included in the piedmont become either discontinuous or do not exist. While there are important geologic differences between the two, in terms of a flow path model the batholithic environment is a simple revision of the piedmont model. The only important differences are:

1. Hydraulic gradients are generally higher due to surface topography in the batholith model.
2. Saprolite and lithified sediments overlie the crystalline rock in the piedmont model. In some cases sediments may overlie the batholith depending on the age and subsequent history. This case was not considered in the models.

Under "crystalline rock" we are considering intrusive igneous rocks and high-grade metamorphic rocks such as gneiss. Extrusive igneous rocks are treated in the basalt model and lower grade metamorphic products have not been considered. Chemically precipitated sediments, such as limestone, are also not considered although they can be classified as crystalline rocks.

Crystalline rock may be considered for a repository for several reasons, including its high strength (minimizing construction and operational problems while enabling deep burial), low permeability, lack of underlying aquifers, and postulated lack of circulating groundwater at depth.

Fluid migration in crystalline rocks is almost entirely along joints and faults and decreases with depth.

For the batholith, topography is rugged and surface runoff carries away the soil as it develops, depositing it in stream beds and the valleys below.

In the piedmont, which lacks the topographic relief required to strip the soils, a permeable weathered horizon develops. As weathering continues, the end product may be a clay-rich low permeability semicontinuous horizon termed "saprolite."

The batholithic areas are relatively young while the piedmont rocks are ancient. A full sequence of sedimentary rocks (sandstones, shales and limestone) can overlie the crystalline basement and these sediments may also exhibit a characteristic weathering profile. Additionally, recent nonlithified sediments may overlie the entire sequence.

Figure 4-3 (Batholith) and Figure 4-4 (Piedmont) show the geologic/hydrologic generic models used to develop the flow path model.

4.4.2 Flow Path Model

4.4.2.1 Batholith Model

Existing groundwater data in batholithic areas is insufficient for regional flow analysis. Because batholiths may be in regions with abundant surface water resources and sparse population density, and exhibit poor water-bearing characteristics, they

are not generally explored or analyzed for their groundwater. Limited data from wells generally pertains only to the top several hundred feet of weathered rock, at most. Data from mines or tunnels is useful but not generally applicable because these structures are usually located in the more tectonically disturbed areas (faulted, folded, fractured, etc.) or in topographically high areas (mountain passes). Data probably exists from underground storage caverns for oil, gas, etc., which may be pertinent.

It is assumed for this preliminary analysis that flow patterns will be similar to the theoretical flow patterns described in our November report (GAI 1977b). Figure 3-11 in that report illustrates the theoretical flow patterns. These patterns will be substantially modified by the topography, fracture systems, faults and variations in permeability expected to occur in batholithic rock. They do, however, form a basis for a preliminary flow path model in batholiths.

The preliminary Generic Batholith Model as shown on Figure 4-3, is composed of two zones in the crystalline rock.

Zone 1: This zone extends from the ground surface down to 50 to 300 feet. It is more intensely fractured and weathered than the underlying zone. Any wells for water supply purposes would tap the unconfined aquifer assumed to exist within Zone 1.

Zone 2: This zone extends downward below the weathered zone to great depths. All permeability is derived from fractures. Zones of higher permeability due to extensive fracture zones or faults are treated as flaws.

The inferred decreases in the permeability of Zone 2 with increasing depth, presumably due to greater overburden pressures, is not considered in this preliminary model but may be considered in a later model.

A schematic of the Generic Batholith Model and a possible pipe analog is shown in Figure 4-7. The general flow pattern is from a recharge source through Zone 2 into Zone 1 and eventually to a lake or stream. This flow pattern is probably a gross simplification of the actual flow pattern but allows a preliminary analysis to be made of a repository located in a batholith.

To simplify the pipe analysis, it is assumed that the repository is located at a point halfway between the recharge and discharge areas and that one-half of the total head drop between recharge and discharge has occurred when water enters the repository. The preliminary model cannot currently consider repository flaws which would tend to reduce the head within the repository (such as mine fracture zones or the backfill case) since such flaws would probably substantially change the entire flow system in the area of the repository.

The hydrologic parameters pertaining to the Generic Batholith Model are given in Table 4-3. The length of the flow path is assumed to be equal to that of a straight line drawn from the repository to the discharge point. Although the actual flow path is probably somewhat longer due to curvature, approximating it by the shortest distance probably introduces only a small error in path length.

In our opinion, consideration of various flaws in and near the repository will probably involve more sophisticated flow modeling. The unflawed case might also be modeled more accurately to check the applicability of the preliminary flow path network presented in this report. A major concern in deciding to refine model batholithic flow systems will be the amount of actual field data on which to base the model parameters.

4.4.2.2 Crystalline Piedmont Model

Generally the theoretical flow patterns described in the previous section should also be applicable to flow within crystalline piedmont environments. Gradients will be lower due to less topographic relief and the entire flow system will be influenced by the overlying sedimentary rocks. The location of the repository within the regional flow system is a major factor in determining flow paths and gradients.

The rock layers considered by the generic model, shown on Figure 4-4, and described in our previous report (GAI 1977b) are as follows:

Surface Sediments: Consist of unconsolidated sedimentary deposits. They generally contain groundwater under unconfined conditions.

Aquitard: Siltstone and shale which forms a confining layer between surface sediments and the underlying aquifer.

Aquifer: A sandstone layer which overlies saprolite layer or, where the saprolite is absent, directly overlies the crystalline rock.

Saprolite: Where present it serves as an aquitard between the sandstone aquifer and the crystalline rock. For definition see our previous report (GAI 1977b).

Crystalline Rock: Depository layer. The degree of fracturing may vary within the crystalline rock. Intensely fractured zones can be treated as flaws.

The crystalline rock within the Piedmont Model is not divided into two zones as in the Batholith Model. It is assumed that any intensely fractured zone near the top of the crystalline rock is filled in with weathering derived clays and is of low permeability.

The preliminary Crystalline Piedmont Generic Model is shown in Figure 48 along with a possible flow path analog for the unflawed case. The flow path within the crystalline rock is similar to that given for a batholith except flow gradients are much smaller. The flow paths within the sedimentary sequence are not shown but will be similar to the paths in the generic salt and shale models.

No flaws are included in the flow network shown in Figure 48. The effect of flaws upon the flow patterns is not easily determined. More sophisticated flow modeling will probably be required to establish the flow path network necessary to consider flaws.

Table 4-4 presents preliminary descriptors for the flow path model.

4.4.3 Flawed Flow Path Model

The model outlined above represents an unflawed situation. It is appropriate to investigate a variety of other conditions that are likely or possible and which represent potential pathways for the release of depository contents. The following is a partial listing of conditions which require consideration in the crystalline rock models.

1. Depository-Induced or Related Conditions:

- a. Fracture zones around openings: Similar to the problem in basalts, see Section 4.2.3, 1a.
- b. Shaft backfill and shaft sealing: Similar to the problem in basalt, see Section 4.2.3, 1b.
- c. Fracturing of depository zone: Similar to the problem in basalt, see Section 4.2.3, 1c.
However, the problem may not be as important as in layered model. This is due to the potential geometric thickness and the probable uniformity (low permeability) of the rock mass surrounding the depository, local induced fracturing may not significantly alter the resaturation or transit times.
- d. Thermally induced groundwater flow: Similar to the problem in basalt, see Section 4.2.3, 1d.

2. Existing Geologic Conditions:

- a. Faults: Similar to the problem in basalts, see Section 4.2.3, 2a. However, faults may be more significant in crystalline formations since they lack the numerous permeable zones which may effectively intercept the flow in basalts.
- b. Geothermal effects: Similar to the problem in basalts, see Section 4.2.3, 2b.
- c. Fracturing (Joints): Batholiths often contain characteristic cooling joints which have great persistence and are well interconnected. Such joints tend to be widely spaced. The fracture permeability of such networks is obviously critical and will require further investigation. The problem could be modeled similar to the procedure discussed for basalts, see Section 4.2.3, 2c.

3. Future Geologic Changes:

- a. Faulting and tectonically induced changes in fracturing: Similar to the problem in basalts, see Section 4.2.3, 3a.
New Intrusive Activity: A remote possibility, but one that would have serious implications for the depository. This problem would probably be considered independently of the flow path model.
- c. Glaciation: Many potential crystalline repository sites were glaciated during the Pleistocene.

4. Man-Induced Pathways

- a. Wells: Wells exist in the upper fractured zone in many crystalline areas. However, the wells are of small yield and shallow. The occurrence of deep wells penetrating to the level of a depository is considered very unlikely.
- b. Undetected boreholes and failed borehole seals: Similar to the problem in sedimentary models. Like basalts, the probability of undetected deep boreholes is less than in sedimentary basins and the consequence is less due to the limited vertical gradients.
- c. Economic minerals: Batholithic intrusions are a principal source of economic mineralization, although most of the ore deposits are formed in specific regions in and around the intrusive. Therefore, it is necessary to consider the effects of exploration holes and mined excavations. If the repository is initially sited to avoid these regions, the prospect of commercial exploitation in the vicinity of the site is remote. Careful evaluation of the mineral potential of the chosen site and its environs is required. Additionally, some thought should be given to the distance away from potentially mineralized areas that the repository should be located.

4.5 PRELIMINARY CONCLUSIONS

This section developed preliminary flow path models for unflawed depositories in basalt, salt domes and crystalline rocks. Based on this information, the following general comments relating to the future modeling effort are presented:

1. Basalts: The basalt flow path models have many similarities to the layered sedimentary sequence. The major differences include a smaller range in vertical gradients and the importance of lateral flow. In addition, the general groundwater flow regime in deep basalts is not as well understood as in sedimentary basins.
2. Salt Domes: It appears that the salt in salt domes may be effectively impermeable. Thus, the main concerns would probably relate to solutioning (either natural or man-induced), diapirism, and man-made pathways (either depository-induced or others). Many of these problems may not be amenable to the current flow path model approach. Rather, these potential release modes would probably be examined separately.
3. Crystalline Rocks: The crystalline rock flow path models differ from the layered models developed for sedimentary basins and basalts. These differences relate to the general uniformity of the crystalline rock and the lack of any highly permeable layers which can act as boundary head conditions and sources of water. These characteristics may lead to difficulties in modeling flaws in the depository. Groundwater circulation in deep crystalline formations is very poorly understood.

The details of the initial flow path models for sedimentary basins were approximated without the use of two-dimensional hydrologic numerical solutions (such as finite element or finite

difference models). This was feasible because the assumed boundary conditions resulted in simple flow patterns. In our opinion, however, the flow patterns in basalts and crystalline rocks are more complex and probably do not lend themselves to such approximations without the use of more sophisticated hydrologic models. Such models would indicate the general geometry, lengths and gradients of the flow patterns. In some models, refined transport models may also be essential in order to evaluate the significance of lateral dispersion.

Flaws in a depository in crystalline rock may have a significant impact on the groundwater flow pattern in the vicinity of the depository. This would result in a modeling problem since the appropriate flow path models would also vary. However, it may be possible to develop a generic modeling approach for these conditions as follows:

1. Assume that the depository flaws have only a local effect; the overall regional groundwater flow patterns are unaffected.
2. Develop two models, A and B.
3. Model A examines the regional flow patterns and can be used to evaluate an unflawed depository.
4. Model B examines the local flow patterns in the vicinity of the depository. The hydrologic heads determined from Model A are used as constant head boundary conditions in Model B. Thus, Model B may result in mixing of flow and waste within the depository vicinity but would not alter the regional flow patterns.
5. The output of Model B (concentrations, times and/or waste pulse characteristics at each exit nodal point) becomes the input to Model A. The output of Model A (concentrations and/or dose) is the final result of the model.

6. This proposed model approach seems consistent with the current LTRM model capability; it would allow for the suitable transfer of nuclides between different zones caused by depository flaws (such as shaft backfill deterioration, etc.); and it maintains the overall regional flow pattern.

TABLE 4-1
PRELIMINARY GENERIC FLOOD BASALT PARAMETERS

	Thickness		Permeability, K cm/sec		Porosity, n	
	Pref.	Range	Pref.	Range	Pref.	Range
Surface soil	700 ft.	0-1700	10^{-3}	10^{-1} - 10^{-6}	.25	.20-.40
Weathered & fractured basalt	1200 ft.	1000-3000	10^{-4}	10^{-2} - 10^{-7}	.05	.01-.15
Dense basalt	250 ft.	200-700	10^{-7}	10^{-6} - 10^{-9}	.005	.01-.0005
Silt, clay interbeds	200 ft.	100-500	10^{-7}	10^{-5} - 10^{-9}	.20	.10-.35
Sand, gravel interbeds	350 ft.	200-1000	10^{-3}	10^{-1} - 10^{-5}	.25	.15-.35
Very dense basalt	200 ft.	100-300	5×10^{-8}	10^{-6} - 10^{-9}	.002	.01-.0005

i_h = .005-.0002, .001 preferred (horizontal gradient)

i_v = .05-.001, .02 preferred (vertical gradient)

These values are based on data presented in our previous report (GAI 1977b).

TABLE 4-2
PRELIMINARY GENERIC SALT DOME PARAMETERS

	Thickness		Permeability, K cm/sec		Porosity, n		Gradient
	Pref.	Range	Pref.	Range	Pref.	Range	
Surface soil	80 ft.	20-180 ft.	10^{-3}	10^{-1} - 10^{-6}	.25	.20-.40	i_n
Unconsolidated sand	100 ft.	0-220 ft.	10^{-2}	10^{-1} - 10^{-4}	.30	.15-.45	i_n, i_v
Sandy clay	100 ft.	50-150 ft.	10^{-5}	10^{-3} - 10^{-7}	.25	.15-.35	i_n, i_v
Salt radius horiz. vertical	2500 repository depth minus overlying sediment.	2000-5000	10^{-10}	10^{-9} - 10^{-12}	.01	.001-.05	none
Clay sheath	600 ft.	300-1000	10^{-8}	10^{-6} - 10^{-10}	.10	.05-.25	i_v
Sheared salt	600 ft.	300-1000	10^{-5}	10^{-5} - 10^{-8}	.02	.005-.10	none
Anhydrite cap rock	500 ft.	0-1300	10^{-7}	10^{-8} - 10^{-11}	.01	.001-.05	i_n, i_v
Calcite cap rock	150 ft.		10^{-3}	10^{-1} - 10^{-5}	.05	.10-.01	i_n, i_v

i_n = .001-.00001, .0001 preferred (horizontal gradient)

i_v = .10-.005, .05 preferred (vertical gradient)

These values are based on data presented in our previous report (GAI 1977b).

TABLE 4-3

PRELIMINARY CRYSTALLINE ROCK - BATHOLITH PARAMETERS

Surface soil	Thickness		Permeability, K (cm/sec)		Porosity, n	
	Preferred	Range	Preferred	Range	Preferred	Range
Zone 1						
Weathered & fractured	50 ft.	10-100	10^{-2}	10^{-1} - 10^{-4}	.30	.25-.35
Zone 2						
Fresh rock	Repository depth minus Zone 1		10^{-8}	10^{-5} - 10^{-11}	5×10^{-5}	10^{-3} - 10^{-6}

Head drop between recharge and discharge 500m - 2,500m; 1,000m preferred.
 Distance between recharge and discharge 3,000m - 50,000m; 20,000m preferred.

It is assumed vertical and horizontal permeability are equivalent, $K_h = K_v$

These values are based on data presented in our previous report (GAI 1977b).

TABLE 4-4
PRELIMINARY GENERIC CRYSTALLINE PIEDMONT MODEL PARAMETERS

	Thickness (m)	Range	Permeability cm/sec	Range	Porosity	Range
Surface Sediments (Aquifer)		0-20	10^{-3}	10^{-1} - 10^{-5}	.30	.20-.40
Shale (Aquitard)	150	100-200	10^{-8}	10^{-6} - 10^{-10}	.10	.05-.25
Sandstone (Aquifer)	150	100-200	10^{-3}	10^{-1} - 10^{-5}	.15	.05-.25
Saprolite (Aquitard)	20	0-30	10^{-6}	10^{-5} - 10^{-7}	.20	.10-.30
Crystalline Rock	Repository depth minus above		10^{-8}	10^{-5} - 10^{-11}	5×10^{-5}	10^{-3} - 10^{-6}

Distance between "recharge" and "discharge" points = 25,000m preferred, 8,000 to 50,000 range.

Horizontal gradient in Sandstone Aquifer = 10^{-3} preferred, 10^{-4} to 5×10^{-3} range.

Head drop between "recharge" and "discharge" = Distance between "rech" and "disch" x ill.

Length of flow path - see Figure 5-8 where AH = head drop between "recharge" and "discharge";

S = depth below sandstone aquifer.

Head drop between sandstone aquifer and surface aquifer = 20m preferred, 5 to 50m range.

These values are based on data presented in our previous report (CAI 1977b).

EQUIVALENT THICKNESS MODEL FOR FLOOD BASALT

Figure 4-1

NOTE : See text for explanation

SALT DOME

Figure 4-2

CRYSTALLINE ROCK - BATHOLITH

Figure 4-3

NOTE: See text for explanation.

NOTES

1. "D" is the total horizontal distance traveled within the actual basalt sequence and the equivalent layers. It is equal in both cases.
2. Flow paths are not to scale.
3. This model may be limited to unflawed case, see text for explanation.

GENERIC MODEL

POSSIBLE FLOW PATH MODEL, FLOW THROUGH FORMATION and SHAFT

GENERIC BASALT MODEL
WITH A POSSIBLE PIPE ANALOG

Figure 4-6

Generic Model

Possible flow path
for unflawed case

NOTES

1. Assumes depository is located approximately halfway between recharge and discharge. This assumption could be varied
2. Geometry and distances based on results of 2 dimensional hydrologic models
- 3 See text for explanation.

Generic Model

NOTE:

1. See figure 5-7
2. See text for explanation

Possible Flow Path
For Unflawed Case

5.0 SIMPLISTIC MODEL EVALUATIONS

5.1 GENERAL

GAI has developed a procedure for approximating the radiation dose release for very simple flow path networks. Although the numerical results of the analysis are only approximations and could even be misleading, in our opinion the results probably represent a reasonable approximation of the more rigorous LTRM model. The purposes of these simplistic models include:

1. The analysis allows us to evaluate the general form of the results and usefulness of potential modifications to the LTRM model. It also allows for a more intelligent decision concerning the selection of scaling sets of parameters.
2. The analysis provides significant insight into numerous areas without requiring the time and expense of a complete LTRM model cycle. This allows many problems to be looked at on a preliminary basis and improves our ability to understand some aspects of the site suitability problem in a timely manner.
3. The results of the analysis enable more intelligent decisions to be made about future priorities.
4. Performing the analysis provides direction to the data base work and allows emphasis to be placed in areas which are of more significance to the overall site suitability effort.

The major simplifications and assumptions of the model evaluations include:

1. The individual dose was computed using 50-year equivalent whole body dose curve (TASC 1978b). The population dose was computed using curves for the equivalent whole body population dose per year (TASC 1978b). Both types of curves are based on a specific river, estuary, ocean and ecological system (TASC 1978a).
2. Only reprocessed high level waste was evaluated.
3. Nuclide retardation was assumed equal to 1.0 for all cases. This is a major simplification and certainly will alter the numerical results for nuclides with high retardation factors. Retardation could be included in model analysis of this type.
4. The effects of both canister dissolution and longitudinal dispersion were represented by simple square wave pulses.
5. The time required for the first nuclide to reach the biosphere was assumed equal to the total path length divided by the velocity of the water and does not account for the shorter arrival times caused by dispersion.
6. The width of the waste dispersion pulse, T , entering the biosphere, was assumed equal to:

$$T = (T_1^2 + T_2^2 + D^2)^{\frac{1}{2}}$$

where $T_1, T_2 = (2\alpha z)^{\frac{1}{2}}/v$

with α = dispersion length, taken as 50 meters

z = path length

v = water velocity

T_1, T_2 = effect of dispersion along any single flow pipe

D = waste dissolution time

7. It was assumed that the depository contained the waste from 6×10^6 MWe.

5.2 INTEGRATED POPULATION DOSE

The integrated population dose is a measure of the total dose release to mankind over the life of the repository. The meaning and evaluation of population dose is discussed in detail in various reports (TASC 1978a, 1978b). For an exploration of population dose computations, see these reports.

Assuming a single release pathway to the biosphere, Figure 5-1 is a plot of population dose integrated over all time as a function of minimum transit time of the first nuclide to reach the biosphere and the canister dissolution time. From this curve the following preliminary comments can be observed:

1. The integrated population dose is essentially constant for all repository performance conditions provided that the waste escapes between approximately 420 years and 3.10^6 years.
2. The canister dissolution time has a significant effect on the integrated population dose integrated over all time for short release times; thus, a relatively long dissolution time will minimize the hazard of an early breach of the repository.

In our opinion Figure 5-1 cannot readily be compared to background radiation. Such a comparison would depend on the total population affected and the length of time that the radiation release was occurring. Figure 5-2 is an attempt to make such a comparison by assuming a total affected population of one million people and a normal background radiation of 0.1 rems/year. The computed width of the waste dispersion pulse reaching the biosphere

represents the length of time the radiation release would occur. The curves indicate that the longer the period over which the waste is released, the smaller the integrated population dose compared to background. This is obvious since there is only so much waste in the depository, whereas background is cumulative each year. For early breach of the repository, a long canister dissolution time (10^4 years) can minimize the population dose to less background. In general, a well-designed repository in a sedimentary basin would probably have waste dispersion pulse widths exceeding 10^5 years (and with retardation most of the waste pulses would exceed 10^6 years). This corresponds to an integrated population dose rate on the order of 0.1 percent of background.

5.3 REPOSITORIES IN SEDIMENTARY BASINS

5.3.1 General

The results of the current LTRM model results for sedimentary basins indicate that two physical barriers to nuclide release exist: the thick, impervious depository rock layer (salt or shale) and the overlying aquifer. Elimination of either barrier may not lead to a serious breach in waste containment due to the remaining long transit times in the other barrier. Thus, the results of the parametric sensitivity studies of one barrier tend to be masked by the effects of the second barrier. In our opinion, a better understanding of each barrier is obtained by evaluating them separately. In this section we present the results of lumped parameter evaluations of single barrier models. This effectively considers a shale (or salt) barrier overlain by a river (i.e., a zero aquifer length) and an aquifer barrier with a completely failed depository layer containment (i.e., zero shale layer thickness and/or an infinitely permeable flaw through the shale).

The following model evaluations are presented:

1. Dose release through an unflawed depository layer (shale, salt).
2. Dose release through the overlying aquifer.
3. Dose release through a flaw in the depository layer (shale, salt).

Only the 50-year equivalent whole body dose was computed. The general flow regime and release pathways used by LTRM (TASC, 1978a) were assumed. This includes a vertical flow through the formations surrounding the depository and horizontal flow to a river through the overlying aquifer.

5.3.2 Depository Layer

The dose release from an unflawed depository layer appears to be a function of the lumped parameter $n/K\Delta h$, where n equals relevant porosity of the rock; K equals permeability of the rock; and Δh equals total water head difference across the depository layer. Waste dissolution time, thickness of depository rock layer, and depository resaturation time are also important. Figure 5-3 is a plot of dose as a function of $n/K\Delta h$ for different canister dissolution times. For the analysis, the depository rock layer was assumed to be 200 meters and the resaturation time was assumed to be 100 years.

To provide additional insight into the data, the figure also indicates the dose as a function of fracture permeability (K_f) and interstitial permeability (K_i) for two head differences based on the following:

1. A fracture porosity, n_f , equal to:

$$n_f = 3.5 \times 10^{-3} (K_f)^{1/3} \text{ (GAI 1977b)}$$

2. An interstitial porosity, n_i , equal to:

$$n_i = .023 \log \frac{K_i}{4 \times 10^{-11}} \text{ (GAI 1977b)}$$

This data is shown by separate scales on the graph. Also indicated on the plots are the dose equivalent to normal background radiation and 1 percent of normal background.

Several interesting observations can be drawn from Figure 5-3 pertaining to fracture flow:

1. The dose release always exceeds background radiation for any measurable finite permeability. This is because of the fast flow velocities through the fracture.
2. The dissolution time has a significant effect on the dose release.
3. Although not shown on the figure, long resaturation times will significantly reduce the dose. In fact, a long resaturation time is probably the main containment provided by a depository layer dominated by fracture flow behavior. Thus, increasing the resaturation time to 500 years would effectively reduce the dose to less than 1 percent background (assuming 10^4 for a waste dissolution time).

Thus, in a depository layer exhibiting fracture flow behavior, resaturation time and waste dissolution time will dominate the dose release of the barrier.

Pertaining to interstitial flow, the data indicate that, for the assumed geometry, an interstitial permeability on the order of 10^{-7} to 10^{-9} cm/sec will result in a dose of less than one percent of background. A tenfold decrease in permeability results in approximately a tenfold decrease in dose. Both the resaturation time and waste dissolution times are relatively unimportant except for the higher permeability ranges.

5.3.3 Aquifer Layer

The dose release from an aquifer appears to be a function of n/Ki where n is the porosity, K is the permeability and i is the horizontal gradient. Aquifer length, dissolution time and depository resaturation time are also important. Figure 5-4 is a plot of dose as a function of n/Ki for several different aquifer lengths. For the analysis, the waste dissolution time was assumed to be 10^4 years with a depository resaturation time of 100 years. To provide further insight into the data, Figure 5-4 also indicates the dose as a function of permeability for different horizontal gradients and assuming a porosity of 0.1.

The data clearly show that the aquifer represents a significant barrier to waste release over a wide range of credible permeabilities, gradients and aquifer lengths. In a freshwater aquifer the effects of nuclide retardation would significantly reduce the computed dose.

5.3.4 Flaw in Depository Layer

Several flaws could breach the depository layer barrier, including deterioration of the backfill, boreholes with failed seals, and permeable fault zones. In general, the effect of the flaw on the overall containment provided by the depository layer

is a function of the relative size and permeability of the flaw. This can be expressed by the lumped parameters $\frac{K_F}{K_D}$ and $\frac{A_F}{A_D}$, where

K_F equals permeability of the flaw, K_D equals permeability of the depository rock, A_F equals flow area provided by the flaw, and A_D equals flow area through the depository. Assuming a depository layer thickness of 200 meters, a head difference across the layer of 60 meters, a layer rock permeability of 10^{-9} cm/sec, and a recharge time of 100 years (essentially the preferred LTRM model parameters for shale), Figure 5-5 was developed. The figure shows the computed dose release through the flaw for different $\frac{K_F}{K_D}$, $\frac{A_F}{A_D}$ and waste dissolution times. As indicated on the figure, the area ratios $\frac{A_F}{A_D}$ shown relate approximately with faults, shafts and boreholes.

The shaft case ignores horizontal transit times in the corridors connecting the waste area with the shaft. All cases assume complete mixing of the waste. The data indicate the following:

1. For highly permeable flaws, the waste dissolution time is important.
2. To limit the effect of the flaw to less than one percent of background, $\frac{K_F}{K_D}$ should not exceed about 10^2 to 10^3 . Assuming a rock permeability of 10^{-9} , this implies that the shaft and borehole permeabilities should be less than about 10^{-6} to 10^{-7} cm/sec.

Figure 5-5 is highly dependent on the simplifying assumptions used in the analysis and does not consider the potential flows down into the repository for very high $\frac{K_F}{K_R}$ values. Figure 5-6 shows

the effect of various corridor lengths on the computed dose for the shaft backfill case. Extended corridor lengths can significantly minimize the effect of backfill deterioration. This curve also indicates the importance of details in the dose model.

INTEGRATED POPULATION DOSE VS. NUCLIDE TRANSIT TIME

Figure 5-1

Note: Assumes a single release pathway, and no retardation

D: Canister dissolution time in years

INTEGRATED POPULATION DOSE RATE RELATED TO BACKGROUND RADIATION

Figure 5-2

1% Background

1. Transit time of the
first nuclide to reach
the biosphere - years

Note: Assumes a single release
pathway, no retardation and
a 10^6 population base

1% Background

10^5

10^6

10^7

of waste dispersion pulse
to the biosphere (years)

2

Note: 1. Δh : Head difference across
depository layer

n : Porosity

k : Permeability

2. Comparisons with background
radiation based on a repository
with 6×10^6 MWe-yr. waste

3. No retardation

4. Resaturation time 100 years

5. Repository layer thickness -200 meters

6. See text for explanation

SIMPLIS,
FOR DEPO.

SIMPLISTIC DOSE MODEL RESULTS FOR DEPOSITORY LAYER BARRIER

Figure 5-3

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1

SIMPLISTIC DOSE MODEL RESULTS FOR AQUIFER BARRIER

Figure 5-4

10^{-7}
 $i = .0005$
 $n = 0.1$

0.005
0.1

radiation

background radiation

Note: 1. L: Aquifer length

i: Horizontal gradient

n: Porosity

k: Permeability

2. Background radiation based

6×10^6 MWe-yr. of waste

3. No retardation

4. Waste dissolution time 10^4 years

5. Resaturation time 100 years

6. See text for explanation of curve

$\sim L = 100$ meters

$\sim L = 1000$ meters

$\sim L = 10,000$ meters

10^4

2

SIMPLISTIC DOSE MODEL RESULTS FOR A FLAW IN DEPOSITORY FORMATION LAYER

Figure 5-5

SIMPLISTIC DOSE MODEL EFFECT OF DEPOSITORY CORRIDOR LENGTH

Figure 5-6

6.0 LOSS OF ADMINISTRATIVE CONTROL (LOAC)

6.1 GENERAL

In our November report (GAI 1977b), we presented a preliminary data base for the evaluation of Loss of Administrative Control (LOAC) and the impact of a repository on future natural resource development. The purpose of this section is to present a methodology consistent with the general LLL approach for evaluation of the risks associated with LOAC.

For the purposes of this section, we will define LOAC as: State in which the performance of the repository is not monitored and the required constraints on the buffer zone(s) are not inferred. This implies:

1. Loss of the ability to exert control: this relates to the loss of an effective governmental body with the resources to enforce laws.
2. Loss of understanding of the repository: this could include loss of records, lack of knowledge about its existence and location and/or lack of understanding about the risks.

The events which could be expected to lead to LOAC might include such cataclysmic events as world war, revolution, pestilence, major climatic changes, major geologic changes and natural disasters. LOAC could also occur due to a general lack of interest after a long period without any radiation releases.

The methodology presented below involves an event tree with associated probabilities and consequences. It might be expected that the probabilities generally increase gradually with time while the consequences decrease with time.

6.2 LOAC EVENT TREE

Figure 6-1 shows a general event tree framework for evaluation of LOAC. Each junction in the event tree has an associated probability. The termination points of the tree represent conditional states of the repository corresponding to a particular consequence.

The junctions on the event tree include:

1. Initial Conditions

Following decommissioning, the performance of the repository will be carefully monitored and evaluated.

2. Repository Performance

The repository either performs as designed or it does not. The probability of adequate performance will be evaluated based on a site specific uncertainty analysis. The probability that the repository will not perform adequately should be very small although it will increase with time.

3. LOAC

Loss of Administrative Control either occurs or it does not. An estimate of the probability of LOAC could be made through an evaluation of the history of wars, revolutions, downfall of civilizations, natural disasters, etc. The probability is expected to be very low at first and increase with time.

4. LOAC Increases Release

LOAC either affects the performance of the repository or it does not. At a specific site, based on the potential resources and regional conditions, there is a certain probability that new wells, mines, boreholes, etc. might breach or affect the repository and increase the release of radionuclides. These probabilities could be estimated through an analysis of potential site natural resources and the number and distribution of existing mines, wells, boreholes, etc. The direction of technological advance also needs to be anticipated, which may change methods of exploration and mining.

The final states or termination points of the event tree as shown on Figure 6-1 for cases without LOAC include:

1. Repository Performs Adequately; there are no unacceptable releases.
2. Repository Does Not Perform Adequately; the monitoring program will determine if an unacceptable level of radiation release occurs. Under such conditions, active and/or passive action could be taken to reduce the radiation to acceptable levels. Active action might include reopening of the depository and removal of the waste and/or special remedial construction, surface remedial measures, and/or other techniques. Passive action might include increasing the size of the buffer zone and/or added site constraints. The economic consequence of these measures would be strongly site-dependent. This emphasizes the significance of considering site demography, the water use

system, and regional natural resources. Thus, depending on these conditions, unacceptable releases may result in simply requiring an increased buffer zone in an unpopulated area with limited surface waters; on the other hand this may result in relocating major population centers in populated areas with a significant surface water resource usage.

The final states for cases with LOAC include:

3. Repository Performs Adequately and LOAC Does Not Affect Performance; there are no unacceptable releases.
4. Repository Performs Adequately but LOAC Affects Performance; there may be a certain level of release depending on the nature of the breach in containment and the time of LOAC after decommissioning.
5. Repository Does Not Perform Adequately; depending on when LOAC occurs, there may be curtailed level of release; due to LOAC the release would not be detected. The release may be further increased due to new wells, boreholes, mines, etc.

For an unacceptable release to occur, a combination of low probability events must occur. Although these probabilities may increase with time, the consequences of release may decrease with time (depending on which type of radiation dose is chosen). Thus, the expected consequence of case number 3 above can be represented by:

$$\text{Expected Risk} = (\text{Probability of LOAC}) \\ (\text{Probability that LOAC increases releases}) (\text{Consequence})$$

Although not considered in the above discussion, after LOAC occurs there is a probability that the administrative control will be regained. This might lead to the repository controls being re-established.

6.3 FUTURE LOAC ANALYSIS

In our opinion, the methodology discussed above represents a viable approach to the problem of LOAC. Preliminary probability distributions and consequences could be developed and utilized to perform a "first-cut" evaluation of LOAC. Should the results indicate the LOAC is significant, the probabilities and consequences can be further refined.

NOTE: See text section 7.0 for explanation of figure.

7.0 REPOSITORY CONCEPTUAL DESIGNS

7.1 INTRODUCTION

The purpose of the following Sections, 7 through 9, of this report is to present a discussion of repository design concepts based on our review and interpretation of existing repository conceptual designs. This discussion is based on:

1. A review of the technical assumptions made for existing designs.
2. An interpretation of the interaction between major design features.
3. A summary of general design criteria that have been established.

The scope of our work under this contract is concerned only with repository designs for bedded salt. We are aware that design work is presently continuing for DOE, not presently documented, not only in bedded salt but in other rock types such as dome salt, shales and crystalline rock. The following sections, however, are based on the designs for bedded salt that were available to us for this contract.

7.2 REVIEW OF EXISTING CONCEPTUAL DESIGNS - BEDDED SALT

The two design documents that are available for review are as follows:

1. Waste Isolation Facility Description - Bedded Salt, by Parsons, Brinckerhoff, Quade, and Douglas, Inc. (1976a)

2. Waste Isolation Pilot Plant (WIPP) Conceptual Design Report, Sandia Laboratories (1977a).

The first report details the design of a repository for the containment of high level waste (HLW) and transuranic waste (TRU), that is, waste with both high and low heat generation rates, respectively. In contrast, the WIPP report describes a repository for the containment of TRU, with low heat generation rates, and has only a limited experimental area for HLW. In both cases the HLW is expected to be in the form of canisters containing reprocessed solidified fuel. The designs do not specifically address the requirements or modifications required for the storage of spent fuel.

The main features of these two designs are detailed in the following sections.

7.2.1 Waste Isolation Facility Description

This is documented in the report prepared for OWI by Parsons, Brinckerhoff, Quade and Douglas, Inc. (1976a).

1. Repository Size and Location

Designed for an approximate depth of 1,800 feet, (549 meters), and includes an area which would be used as a pilot facility. Underground storage area is 77 acres for pilot facility, 1,600 acres for full facility. Overall size of total repository is 2,000 acres. Designed operating life is 20 years.

2. Waste Form and Packaging

Designed for:

- a. HLW - intense radiation and high heat generation rates.
- b. Intermediate level TRU - high intensity gamma radiation, and low level heat production.
- c. Low Level Waste (LLW) - Low levels of gamma radiation and no heat production.

Each waste form is stored in a separate, designated area within the facility.

The HLW and TRU waste must be shielded or handled remotely and would be packaged in canisters. The LLW would be packaged in 55-gallon drums.

3. Waste Retrieval Requirement

The pilot facility will be ventilated and open for inspection for the life of the repository. All storage rooms will be sealed on completion of waste placement but will have provision to allow for reventilation to achieve access at a later date.

7.2.2 WIPP Conceptual Design

This is documented in the report prepared for ERDA by Sandia Laboratories (1976a).

1. Repository Size and Location

Designed for an approximate depth of 2,100 to 2,700 feet, and includes a small experimental area for HLW canister storage over an extended time period. Designed operating life is 25 years.

2. Waste Form and Packaging

Designed for: ERDA Low Level Transuranic Waste (LLW), ERDA Intermediate Level Transuranic Waste, and high level waste experiments. The second two categories of waste must be remote-handled and would be packaged in canisters. The remote-handled waste (RH) is stored on the lower repository level, which is isolated to the maximum extent from the upper level in which the LLW is stored.

3. Waste Retrieval Requirement

All waste will be retrievable until such time that the pilot plant is converted into an operational repository for permanent disposal. Waste salt will be used to backfill the rooms after it has been determined that the facility will be converted into a full repository.

The physical layout and construction of the repositories described in these two reports varies in many respects, but a detailed review of these areas is considered beyond the scope of this report. This should, however, be completed when further clarification of required design features and performance criteria has been made.

7.2.3 Comments on Conceptual Designs

The repository conceptual designs described above were based on certain assumptions that were considered appropriate at the time they were prepared. As such, while we consider these designs to be quite competently and thoroughly engineered in many respects, they do not fully consider design alternatives. That is, they are each based on a rather specific waste emplacement scenario and predicted conditions for heat generation.

An important objective of the existing designs, or of any other design, is the verification of the laboratory investigations, design data, and procedures on which the design is predicated. The logical flow of data acquisition and analysis is not, in our opinion, clearly presented to indicate the decision points that should exist in the transition from experimental, or pilot plant, to operational repository phases of the program.

While it may be appropriate to ensure the success of the repository design concepts before proceeding with underground construction and excavation, we consider that it would be prudent to establish and follow through with a design verification procedure. Clearly this would provide an increased measure of confidence that the data on which the design has been based adequately represents the range of real conditions. Similarly, monitoring procedures to determine that the performance of engineered features is maintained over a period of years (e.g., borehole seals) should be considered as an integral part of the decisions concerning waste retrieval and the placement of backfill for decommissioning.

We do not consider that a responsible in-depth review of the existing repository conceptual designs can be made at this time by Golder Associates. We have identified several areas, which are discussed below, where the basis for some of the fundamental assumptions is not included with the reports, and our observations at this time would reflect this lack of information. We have therefore attempted initially to address the overall concepts involved, and recognize that the more detailed engineering will require further review.

At this stage we have not been able to obtain access to the individuals or organizations concerned with the preparation of the data and the final reports, and so clarification of points in question has not been possible. Our only other source of information for review has been from data published in documents currently in the public domain which are, inevitably, subject to individual interpretation and application. The state of the information base may, therefore, lead to incorrect conclusions.

With the above caveats, we present the following general comments on the WIPP site report:

Mine Structural Design:

There is no clear justification presented for the design procedures that were used to calculate the rock pillar and room dimensions. It is well known that rock mass strengths predicted from documented pillar failures are rather less than the measured strengths of small samples for pillars with moderate height to width ratios. In contrast, larger pillars can retain a strong elastic core, even while progressive failure may occur. In addition, no consideration has apparently been given to the location and orientation of heterogeneties that are known to occur in the salt. We do not consider that either the method used was appropriate and the effects of thermal loading were not adequately understood.

The basis for the deformations that have been considered around the repository openings is a creep relationship developed for potash. We understand that the repository is likely to be constructed in a halite layer, and the report does not demonstrate the validity of this same relationship for halite. We believe that a nonlinear creep relationship for halite must be established, and that particularly the influence of the increased temperatures that are expected must be presented.

Waste Handling in Shafts:

Shaft operations are inherently among the most hazardous in a mining operation and are controlled to a reasonable standard of safety by use of highly developed equipment and strict operating and maintenance standards. Two factors make the handling of nuclear waste more difficult than normal operations:

1. The absolute necessity of avoiding malfunctions to minimize the chance of radioactive waste being stuck in the shafts; and
2. The high degree of automation (i.e., unmanned operation) required, particularly in the remote handling facilities.

It is not clear in the WIPP report how comprehensive the required safety features such as interlocks and other protective devices are intended to be, or how accessibility for shaft maintenance is to be achieved in remote handling facilities.

Separation of mine construction access from waste placement access is required, and we suggest the positioning of the waste handling shafts remote from the man/material shaft. This arrangement could cope better with an unexpected water or gas inrush to the mine construction area.

Ventilation:

In this brief review we have not discovered the basis for the fundamental assumptions underlying the ventilation calculations, i.e., air volumes and velocities. A velocity of 50 fpm has been accepted for the storage areas, but it is not clearly demonstrated to be adequate to limit temperatures to acceptable levels. The interfacing between the overall thermal effects and the heat removed by the ventilating air has not been discussed.

Concept of Waste Retrieval:

Provision is made to use precise survey equipment for the location of emplaced waste when retrieval is required. If room closure is indeed substantial, it may include considerable floor "heave," which will complicate location procedures.

Backfill System:

The design basis for the proposed system of backfilling with crushed salt is not addressed.

Choice of Equipment:

Safe operation of the facility, and in particular the remote handling system, will depend upon proper operation of complex equipment, much of which is currently only in the conceptual stage of development. The security of this equipment against potential accident conditions such as power loss, fire, explosions, etc., has not been clearly established.

8.0 REPOSITORY DESIGN CONSIDERATIONS

8.1 INTRODUCTION

A proper consideration of interactive design performance criteria can be made only if they are based on either an existing acceptable repository design or on a credible set of design assumptions. These assumptions may include limiting factors that can be established for:

- acceptable rock type for repository construction;
- acceptable size of the repository and depth below surface;
- waste form and packaging;
- requirements for retrieval of waste;
- cost of repository;

and certain other geological, hydrological and thermo-mechanical factors. From these basic assumptions a number of candidate designs can logically be developed, in conjunction with other studies involving radionuclide risk determination and, possibly, dose calculations. Each candidate design must be complemented with a description of appropriate operating procedures.

Repository design factors that affect radiation hazards can be generally classified into two categories:

1. Those that directly affect the postsealing performance of the repository and may contribute to the release of radioactive material to the biosphere, leading to hazards to the general public.

2. Those that impact only the presealing performance of the repository. These factors may, in certain disaster scenarios, impact the general public but would largely affect occupational groups during repository operation.

Clearly, there are some design features that may influence both presealing and postsealing performance, and it would therefore be necessary to determine which of these provides the most critical design performance criterion.

Quite clearly, the repository design must include a consideration of the effects of all known or possibly undetected geologic and hydrologic factors. In the operating phase of the repository, these would include the hazards associated with intercepting high pressure gas or water reservoirs. It is therefore considered essential that the studies concerned with design performance criteria and site suitability criteria are closely coordinated.

At this stage we would propose the following general classification:

Presealing Performance

1. Repository waste storage capacity
2. Shaft excavation and construction
3. Borehole sealing
4. Pillar and room dimensions
5. Ventilation system and heat generation
(depends in part on waste form)
6. Rate of excavation
7. Repository excavation techniques and support
8. Retrieval system
9. Equipment selection and operation

10. Partial sealing or backfilling
11. Monitoring

Postsealing Performance

1. Backfilling and shaft sealing
2. Borehole sealing
3. Waste form, packaging and thermal effects
4. Long-term subsidence or uplift
5. Monitoring

The contribution to radioactive release made by those design features that are classified as significant to postsealing performance can be assessed at this time using the general hydrologic waste transport model (LTRM). This would be achieved by:

- revising descriptors and predictors that have been previously assumed under site suitability criteria, based on a more detailed review of available data and technologic progress.
- revising estimates of the type and number of pathways (for example, number of shafts) to surface.
- examining the long-term thermo-mechanical effects in more detail, to include the effect of rock disturbance on previously assumed predictors for rock permeability and preferred fracture paths.

The effects due to those design features that are classified as significant to presealing performance require an alternative methodology for risk determination and assessment, and the application of uncertainty analysis procedures.

Currently, under separate contract we are involved in assessing a methodology and data base for the following six specific design performance tasks:

1. Shaft and borehole sealing
2. Equipment performance requirements
3. Waste/rock interaction
4. Mine structural design
5. Decommissioning
6. Excavation technology

These tasks address both presealing and postsealing factors. Where appropriate, the LTRM waste transport model will be used to assess their significance, but as of this time, we do not have a procedure for objectively evaluating the presealing factors.

The following sections describe the important design features and their interfacing in an overall repository design, based on our interpretation of existing documented data.

8.2 DISCUSSION OF DESIGN FACTORS

8.2.1 Size of Repository

The size of a repository is determined not only by the required total storage amounts but also by the waste form and packaging. Repository size can be specified to be either a maximum acceptable storage area, or for a maximum amount of various waste forms to be stored at a given site, or by a combination of both. For a particular waste form, repository room size is determined by the physical dimensions of the waste package and the emplacement/retrieval equipment, and by the storage configuration. Storage configuration is likely to be either:

- vertical placement in drill holes for high level waste and spent fuel canisters, and for intermediate level transuranic wastes;

- horizontal placement in drill holes for the above;
- horizontal stacking of canisters in one or more tiers for intermediate level transuranic waste; or
- stacked drums for low level transuranic wastes.

Given a specified room size, the dimensions of the intermediate pillars will be governed by several interlinked parameters, including:

- depth of the repository below surface;
- waste spacing and thermal power output;
- thermal and mechanical properties of the host rock;
- heterogeneity of the host rock;
- degree of ventilation provided; and
- pre-mining in-situ stress.

The appropriate size of the pillars cannot be determined unless the expected performance of the pillars has been clearly stated for the anticipated range of conditions (such as fracturing, temperature rise, creep, etc.). That is, it is necessary to determine what types of pillar behavior are generally acceptable over an extended period of time, in terms of stresses and deformations, mechanical strength and the effect of thermal stresses. As the thermo-mechanical properties of the host rock are not well defined, particularly at elevated temperatures, the results of numerical or analytical methods for pillar design are subject to considerable interpretation.

However, by calculating a range of credible pillar sizes, the resulting repository size for a given waste storage capacity and particular pillar dimensions could be readily determined.

8.2.2 Shafts and Shaft Sealing

Shaft construction and design, including size and location, will be dictated by the expected shaft duty. All shafts will be required to be sealed by grouting against water intrusion during sinking operations where such shafts pass through flowing aquifer zones. This is a standard operational practice.

Shaft operations are generally the bottleneck of all underground mines due to their limited dimensions and are the only source of entry and exit to the mine. This will also be the case for a repository, and hence it is essential that shaft operations are not hindered by either accident occurrences or by unforeseen maintenance work. For these two reasons we suggest that the shafts may have to be concrete-lined for the entire length. This would control minor rock spalling, which could damage critical installations, and would also allow for more precise operating tolerances.

Of all aspects of the repository, the shafts and shaft linings are probably the most susceptible to seismic shocks; this may be particularly true for either the upper part of the shaft where near-surface effects may be increased or at lithologic boundaries between the salt and the overlying rocks. Fracturing of a shaft lining could well prejudice the security of the grout seal against water intrusion, and, if pumping provisions are inadequate, possibly create flooding conditions in the repository.

8.2.3 Waste Retrieval

In our opinion this is quite clearly one of the most significant factors in repository design, both in terms of the cost and confidence in performance predictions, and possibly in risk estimates. The requirements for waste retrieval will impact:

- ventilation requirements, if continued cooling of all rooms is required;
- reopening and possibly remining costs (due to rock failure and/or creep at elevated temperatures) if rooms are to be closed off but kept open after waste emplacement; and
- the use of complex remining systems if rooms are to be backfilled after waste emplacement, and retrieval is subsequently required.

It is clear that there will be trade-offs between the higher ventilation costs required to maintain acceptable temperature levels in the repository and the requirements for either supporting or remining rooms where accelerated creep has been experienced due to high temperatures. The placing of backfill after waste emplacement may reduce the extent of creep closure, but again, the difficulties associated with remining the backfill would remain.

Another important factor to be considered is the time requirements for retrieval. By definition, any retrieval system conceived will probably be at least as lengthy a process as emplacement, and would have to be carried out in a controlled manner, i.e., not under accident conditions or as a result of other disaster events such as flooding and subsequent salt dissolution or a major collapse in a portion of the repository.

In terms of repository design and the uncertainties surrounding the geologic and hydrologic parameters, the requirement for waste retrieval and the conditions under which it would be deemed essential are of paramount importance. For example, interception of a previously undetected hydrologic feature (such

as a large freshwater aquifer or pocket) or geologic feature (breccia pipe or fault, which in turn could provide a pathway for water intrusion) could create extremely undesirable working conditions in emplacement rooms and may make safe retrieval impossible using the "designed" system. The problem is not just that of the immediate release of radioactivity, but rather an assessment of those events that could possibly disrupt the planned, engineered features on which the long-term security of the repository is predicated.

We therefore suggest that the concept first documented for OWI in the Waste Isolation Facility Description by Parsons, Brinckerhoff, Quade, and Douglas, Inc., should be extended; that is, not only should the repository development operations be separated from waste emplacement, but that the repository should be developed as a series of modular units, or mini-repositories, which could be developed, explored, approved and licensed in sequential fashion. This would allow operations to be halted at any time, for whatever reason, without prejudice to the security of the existing emplaced waste.

8.2.4 Ventilation Requirements

The ventilation requirements will be determined essentially by the linear footage of openings in which ventilation is maintained and by the volume of air required to control temperatures and provide a suitable working environment. It has been estimated that for a possible maximum ventilation requirement, to maintain the complete repository in an acceptable working environment, up to 16 ventilation shafts would be required (eight intake and eight exhaust). The design of an efficient system based on this large number of shafts would be simplified if a modular development scheme were used, as it would be required in any event to seal areas one from another to control ventilation circuits.

Two other problems are posed by such an extensive system. First, the increased total shaft area will provide additional pathways to surface in the postsealing mode. Second, the location of the shafts is likely to be critical, as it is possible that a convection-type cell could be set up between shafts should some be sited hydraulically "downstream" of others. The siting of these shafts would also impact surface layout considerations, including perhaps the requirements for waste salt disposal.

8.2.5 Decommissioning

There are two important factors associated with decommissioning, these being the associated costs and the material and procedures established for sealing the repository. The four alternative schemes are:

- backfill the rooms continuously as waste is emplaced;
- backfill the rooms at the end of the operating life of the repository;
- backfill at some intermediate point in time, perhaps when retrieval requirements have been better defined; or
- no backfill.

In the first scheme, the use of crushed salt, obtained from ongoing repository excavation, would minimize the costs of both backfilling and hoisting. Crushed salt would merely be transported from the mining faces to areas that were being backfilled; due to swell, approximately 50 percent of the excavated salt would still have to be hoisted. Obviously this figure would also be increased if the scheduling of the repository development and emplacement were not carefully matched.

If an alternative backfill material is determined to be more suitable, then obviously the hoisting costs associated with salt are not reduced as the full excavated volume must be hoisted to surface, and the additional cost of obtaining and stowing the alternative material is incurred.

The function of the backfill requires some clarification, in that the constraints on its performance are in terms of its permeability, porosity and rigidity. It is not clear at this time from the ongoing site suitability studies whether an impermeable and/or porous backfill is most appropriate, or even no backfill at all. Practically, there may be limitations on the lower bound permeability that can be achieved with most conventional backfill materials, or even with such high cost alternatives as concrete.

The rigidity of the backfill may contribute to the long-term support of the repository. However, depending on the range of thermo-mechanical response in the pillars and the overlying rock, the local support provided to the repository by the backfill may be insignificant compared with fracturing caused by subsidence or uplift due to creep and/or thermal expansion. We would expect that the backfill would never assume lithostatic pressure unless the backfill material compacts to a state where the modulus of the backfill equals or is greater than the surrounding rock.

8.2.6 Natural Barriers Versus Engineered Features

The goal of LLL's work for NRC is to establish a defensible set of technical information upon which NRC will base regulatory decisions. It is conceivable that for a specific site, site suitability studies may not establish a credible set of natural barriers

to radioactive release. Acceptability for such a site would rely on engineered barriers. It is also true that some engineered features, such as shafts, provide alternative release pathways to the biosphere, and these must necessarily be sealed with an engineered barrier.

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9.0 PRELIMINARY COMMENTS FOR DESIGN PERFORMANCE CRITERIA

9.1 GEOLOGICAL/HYDROLOGICAL FACTORS

The generic site for bedded salt developed as part of the work for site suitability criteria should be used as a basis for all geological and hydrological considerations at this stage. The range of mechanical behavior for salt observed from operating salt and potash mines would be used to evaluate design parameters for repository room size, rock support requirements, and pillar dimensions. The effects of thermal stresses and creep would be evaluated using currently available numerical methods.

9.2 WASTE FORM AND HANDLING

The varying radiation and heat generation rates for the alternative waste forms indicates that at least two distinct areas may be required within a repository, based on the requirement for remote handling of some waste forms (Parsons, Brinckerhoff, Quade, and Douglas, Inc. 1976a). The waste forms currently being considered are:

1. Remote Handled:
 - a. Reprocessed solidified HLW
 - b. Spent fuel rods
 - c. Intermediate level TRU
2. Contact Handled:
 - Low level TRU

Within the area designated for remote handling, alternative placement configurations could be determined, based on the varying thermal output of the waste forms.

Canister configurations have been developed for the WIPP site, and these may be appropriate. Packaging for spent fuel rod assemblies is not yet defined and is currently being studied by LLL.

9.3 WASTE RETRIEVAL

The repository design will probably incorporate provisions for waste retrieval, at least for the required period of time to demonstrate that the repository design concept is satisfactory. It is important, therefore, that the methods by which data is accumulated and analyzed are clearly defined, to allow a logical design verification procedure to be followed.

9.4 REPOSITORY DEVELOPMENT

The mining operation should be operated independently of the waste storage operation for maximum security, both from the effect on occupational radiological risk and of undetected natural geologic and hydrologic features. This separation or barrier has not been utilized in any of the available repository designs (Parsons, Brinckerhoff, Quade, and Douglas, Inc. 1976a; Sandia 1977).

Respectfully submitted,

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APPENDIX A

REFERENCES CITED

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Archie, G.D., 1950. Introduction to Petrophysics of Reservoir Rocks. Amer. Assoc. Petrol. Geol. Bull., V. 34, pp. 943-961

Atlantic Richfield Handford Company, 1976. Preliminary Feasibility Study on Storage of Radioactive Wastes in Columbia River Basalts, V. I and II, prepared for U.S. Energy Research and Development Administration.

Bradley, R.F., and J.C. Corey, 1976. Technical Assessment of Bedrock Waste Storage at the Savannah River Plant. Savannah River Laboratory ERDA Contract AT(07-2)-1.

Brown, R.D., and J.G. Vedder, 1967. Surface Tectonic Fractures Along the San Andreas Fault, California, The Parfield-cholame, California Earthquakes of June-August, 1966--Surface Geologic Effects, Water-Resources Aspects, and Preliminary Seismic Data, R.D. Brown, Jr., et al. ed., Professional Paper 579. pp. 2-23, U.S. Geological Survey, Washington, D.C.

Dickey, et al., 1968. Abnormal Pressure in Deep Wells of South-western Louisiana. Science, V. 160, No. 6828, May.

Golder Associates, Inc., 1977a. Development of Site Suitability Criteria for the High Level Waste Repository for Lawrence Livermore Laboratory, June.

Golder Associates, Inc., 1977b. Second Report Development of Site Suitability Criteria for the High Level Waste Repository for Lawrence Livermore Laboratory, November.

Hurr, R.T., and D.B. Richards, 1966. Groundwater Engineering of the Straight Creek Tunnel (Pilot Bore), Colorado. Engineering Geology, V. 3, No. 2.

Jenks, G.H., 1972. Radiolysis and Hydolysis in Salt Mine Brines, Oak Ridge National Laboratory, March. ORNL-3717.

Lawrence Livermore Laboratory, 1978. SSC Residual Uncertainty Management Framework, unpublished report by T. Harvey.

Marine, W., 1973. Geohydrology of Buried Triassic Basin at Savannah River Plant, South Carolina.

Miller, C.H., D.R. Cunningham and M.J. Cunningham, 1974. An Air Injection Technique to Study Intensity of Fracturing Around a Tunnel in Volcanic Rock. Bulletin of the Association of Engineering Geologists, V. XI, No. 3.

Parsons, Brinckerhoff, Quade and Douglas, Inc., 1976a. Waste Isolation in Facility Description -- Bedded Salt. Y/OWI/SUB-76/16506.

Parsons, Brinckerhoff, Quade and Douglas, Inc., 1976b. Thermal Guidelines for a Repository in Bedrock. Available from NTIS, Y/OWI/SUB-76/16504.

Sandia Laboratories, 1977a. WIPP Conceptual Design Report. ERDA Contract No. At(29-1) 789.

Sandia Laboratories, 1977b. Risk Methodology for Radioactive Waste Disposal in Geologic Media. Draft report submitted to U.S. Nuclear Regulatory Commission.

Sandia Laboratories, 1977c. Thermally Induced Movement of Nuclear Waste Canisters in Salt Formations. In Meeting of American Nuclear Society, November 29. San Francisco, California.

Smith, C.G. Jr., 1976. Hydrologic Stability of Salt Domes. In Salt Dome Utilization and Environmental Considerations, Proceedings of a Symposium, Louisiana State University, Baton Rouge, November 22-24, sponsored by the Institute for Environmental Studies.

Snow, D.T., 1968. Rock Fracture Spacings, Openings and Porosities. Journal Soil Mech. Foundation Div. Proc. ASCE. V. 94, pp. 73-91.

Tchalenko, J.S., and N.N. Ambrayeses, 1970. Structural Analysis of the Dasht-e Bayaz (Iran) Earthquake Fractures, Geological Society of America Bulletin. V. 81, pp. 41-60.

The Analytic Sciences Corporation, 1977a. The TASC Geology-Hydrology Model, Technical Information Memorandum No. 1103-1-2. Contract No. 6064103, August 2.

The Analytic Sciences Corporation, 1977b. Conclusions from the Site Suitability Analysis to Date, draft, September.

The Analytic Sciences Corporation, 1978a. Analysis of Nuclear Waste Management Options, prepared for Lawrence Livermore Laboratory.

The Analytic Sciences Corporation, 1978b. Current Status of Site Suitability Data Base Expansion. Technical Information Memorandum prepared for Lawrence Livermore Laboratory.

Thoms, R.L., et al., 1977. Site Specific Study for Possible Ongoing Salt Dome Movement. In Energy Resources and Excavation Technology Procedures of the 18th U.S. Symposium on Rock Mechanics, Keystone, Colorado, June 22-24. Golden, Colorado: Colorado School of Mines, 1977.

Webster, D.S., J.F. Proctor, and I.W. Marine, 1976. Two-Well Tracer Test in Fractured Crystalline Rock. U.S. Geol. Survey Water Supply Paper 1544-I.