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Albuquerque, New Mexico 87185

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January 2, 1985

WM-RES
WM Record File A-1165 SNL
WM Project 10, 11, 16
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PDR ✓
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Ms. Leslie A. Peeters
Repository Projects Branch
Division of Waste Management
U.S. Nuclear Regulatory Commission
7915 Eastern Avenue
Silver Spring, MD 20910

Dear Ms. Peeters:

Enclosed is the summary of activities during December 1984 for the following tasks (A-1165): (I) Assisting in the Development of the Licensing Assessment Methodology (II) Monitor and Review Aspects of DOE programs; (III) Identifying Techniques for Probability Assignments; and (IV) Short Term Technical Assistance.

Sincerely,

Robert M. Cranwell

Robert M. Cranwell, Supervisor
Waste Management Systems
Division 6431

RMC:6431:jm

Enclosure

Copy to:
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A-1165 PDR

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PROGRAM:	Licensing-methodology Assistance	FIN#:	A-1165 Task I
CONTRACTOR:	Sandia National Laboratories	BUDGET PERIOD:	10/84-9/85
NMSS PROGRAM MANAGER:	L. A. Peeters	BUDGET AMOUNT:	$150K
CONTRACT PROGRAM MANAGER:	R. M. Cranwell	FTS PHONE:	844-8368
PRINCIPAL INVESTIGATORS:	R. L. Hunter	FTS PHONE:	846-6337

PROJECT OBJECTIVES

To assist in the overall development and integration of the licensing assessment methodology.

ACTIVITIES DURING DECEMBER 1984

We have prepared a draft summary of the Golder Associates' Final Report on engineered barriers (attached). It is our conclusion that the report makes little or no contribution to the overall licensing assessment methodology.

PROGRAM:	Monitor/Review Aspects of DOE & other National and International Waste Management Programs	FIN#:	A-1165 Task II
CONTRACTOR:	Sandia National Laboratories	BUDGET PERIOD:	10/84-9/85
NMSS PROGRAM MANAGER:	L. A. Peeters	BUDGET AMOUNT:	$86K
CONTRACT PROGRAM MANAGER:	R. M. Cranwell	FTS PHONE:	844-8368
PRINCIPAL INVESTIGATORS:	R. L. Hunter	FTS PHONE:	846-6337

PROJECT OBJECTIVES

To monitor and review the performance assessment aspects of DOE and other national and international waste management programs.

ACTIVITIES DURING DECEMBER 1984

No activity during December. We received the EA's and began the reviews in early January.

PROGRAM:	Probability Techniques	FIN#: A-1165 Task III	
CONTRACTOR:	Sandia National Laboratories	BUDGET PERIOD:	10/84- 9/85
NMSS PROGRAM MANAGER:	L. A. Peeters	BUDGET AMOUNT:	$202K
CONTRACT PROGRAM MANAGER:	R. M. Cranwell	FTS PHONE:	844-8368
PRINCIPAL INVESTIGATORS:	R. L. Hunter	FTS PHONE:	846-6337

PROJECT OBJECTIVES

To identify techniques for assigning probabilities to geologic processes and events.

ACTIVITIES DURING DECEMBER 1984

December 21, we submitted a letter containing several recommendations for expert panelists. Not all the resumes expected from the experts contacted by telephone have been received, however. We will submit the rest of the recommendations as soon as possible. We will begin the contracting process as soon as NRC chooses the panelists.

PROGRAM:	Short-Term Technical Assistance	FIN#:	A-1165 Task IV
CONTRACTOR:	Sandia National Laboratories	BUDGET PERIOD:	10/84-9/85
NMSS PROGRAM MANAGER:	L. A. Peeters	BUDGET AMOUNT:	$50K
CONTRACT PROGRAM MANAGER:	R. M. Cranwell	FTS PHONE:	844-8368
PRINCIPAL INVESTIGATORS:	R. L. Hunter	FTS PHONE:	846-6337

PROJECT OBJECTIVES

To monitor and review the performance assessment aspects of DOE and other national and international waste management programs.

ACTIVITIES DURING DECEMBER 1984

No activity.

SNLA

DRAFT SUMMARY

813-1180 NUREG/CR-4026

PERFORMANCE OF ENGINEERED BARRIERS IN DEEP GEOLOGIC REPOSITORIES FOR HIGH LEVEL NUCLEAR WASTE (HLW): SUMMARY AND RECOMMENDATIONS

FINAL REPORT (TASK 5)

SEPTEMBER 1984

add fig 3-1 3-2 10-4

D. L. Pentz
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Golder Associates Inc.

In Association With:

The Analytic Sciences Corporation
Science Applications Inc.

Prepared for
U.S. Nuclear Regulatory Commission
Under Contract NRC-02-81-027

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1.0 INTRODUCTION

This report, the culmination of two years of study, considers engineered-barrier performance in a deep geologic repository for high-level nuclear wastes.

1.1 PROJECT OBJECTIVE

This project was initiated to evaluate the relative performance of engineered barriers within a mined geologic repository. Specific objectives of the project are:

1. To conduct a critical review of selected alternative engineered-barrier systems.

2. To develop parts of an evaluation methodology that may be used by NRC in their ongoing review of the Department of Energy (DOE) design effort on engineered barriers.

3. To provide recommendations on the next steps in developing defensible predictions on the performance of engineered barriers in nuclear waste repositories.

1.2 PROJECT OVERVIEW

This project has resulted in a number of reports. Examination of the following situations has been included in the various studies:

- The performance of engineered barriers in a basalt repository, with waste emplacement in short vertical boreholes.

- The performance of engineered barriers in a basalt repository, with waste emplacement in long horizontal boreholes.

- The function of shaft seals in a basalt repository.

- The performance of engineered barriers in a bedded salt repository, with waste emplacement in short vertical boreholes.

- The approach to performance analysis of engineered barriers in a tuff repository, located either above (unsaturated) or below (saturated) the water table.

The analyses undertaken under the terms of this contract have specifically excluded evaluations of the acceptability of overall repository performance at any particular site with respect to the draft EPA criteria, though the methodologies that might be used to predict performance with respect to EPA criteria have been considered. Further, this project has not attempted to comprehensively evaluate the acceptability of engineered-barrier performance with respect to NRC criteria.

1.3 TASK APPROACH

The approach used in this task has been to examine the applications of performance analysis (i.e., the calculation methodology needed to compare against a standard) as well as the manner in which the data is described and analyzed. The uncertainties associated with the input elements and output predictions are analyzed, and finally recommendations for engineered-barrier performance objectives and ongoing design activities are provided.

move up text

2.1.3 Engineered-Barrier System

The engineered-barrier system means the underground facility and the waste packages.

2.1.5 Underground Facility

Underground facility means the underground structure, including openings and backfill materials, but excluding shafts, boreholes, and their seals. Note that the underground facility is bounded by the extent of the underground excavation. Sealed shafts and sealed boreholes are a part of the geologic repository operations area but are not part of the underground facility. Note also that the underground facility excludes the disturbed zone.

2.1.6 Waste Package

Waste package means the waste form and any containers, shielding, packing, or other absorbent materials immediately surrounding an individual waste container. Note that by this definition, if package backfill materials are considered to be part of the waste package, then the waste package can be in contact with the geologic setting. In this project, the waste package has been defined to exclude such backfills, and include only the waste canister and the waste form contained within; i.e., that which is transported from the surface to the position of placement and which may be subsequently retrieved if necessary and removed as a unit from the repository.

3.0 PERFORMANCE ELEMENTS

3.1 METHODOLOGY AND MODELS

The methodology which is used to predict long-term performance involves the simulation of radionuclide movement out of waste packages and towards the accessible environment. This simulation has slightly different elements for fully saturated and unsaturated repositories, as shown in Figure 3-1.

For a repository which is located in a saturated horizon, this performance approach has several implicit assumptions.

First, it is assumed that resaturation is necessary before the waste package may be breached, before nuclides can be released from the waste form, and before nuclides can be transported away from the waste form. In some environments, it may be demonstrated that the waste package is breached (e.g., crushing failure due to rock pressure) before resaturation is complete. Second, it is assumed that the waste form is not in direct contact with the geologic setting, and thus transport must occur through the engineered-barrier system prior to transporting through the geologic setting. Finally, it is assumed, if nuclides reach the accessible environment, that transport will have occurred through the saturated portion of the geologic setting rather than through any overlying unsaturated portion of the geologic setting.

While situations can be hypothesized for which these assumptions are not valid, these assumptions have been considered reasonable and demonstrable for the disposal systems examined in this project. If packages are predicted to be mechanically crushed prior to resaturation, then the first two assumptions are invalidated, and an alternate performance approach must be used. If mechanical crushing does occur, waste form release by dissolution and/or leaching can begin immediately following resaturation. Such a scenario would require predictions of the exposed surface area of the waste form, the size distribution and physical dispersion of the waste form, and the extent to which individual nuclides, either because of chemical mobility or physical state, may have moved into the engineered-barrier system or geologic setting. The balance of the performance analysis would basically remain the same as for the corrosive-breach of the waste container.

The differences between the saturated- and the unsaturated-performance approaches reflect the lack of understanding of the performance phenomena associated with the unsaturated repository. For example, the extent to which partial or periodic resaturation must take place in order for the waste package to be breached, and for the release and transport of radionuclides to the accessible environment to occur is not currently known. Further, it is not known whether radionuclides, if released from the package, would move to the accessible environment either directly through the unsaturated portion of the geologic setting or through the saturated portion before being released, and also the extent to which this is a site-specific issue. Because the mechanisms of performance in an unsaturated repository are poorly understood, the performance approach shown in Figure 3-1 is more general than for the saturated repository and thus has no significant implied assumptions.

While the performance approach depicted in Figure 3-1 suggests a single model for each step, in fact many individual, coupled numerical simulation models are required. This is shown in Figure 3-2 for the saturated repository simulation, in which the required major simulation models are identified. Each of the simulation models shown in Figure 3-2 may also require a number of submodels to evaluate the performance measure, as well as a significant amount of input data. In order to assess the performance of a repository system, either an explicit model for each of the listed items would be required, or else some simplification must be made in the performance assessment which allows calculational steps to be neglected or easily approximated.

3.3 PERFORMANCE PREDICTIONS

Predictions of repository performance may be expressed in many different forms. Four performance objectives are specified in current Federal Regulations. These four objectives are the waste package lifetime, the flux of radionuclides out of the engineered system, the flux of radionuclides out of the undisturbed geologic setting, and the prewaste emplacement travel time of groundwater through the undisturbed geologic setting. Considering only the flux of radionuclides out of the engineered system, for example, the performance of a repository at any time is expressed as:

$$q_i = \text{function (external processes, external events, input parameters, geologic time).}$$

Each of the input variables (including external events), except time, can be described in a probabilistic format.

The relationship requires that external events, and the consequences of those events, are explicitly and quantitatively defined. Repository performance will be calculated for each set of external events, where a set is either of an individual event occurring, or a combination of the probabilities or more than one event occurring at a particular time. Additionally, repository performance would be calculated for the case of no external events.

4.0 PERFORMANCE REQUIREMENTS

The NRC final technical rules (NRC, 1983) and the EPA draft standard (EPA, 1982) establish four quantitative long-term performance standards. These are for the waste package lifetime, radionuclide flux out of the engineered-barrier system and prewaste emplacement groundwater travel from the disturbed zone to the accessible environment for the NRC, and radionuclide flux into the accessible environment for the EPA.

4.1 NUCLEAR REGULATORY COMMISSION

4.1.2 Waste Package Lifetime

NRC establishes, in Section 113 of 10CFR60, minimum performance standards for waste packages in a repository, as follows:

> Containment of HLW within the waste packages will be substantially complete for a period to be determined by the Commission taking into account [overall performance factors], provided that such period shall not be less than 300 years nor more than 1000 years after permanent closure of the geologic repository.

This requirement is not intended to significantly influence long-term performance, and obviously would not influence the long-term performance of a system designed to perform for periods of up to 100,000 years. This requirement is instead intended to assure containment not only of short-life radionuclides but also all radionuclides during the period in which the temperature in the engineered-barrier system is at its peak.

A number of key technical details not specified in this requirement concern the calculation of waste package performance and demonstration of compliance with the standard. These are discussed below.

- Substantially Complete Containment--The release of radionuclides is a continuum. Radionuclides contained within the waste form will diffuse or "seek" to move from the location of high concentration (the waste form) towards a position of lower concentration (i.e., towards the accessible environment). Before water comes into contact with the waste form, solid diffusion will be the predominant transport mechanism for nuclides which are in solid form (which for the purposes of this discussion are the only nuclides considered, neglecting the potential for gaseous nuclides which will exist in a significant fraction in spent fuel). Groundwater, supplemented by heat, radiation, and any other deleterious conditions present, will lead to the eventual breach of the waste container or package, allowing a path for water flow to the waste form. If the waste form is spent fuel, the fuel cladding contains, after several hundred years, very low concentrations of activated structural elements (principally nickel, zirconium, and niobium isotopes) and very low concentrations of fission products and transuranics. The fuel cladding must subsequently be breached before "significant" concentrations of radionuclides are exposed to water. Subsequently, radionuclides will begin to move more rapidly away from the waste package, through diffusion in the solute if no flow exists, or carried in solution if flow does exist. Once outside of the waste container, radionuclides may still be inside of the "package" because the NRC defines the package to include "the waste form and any containers, shielding, packing, and other absorbent materials immediately surrounding an individual waste container." The "waste package" may then include, for example, sorbing clays (such as sodium bentonite) which might be placed around the waste container. Thus, before radionuclides are no longer "contained" within such a "waste package," the nuclides must be transported through the sorbing material, during which radionuclides may travel at a speed equal to a fraction (i.e., the retention coefficient) of the groundwater speed; this retention coefficient will be a function of temperature and many other factors for each chemical form and condition of each element. This describes one specific performance "continuum" for each of the waste packages within a repository.

"Containment" could then be defined by the licensee as (1) when any radionuclides leave the external boundary of the waste package (including the sorbing material if present); (2) when any radionuclides pass through the waste container; or (3) when the waste container provides a pathway for any radionuclide transport, regardless of whether any radionuclides are transported. "Substantially complete containment" could imply either that all packages may fail, but only release a small, acceptable fraction of the radionuclide inventory, or that a very small fraction of containers could release large fractions of their inventory while the large majority of packages provide complete containment. Demonstrating compliance with the requirement has four obvious degrees of freedom:

1. The number of packages failing to provide containment.

2. The magnitude of the release from waste packages.

3. The uncertainties associated with the predictions.

4. The time at which containment is lost and the times at which releases occur.

Whichever definition is used, the term "substantially" will need to be defined in quantitative terms (e.g., what percentage of the total inventory of a package, or of the total packages in a repository is "substantial"). It is presently understood by the NRC that DOE will propose a definition of "substantially complete" and assert how it is incorporated into the system analysis.

- <u>Uncertainties of Predicted Performance</u>--No philosophy is provided by the standard as to acceptability of various methods of dealing with uncertainty (or indeed on the precise formulation and use of the performance calculation).

- <u>Supporting Experimentation</u>--The requirement for testing to validate performance parameters is related to conventional engineering requirements, such as a component reliability or material durability standards. The engineering community has established, in many cases, certification programs through which compliance with such standards may be demonstrated. However, in nearly all of these cases, the period during which the component or material has been developed and tested is nearly equal to, or in some cases longer than, the designed performance period. For example, the steel sections used as reactor vessels are derived from materials and configurations used for many years in nonradioactive boilers and pressure vessels. The introduction of radiation as a part of the operating environment required some periods of material testing and evolution. With a service life of 40 years, the time during which testing and certification proceeded, plus the historical application of such materials to similar but nonradioactive environments, suggested that an extrapolation to the 40-year service life could be justified. However, the required service life of a waste package may be up to 1000 years. There is a limited engineering experience base (in terms of time) from which to draw. If a repository is to be operational within the time frame required by the Nuclear Waste Policy Act, then the testing and certification period for waste packages is quite limited in proportion to the potential service life requirements. Thus, a proposal must be developed for demonstrating the acceptable performance of waste packages.

- Other than HLW--The NRC specifies the waste package performance for HLW, which is considered to include both spent fuel and solidified high-level wastes from reprocessing. However, radioactive wastes other than HLW are currently in the DOE planning base for disposal in a repository (Best and others, 1983). Thus, a proposal for waste package service life will be required for these other waste types.

4.1.3 Engineered-Barrier System

The NRC establishes requirements for the performance of the engineered-barrier system in Section 113 of 10CFR60, as follows:

> The release rate of any radionuclide from the engineered-barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the Commission, provided that the requirement does not apply to any radionuclide which is released at a rate less than 0.1% of the calculated total release rate limit. The calculated total release rate limit shall be taken to be one part in 100,000 per year of the inventory of radioactive waste originally emplaced in the underground facility, that remains after 1000 years of radioactive decay.

Given this definition, a minimum inventory level can be established, which is equal to 10^{-5} of the total 1000-year curie inventory. Thus, one measure of the barrier-system performance period for a given radionuclide is that period at the end of which the inventory is permanently less than the de minimis value. For example, if a simple engineered-barrier system contains one MTHM of spent fuel and at 1000 years the radionuclide content is 100 curies per MTHM, then the de minimis level is 0.001 curies. The time at which the inventory of each isotope becomes permanently less than this value marks the end of the period of performance for that nuclide under this standard. For those radionuclides which have a very small fission yield, or which have short half-lives, this approach is a simple method of demonstrating compliance with the standard, i.e., if at the end of the containment period of 300 to 1000 years, the total inventory of an isotope is less than the de minimis level, and the inventory of that nuclide will always remain below the de minimis level, then compliance with the containment requirement assures compliance with the barrier system requirement. However, for the nuclides which exceed the de minimis inventory at the end of the containment period, or which will exceed the de minimis inventory at some later decay period (applicable to some daughter products of the actinides) a positive demonstration of compliance with this standard is required for each nuclide.

The NRC's requirement for performance of the engineered-barrier system does not presume a particular design concept, nor a concept of site-specific performance. For certain design concepts and definitions, the waste package is in direct contact with the geologic setting. These designs include vertical waste package emplacement in the floor of a drift, or emplacement in horizontal boreholes which extend into the wall of a drift(s), and in which the backfill surrounding the waste container is considered to be part of the waste package and thus is not part of the engineered-barrier system. Depending upon the characteristics of the geologic setting, the predominant direction of radionuclide movement may be directly from the waste package into the geologic setting, thus requiring that the waste package performance meet this standard.

A number of performance variables must be defined prior to the evaluation of system performance against this standard. These include:

- Uncertainties of Predicted Performance--As discussed previously in this report, the performance of the disposal system is inherently uncertain. This standard is expressed in discrete terms, however. Thus, the uncertainty associated with the performance models themselves must also be considered and then defined to determine acceptability.

- Supporting Experimentation--While a mathematical projection of system performance may apparently indicate compliance, any projection is an extrapolation of a very limited period of observation to a very long time into the future, and there may be uncertainties in understanding performance models. Clearly there is a pressing need to define the scope of field tests and the time frame in which they should be conducted, since these will be essential to defend the minimum level of data acquisition of all system components prior to a license application.

- Future Processes and Events--The NRC rule states that the engineered system standard is only applicable to anticipated processes and events. This implies that the engineered system must be capable of performing under all conditions or processes which have operated or are continuing to operate during the Quaternary period. This study has only considered a limited set of unfavorable scenarios which may fall into this class. In a license application it would seem necessary to specify and support the probability of each of the anticipated processes and events.

4.4 REFERENCES

R. E. Best, J. W. Voss, and C. Brooks, "Repository Planning - What Wastes Will Be Received," Proceedings of the American Nuclear Society, November 1983. Available in public technical libraries.

U.S. Environmental Protection Agency, Code of Federal Regulations 40, Part 191, "Environmental Standards and Federal Radiation Protection Guidance for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," U.S. Gov't Printing Office, 1982. Available in public technical libraries.

U.S. Nuclear Regulatory Commission, Code of Federal Regulations 10, Part 60, "Disposal of High Level Radioactive Wastes in Geologic Repositories," U.S. Gov't Printing Office, 1983. Available in public technical libraries.

5.0 CURRENT UNDERSTANDING OF REPOSITORY PERFORMANCE

Considerable effort has been dedicated by the DOE to the development of engineered barriers which would be used to initially isolate radionuclides from the geologic setting, and also to control their release to the geologic setting over very long time periods. Other tasks in this project have examined methods by which the effectiveness of engineered barriers might be determined, and reviewed their present state of development. Studies that have considered hypothetical designs in basalt, bedded salt, and tuff, and detailed discussions are contained in Golder 1983a, 1984, and 1983b.

The results of these studies are not conclusive, since major uncertainties are inherent in both input data and in the numerical modeling of the physical and chemical processes, and because engineered-barrier performance can only be measured within the overall context of total repository performance which includes the geologic setting. At the time these studies were completed, the data necessary to defensibly define the repository system was either only partially available or did not exist.

The studies completed in this work were undertaken to evaluate the relative performance of engineered-barrier systems in mined repositories. The conceptual design of the reference repositories included several components: the design and layout of the mined rooms, shafts, and interconnecting tunnels; the design of the waste packages (canisters); and the design of engineered-barrier systems to protect the canisters and prevent or retard radionuclide escape. It is the engineered-barrier components upon which the studies have focused.

The performance assessment of the engineered-barrier system included analyses of baseline repository conditions and alternative release scenarios by which radionuclides were transported to the accessible environment. In attempting to formulate plausible repository release scenarios, there has been a tendency to concentrate on groundwater flow as being the most likely means by which radionuclide transport to the accessible environment would occur. Thus in all cases, in order to construct plausible models, it has been necessary to conceptualize groundwater flow regimes, geological conditions (present and future), repository layouts, and engineered-barrier materials. The approach has therefore been to postulate credible base environmental conditions for each site which are held fixed, the variables in the model then being the engineered-barrier material properties. In attempting to bound the problems, possible failure situations have been hypothesized. Conceptual models have been formulated on both repository and emplacement room scales, but as mentioned earlier, the scarcity of adequate data has imposed severe limitations upon the extent to which the uncertainties in the physical and chemical processes involved in nuclide release can be defensibly quantified within useful bounds.

5.1.2 Uncertainties in Modeling

Assessment of engineered system performance requires conceptual and numerical models which will faithfully reproduce the known physical laws, such as fluid flow, with a quantifiable degree of certainty.

The major sources of uncertainty may be identified as:

1. Uncertainty in the data from which model parameters are derived.

2. Uncertainties introduced by the lack of understanding of the physical and chemical processes and phenomena controlling performance.

3. Uncertainty in modeling the physical processes, including constitutive relationships, and also in numerical solution techniques.

4. Uncertainty in the hypothesized radionuclide release mechanisms, including the analysis of external events.

The uncertainty in radionuclide release mechanisms is also associated with the (conditional) probability of a given failure sequence actually occurring.

Sources of uncertainties have been discussed in detail in preceding reports (Golder, 1983a, 1983b, 1984) and apply equally to all the site studies (salt, basalt, tuff) so far performed. Uncertainty analyses have been performed and are discussed in the above-referenced reports.

It is our opinion that the overall matter of uncertainty must be addressed preferably before the formal site licensing process is begun. First, defensible methods must be developed by which uncertainty in data and uncertainties in the computational models may be quantified. Acceptable levels of uncertainty in predicted repository performance must be established. Finally, the uncertainties must be assessed and reduced, if necessary, by improving the data base.

5.2 BASALT DISPOSAL SYSTEM

5.2.1 <u>Disposal Concept</u>

The disposal concept proposed by DOE involves repository siting and development in the Pasco Basin basalt flows at the Hanford site. DOE has not established their reference repository design, but is currently considering both horizontal and vertical waste emplacement schemes in a single level repository at a depth of approximately 3500 feet. The vertical emplacement scheme involves a series of boreholes in the floor of mined drifts. Waste packages would be emplaced in the boreholes and backfilled with various alternate materials, including sorbing clays or crushed run-of-mine rock. A single waste package would be emplaced in each borehole. The horizontal concept involves the boring of long holes (300 to 500 feet) between two drifts. A number of waste packages would be emplaced in each hole. The boreholes would be backfilled with alternative materials, including a sorbing clay or crushed aggregate. In both emplacement schemes, the storage rooms may be backfilled with either crushed rock or other engineered backfill.

The effect of site conditions on engineered-barrier performance was considered by evaluating the flow field and potential release of radionuclides for:

- The undisturbed geology at the reference site (base case).

- A fault close to the repository, extending from the repository horizon to the deepest interflow-interbed zone in the Saddle Mountains unit.

- Increased vertical hydraulic conductivity of all dense basalt units except the Umtanum, to evaluate uncertainties in the assumed postclosure hydrologic data.

- A failed shaft backfill and/or seal.

For subsequent calculations of release from the engineered system, a waste package life of 1000 years was assumed. Analyses have shown that package backfill can effectively contribute to engineered system performance by (1) delaying the initial contact of water to the waste package, and (2) by reducing the rate at which radionuclides are released from the waste package. The former is attained through isolation with clays and through corrosion control. The latter is attained primarily through low radionuclide solubilities and by maximizing sorption in the engineered system.

Emphasis in the development of engineered barriers has been given to using backfill materials to impede groundwater flow through the repository, since package corrosion and water transport are seen as the most likely means of nuclide escape. Therefore, materials such as bentonite and zeolites have received a great deal of attention as potential backfilling materials for emplacement rooms. Room scale backfills contribute most effectively to overall system performance if the residence time of contaminated water, and thus nuclides, is maximized <u>within the backfill</u>. This is achieved by (1) maximizing the backfill porosity and radionuclide retardation coefficient, (2) ensuring that the backfill hydraulic conductivity is high relative to the basalt, and (3) locating the waste package so that flow of contaminated water through the room backfill is achieved. In view of this, the use of relatively impervious backfill materials and the emplacement system design should be carefully evaluated to assure that the system minimizes the radionuclide release rate to the geologic setting to achieve compliance with the NRC criteria.

The predicted releases to the geologic setting were not significantly affected by the alternative geologic scenarios for the ranges of data considered, from which it is concluded that the overall performance of a given site is unlikely to be significantly improved by the engineered-barrier systems currently being considered. For a scenario in which shaft failure was evaluated, the study concluded generally that the overall performance of the repository was not significantly affected due to (1) the localized influence of the shaft(s) on the total flow through the repository, and (2) the possibility that retention time in the shaft backfill would, in fact, increase the travel time to accessible environment (see Golder 1983a, Section 3.8, for a discussion of this scenario).

5.3 SALT DISPOSAL SYSTEM

5.3.1 Disposal Concept

The salt disposal concept involves the emplacement of waste packages into either a bedded salt deposit or a salt dispir or dome.

The repository design concept currently most favored for salt involves the emplacement of single waste packages into vertical boreholes in a single level repository at a depth of approximately 2500 feet. Package and room backfills which are being considered include crushed salt as well as sorptive or impervious clays. Salt is currently favored as a backfill because, with time, the emplaced salt will reconsolidate to a material condition which resembles the virgin condition.

The geologic conditions evaluated (Golder, 1984) were assumed to fall into two categories: (1) in which the geology remained undisturbed, and (2) in which a situation arose which threatened the integrity of the repository. Porous flow through salt is considered not to occur, however, and movement of fluids through intact salt occurs by diffusion. In the second case flow may be postulated due to breaching of the repository, for example by drilling, shaft seal failure, dissolutioning, seismic events, etc.

Each of the models discussed in Section 5.2.2 for basalt are also necessary for a salt repository performance assessment. Additionally, to evaluate repository design and its effect on the site, models to determine creep deformation of the host salt and reconsolidation of the backfill are needed. The studies reported (Golder, 1984) did not incorporate these latter models because of the very limited data base, and assumptions on ranges of data representative of postclosure conditions were therefore used.

Following resaturation, the waste package, which was assumed to be structurally designed to withstand the crushing forces of salt, was determined to corrode and fail over time periods up to 20,000 years.

Crushed salt as an engineered barrier, together with the host geology, results in acceptable repository performance, as measured by possible releases to the accessible environment. Further, this analysis shows that there is little reason for the development of more sophisticated engineered barriers than crushed salt.

Another calculation of engineered-barrier performance was made for a potentially unfavorable scenario. This assumed that a complete flow circuit developed from the upper aquifer through failed shaft seals, and through a failed borehole seal, a new borehole, or a fault. Release of these nuclides would still meet the EPA integrated release standard.

5.4 TUFF DISPOSAL SYSTEM

5.4.1 Disposal Concept

The tuff disposal system location is currently proposed in the unsaturated (vadose) zone in Yucca Mountain at the Nevada Test Site. The engineering for the tuff repository was in its very early stage at the time this work was undertaken. Currently both horizontal and vertical waste emplacement schemes are under consideration. Backfills being considered include run-of-mine rock and sorptive clays. Specific and final selection of backfills cannot be made until a better understanding of repository performance is achieved, such that performance requirements of the engineered-barrier system can be established.

5.5 REFERENCES

Golder Associates, "Evaluation of Engineered Barriers Design and Performance in an Underground Basalt Repository." Draft Vols. I, II, and III, prepared for the Nuclear Regulatory Commission under Contract NRC-02-81-027, February 1983a. Available from the NRC PDR.

Golder Associates, "Evaluation of Engineered Barriers Design for a High-Level Nuclear Waste Repository in Tuff," Draft, prepared for the Nuclear Regulatory Commission under Contract NRC-02-81-027, November 1983b. Available from the NRC PDR.

Golder Associates, "Engineered Barriers Systems Design for a High-Level Nuclear Waste Repository in Deep Basalts," Draft, prepared for the Nuclear Regulatory Commission under Contract NRC-02-81-027, June 1983c. Available from the NRC PDR.

Golder Associates, "Evaluation of Engineered Barriers Design and Performance in a High-Level Nuclear Waste Repository in Bedded Salt," Draft, prepared for the Nuclear Regulatory Commission under Contract NRC-20-81-027, January 1984. Available from the NRC PDR.

6.2 MULTIBARRIER SYSTEM

The NRC Rule contains many direct and indirect provisions for multibarrier disposal systems, where the barriers are (1) the waste package, (2) the waste form, (3) the room backfill, and (4) the geologic setting. The engineered-barrier system, comprising the first three barriers, can contribute to isolation in two ways, as stated by the NRC (NRC 1982):

> ... first by controlling the release rate of radioactive materials to the geologic setting, thereby reducing the contribution which the geologic setting must make, and second, by providing a source of isolation which is relatively independent of the geologic setting and which can therefore mitigate the consequence of unforeseen failure of that setting.

6.2.1 Role of Multiple Barriers

The relationship between transport of radionuclides in the engineered-barriers system (and release from the engineered system) and in the geologic setting is complex. The sensitivity of the performance of a barrier to an unanticipated process or event may be different for the waste package, for repository backfill, and for the geologic setting. For example, events such as major faulting or microseismic swarms may have little effect on the regional groundwater flow regime, but cause a significant increase in flow through the engineered system such that processes such as corrosion or waste from leaching and radionuclide solutioning are accelerated. Again, processes such as the accelerated advance of a solution front, or major uplift, may substantially change the regional flow regime, but have little effect on flow through the engineered system and radionuclide release rate.

To evaluate such processes and events, and to limit the consequences of their occurrence, it would be necessary to:

1. Determine the processes and events to be considered.

2. Identify conceptual and mathematical models.

3. Determine data on event or process likelihood of occurrence, magnitude, rate, and effect.

4. Determine the impact on the repository system.

5. Set performance objectives for subcomponents of the repository system that compensate for the effects of the unanticipated processes and events considered.

This approach implies redundancy, or a degree of conservatism, in the design of engineered barriers and the determination of performance objectives. Without this redundancy, the concept of "defense-in-depth," implying the existence of backup safety systems, may not be appropriate to a repository and its long-term performance because there are no sequential systems to "turn on" as a result of various external conditions occurring. In fact, failure of one component, such as groundwater flow through the site, may under some conditions tend to accelerate release from the engineered system because of the dependent nature of performance.

A second role of multiple barriers is defined as compensating for uncertainties in other barrier systems. Again, this process can only be achieved by setting performance objectives which contribute to the overall system performance in a quantified way. Clearly, there are several methods of predicting the performance of a barrier component and assessing the uncertainties associated with that prediction. As stated earlier, the engineered system and the site are not independent, and uncertainties in the site may have to be included, either implicitly, or explicitly, in the performance assessment of the engineered system.

These synergistic effects may be considered either indirectly, using simple models, or directly using coupled-effects models. In setting performance objectives for components of the engineered and site systems, it is important to understand the degree of dependence (or independence) between the systems, and the relative sensitivity of those objectives to the various parameters.

An approach to analyzing multiple barrier performance interactions is discussed below.

6.2.2 Multiple Barrier Performance Interaction

Multibarrier disposal systems can influence both predicted performance and also the uncertainty of the overall predicted performance and subcomponent performance. Clearly, there are several ways of making a performance assessment; one of these is by the explicit use of probability density functions (pdf's) to define the uncertainties associated with the value of performance parameters. Other ways are possible.

Using pdf's, the performance of components within barrier systems can be determined; for alternative design concepts, a different mean value and distribution may be determined. Similarly, considering unanticipated processes or events, changes in the local environment at the repository would also influence the mean value and distribution of component performance. The integration of component performance, considering all potentialities, then leads to a prediction of system performance.

To review the implication of this process, assume for simplicity that the repository performance model can be specified in terms of two time-dependent transfer functions. The functions reflect time-dependent performance (either rate or flux) of the engineered-barrier system and the geologic setting. As discussed earlier, neither transfer function is independent of the other.

Considering first the transfer function of the geologic setting G(t), this function has a characteristic shape for a specific site and for a specific level of characterization. Thus, assuming a source of radionuclides transported from the engineered-barrier system which has a single, time-dependent mean value, E(t), then the shape of the distribution G(t) representing the geologic setting may be as shown in Figure 6-4a. If E(t) has a characteristic pdf, as shown in Figure 6-4b, then the distribution G(t) may be as shown in Figure 6-4a. The corresponding calculations of overall performance, R(t) are also shown in Figure 6-4a.

Consideration of these functions and their mathematical relationship leads to the following possible conclusions:

- For a given site and a given level of characterization which establishes a set of pdf's, or the "uncertainty" of the geologic setting, the engineered-barrier system can reduce the mean value of overall performance, but regardless of its performance cannot reduce the "uncertainty" of overall repository performance, R(t), except by mitigating the consequences of significant but uncertain scenarios.

- For a given site, expenditures of money or investments of time can conceivably improve repository performance, R(t). The first is to "buy" an improved engineered-barrier system, which, as stated above, generally does not diminish the "pdf," but can reduce the mean performance. The second is to "buy" a higher degree of site characterization, which may or may not improve the mean value of performance, but presumably will diminish the "pdf."

- The combined impact of improved E(t) and G(t) on predicted performance is illustrated in Figure 6-7 in terms of cumulative distribution function, or the probability that repository performance will be better than some value. For example, the change in probability that the EPA standard will be met as either or both E(t) and G(t) are improved has been illustrated.

- The primary means of reducing both the mean performance $\overline{R(t)}$ and the uncertainty in R(t) is to select a site which has the "best" performance characteristics (relative to others being considered) and which are less variable, more easily characterized, and thus has a characteristic G(t) which already has a narrow "pdf."

- For a given site, expenditures to improve the site characteristic G(t) (i.e., to characterize the site) will reduce the uncertainty, σ_R, while expenditures to improve E(t) (i.e., to improve the engineered system) will improve mean performance, R(t). The absolute values of such investment decisions may be less significant to the NRC than to the DOE (for making decisions) but cannot be ignored by the NRC.

7.0 TECHNICAL RECOMMENDATIONS

7.1 DEFINE ACCEPTABLE PERFORMANCE

Each measure of performance (waste package lifetime, groundwater travel time, transport in engineered barriers, and transport in geologic setting) has many more degrees of freedom than are constrained or defined by the regulatory specifications. These include consideration of the probabilistic nature of repository performance and the treatment of future processes and events in performance calculations. Therefore, it is recommended that the NRC establish as early as possible precisely the basis on which it intends to interpret the requirements contained in 10CFR60, and the methods by which acceptable performance can be demonstrated. In the absence of stating such rationale a priori, NRC must establish the rationale by which it will judge the acceptability of a license application by the DOE.

7.2 DEMONSTRATION OF COMPLIANCE

The performance data sets at any of the alternative potential sites are presently poorly defined in the sense of having sufficient measured data sets to defend the corresponding probability distributions or conceptual models, i.e., the defense must rely at this stage on subjective expert opinion.

It is essential that the DOE establish the relevant performance parameters, the environmental ranges of significance, and finally obtain sufficient quantities of relevant individual data points for each parameter such that defensible assessments of performance can be made.

Inherent in this is the necessity of assuring the quality and validity of this data. This includes the dictate that defensible experiments and field measurements be performed, that the results of these experiments be treated in a statistically proper manner, and that extrapolations and interpolations be made only when necessary, but are at all times fully disclosed. Additionally, defensible models of performance phenomena must be constructed and verified.

It is recommended that the NRC establish a regulatory position directed toward ensuring that a satisfactory and defensible data base is available to defend performance projections.

7.3 DESIGN FOR COMPLIANCE

In examining the current DOE approach to selecting engineered barriers, repository designs and sites, and to obtaining site data, it is not always evident what their design rationale and objectives are based on. It is recommended that the DOE structure its decision hierarchy in every programmatic decision to ensure that performance objectives are attained. While this report has principally dealt with long-term performance, clearly, all elements of performance must be included in this decision process.

This recommendation requires that a clear understanding of each sites' performance be developed to support the decision-making process. The key is to ensure that all elements of performance of the engineered system are considered, including the interrelation of the engineered system with the geologic settings.

The adoption of a decision-making methodology using performance as a decision priority will contribute to (1) the acquisition of the necessary data, and (2) selection of designs and sites which have superior performance. Ultimately, these actions will contribute to attaining technical consensus on the performance defensibility of repository performance projections.

A-1165, Task I
1183.010
December 1984

THIS IS AN ESTIMATE ONLY AND MAY NOT MATCH THE INVOICES SENT TO NRC BY SANDIA'S ACCOUNTING DEPARTMENT.

	Month	Current Year-to-Date
I. Direct Manpower (man-months of charged effort)	1.0	1.7
II. Direct Loaded Labor Costs	8.0	16.0
Materials and Services	0.0	0.0
ADP Support (computer)	0.0	0.0
Subcontracts	0.0	4.0
Travel	0.0	0.0
Other	0.0	0.0
TOTAL COSTS	8.0	20.0

Other = rounding approximation by computer

III. Funding Status

Prior FY Carryover	FY85 Projected Funding Level	FY85 Funds Received to Date	FY85 Funding Balance Needed
None	150K	150K	None

A-1165, Task II
1183.020
December 1984

THIS IS AN ESTIMATE ONLY AND MAY NOT MATCH THE INVOICES SENT TO NRC BY SANDIA'S ACCOUNTING DEPARTMENT.

		Month	Current Year-to-Date
I.	Direct Manpower (man-months of charged effort)	0.2	0.5
II.	Direct Loaded Labor Costs	2.0	6.0
	Materials and Services	0.0	0.0
	ADP Support (computer)	0.0	0.0
	Subcontracts	1.0	2.0
	Travel	0.0	0.0
	Other	0.0	0.0
	TOTAL COSTS	3.0	8.0

Other = rounding approximation by computer

III. Funding Status

Prior FY Carryover	FY85 Projected Funding Level	FY85 Funds Received to Date	FY85 Funding Balance Needed
36K	86K	50K	None

A-1165, Task III
1183.030
December 1984

THIS IS AN ESTIMATE ONLY AND MAY NOT MATCH THE INVOICES SENT TO NRC BY SANDIA'S ACCOUNTING DEPARTMENT.

	Month	Current Year-to-Date
I. Direct Manpower (man-months of charged effort)	0.7	0.9
II. Direct Loaded Labor Costs	6.0	9.0
Materials and Services	0.0	0.0
ADP Support (computer)	0.0	0.0
Subcontracts	0.0	0.0
Travel	1.0	1.0
Other	0.0	0.0
TOTAL COSTS	7.0	10.0

Other = rounding approximation by computer

III. Funding Status

Prior FY Carryover	FY85 Projected Funding Level	FY85 Funds Received to Date	FY85 Funding Balance Needed
52K	202K	150K	None

A-1165, Task IV
1183.040
December 1984

THIS IS AN ESTIMATE ONLY AND MAY NOT MATCH THE INVOICES SENT TO NRC BY SANDIA'S ACCOUNTING DEPARTMENT.

	Month	Current Year-to-Date
I. Direct Manpower (man-months of charged effort)	0.1	0.1
II. Direct Loaded Labor Costs	1.0	1.0
Materials and Services	0.0	0.0
ADP Support (computer)	0.0	0.0
Subcontracts	0.0	-1.0
Travel	0.0	0.0
Other	0.0	-1.0
TOTAL COSTS	1.0	-1.0

Other = rounding approximation by computer

III. Funding Status

Prior FY Carryover	FY85 Projected Funding Level	FY85 Funds Received to Date	FY85 Funding Balance Needed
None	50K	50K	None

A-1165

TOTAL FOR 1183.010, 1183.020, 1183.030, and 1183.040

December 1984

THIS IS AN ESTIMATE ONLY AND MAY NOT MATCH THE INVOICES SENT TO NRC BY SANDIA'S ACCOUNTING DEPARTMENT.

	Month	Current Year-to-Date
I. Direct Manpower (man-months of charged effort)	2.0	3.2
II. Direct Loaded Labor Costs	17.0	32.0
Materials and Services	0.0	0.0
ADP Support (computer)	0.0	0.0
Subcontracts	1.0	5.0
Travel	1.0	1.0
Other	0.0	-1.0
TOTAL COSTS	19.0	37.0

Other = rounding approximation by computer

III. Funding Status

Prior FY Carryover	FY85 Projected Funding Level	FY85 Funds Received to Date	FY85 Funding Balance Needed
88K	488K	400K	None