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MEMORANDUM FOR: Hubert J. Miller, Chief
Repository Projects Branch
Division of Waste Management

FROM: John T. Greeves, Acting Chief
Engineering Branch
Division of Waste Management

SUBJECT: CONTRACT NO. NRC-02-81-027 ENTITLED "PERFORMANCE OF ENGINEERED BARRIERS IN A GEOLOGIC REPOSITORY"

As requested by memorandum from C. L. Pittiglio (WMRP) dated November 30, 1983 we have reviewed the draft Task 4 report from the subject contract. The report is entitled "Evaluation of Engineered Barrier Designs and Performance for a High-Level Nuclear Waste Repository in Tuff."

We have one general comment which involves a number of definitive statements, found throughout the report, which address both hydrologic phenomena and performance. These statements should be critically reviewed by the Geotechnical Branch and a decision made as to the appropriateness of NRC making such conclusive judgements at this early stage in the site characterization process.

In addition, a number of specific comments are provided on attached 'marked-up' pages. Some examples of the above noted definitive statements are included. Please contact T. L. Seamans, WMEG, if you have any questions regarding these comments.

E. A. Wick for

John T. Greeves, Acting Chief
Engineering Branch
Division of Waste Management

Enclosure: As stated

cc: C. L. Pittiglio, WMRP

OFC	WMEG	WMEG	WMEG			
NAME	TLSeamans:lcs	MSNataraja	JTGreeves			
DATE	12/23/83	12/28/83	12/28/83			

1.0 INTRODUCTION

This report presents technical analyses of the portion of Task 4 of Nuclear Regulatory Commission Contract NRC-02-81-027 which considers a saturated and unsaturated repository in tuff at Yucca Mountain in the Nevada Test Site. This work has been performed by Golder Associates, Inc., with the assistance of The Analytic Sciences Applications, Inc. The U.S. Nuclear Regulatory Commission (NRC) has initiated this study to examine methodologies for evaluating the relative significance of individual engineered components of a mined geologic repository for high-level radioactive waste. This introductory section presents the objectives of the project, the approach and overview of the project, and a statement of scope and organization of this report.

1.1 PROJECT OBJECTIVE

This project was initiated to evaluate the relative performance of engineered barriers within a mined geologic repository, in terms of providing isolation of radionuclides within a waste package and the controlled release of radionuclides to the acessible environment. Specific objectives of the project are:

(1) to conduct a critical review of the selected alternative engineered barrier systems.

(2) to develop parts of a performance evaluation methodology which may be used by NRC in their ongoing review of the Department of Energy (DOE) design effort on engineered barriers.

(3) to recommend guidelines for the design and construction requirements, and performance verification of engineered barriers which could be used in regulatory guidance supporting NRC's rulemaking effort.

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GENERALIZED PERFORMANCE ASSESSMENT METHODOLOGY

Figure 2-1

HOW ABOUT CANISTER CRUSHING / SHEARING DUE TO UNSTABLE EMPLACEMENT HOLE ?

	WASTE PACKAGE BREACH →	NUCLIDE RELEASE FROM WASTE FORM →	NUCLIDE TRANSPORT IN ENGINEERED SYSTEMS →	NUCLIDE TRANSPORT IN GEOLOGIC SETTING
SATURATED REPOSITORY	RESATURATION AND CORROSION	LEACHING LIMITED BY NUCLIDE SOLUBILITY	SORPTIVE TRANSPORT	SORPTIVE TRANSPORT
UNSATURATED REPOSITORY	CORROSION BY CYCLIC RESATURATION AND SUBSEQUENT CORROSION, MECHANICAL DEGRADATION, OR CORROSION WITHOUT RESATURATION	LEACHING DURING CYCLIC RESATURATION; LEACHING IN PARTIAL SATURATION	SORPTIVE TRANSPORT DURING CYCLIC RESATURATION OR IN PARTIAL SATURATION	SORPTIVE TRANSPORT DURING CYCLIC RESATURATION OR IN PARTIAL SATURATION

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2.0 METHODOLOGY

In order to assess the performance of engineered barriers in a repository an understanding of the hydrologic conditions is required. The approach to performance assessment will clearly differ if the repository is in the saturated or unsaturated zone. The performance methodology, however, can be generalized into several similar major processes with only details varying for each medium and set of conditions as shown in Figure 2-1, and discussed below.

Four processes must be simulated to calculate repository performance. The first of these is <u>waste package breach</u>. In the saturated zone, the most likely means of this occurring is by saturation of the closed repository and subsequent corrosion of the waste package. Alternatively, mechanical degradation of the package by crushing is possible, but this likelihood should be prevented or minimized through careful design. In the unsaturated zone, again corrosion is viewed as the most likely potential means of breaching a package. However, saturation as for a repository in the saturated zone, will not occur unless the water table rises above the repository horizon. It is possible that a cyclic saturating and draining may occur, however, due to climatic changes that influence the water balance of the basin. If this occurs, presumably corrosion would occur during these periods. Even if saturation does not occur, there is both liquid and vapor phase water present in the unsaturated zone and corrosion can occur in such an environment albeit slowly. Mathematically, modeling these liquid and vapor phase corrosion processes will require an understanding of the site specific hydrology, Chemical environment an understanding of corrosion under variably saturated conditions, and an understanding of how heat and radiation effect the kinetics of both processes.

The second process is nuclide release from the waste form. For a saturated repository, this process is simulated as leaching, which is fundamentally a process of corrosion and solid diffusion, at a maximum rate limited by

At first glance, groundwater travel time to the hypothesized distant (20-100 km) discharge points are long because hydraulic conductivities and gradients are low, and Carbon-14 dating of water emerging at Ash Meadows implies an average groundwater residence time of over 10,000 years (Grove et al, 1969; Winograd and Pearson, 1976). However, even the approximate path that wastes would traverse between the repository and discharge point is unknown and this path is certain to traverse almost exclusively fractured media. Effective porosity of fractured materials is typically low; thus, groundwater travel times can be surprisingly short under such circumstances. Estimates of groundwater travel time to the 10 km accessible environment measuring point range from 10^2 to 10^5 years (Dove et al, 1982).

3.3.3 Effectiveness of Engineered Barriers in Saturated Zone

As the local flow field in the tuff repository is assumed currently to be very similar to that of the basalt repository (vertical flow field in fractured media) similar barriers to those suggested for basalt would be effective (see Golder 1983a for discussion of basalt). That is, if waste can be located upgradient from excavated cavities, then backfilling with high hydraulic conductivity (relative to the host), high porosity material will promote flow through the backfill which can be designed to yield low interstitial velocities and high sorption. Not clear

If horizontal flow through storage rooms is found to be significant, then the need for tunnel seals must be considered. Tunnel seals would act to reduce the flow rate in the permeable room backfill. Whether or not this is beneficial is dependent on the design and site conditions. As previously noted, groundwater velocities in the porous backfill are much lower than in the fractured host rock. Flow through long tunnels of porous backfill can be beneficial. If room seals divert flow into the host rock then they could
*1 prove to be counterproductive.

Bullfrog unit and the surrounding hydrologic environment, it is likely water ingress will range from 10^{-1} to 10^{2} m^3/yr per square meter of excavation in plan view of the repository (roughly 10^1 to 10^4 GPM for for the entire repository depending on the design). Such volumes would not present a problem to repository operations. If the repository is backfilled with material of higher conductivity than the host rock, the time required for the repository to refill with water ranges from months to as long as 50 years. Such a time frame is insignificant to the period of waste containment. Backfilling the repository with a tight clay could increase the time required to flood the repository by at most two orders of magnitude. However, even five thousand years is short with respect to long term containment requirements.

3.3.2 Flow to the Accessible Environment and Discharge Points

Once the repository is saturated, it is expected the system will repressurize rapidly and the flow regime will revert to the general configuration of the pre-repository regime with minor perturbations caused by the repository excavation and subsequent backfilling (if carried out) and, during the first 10,000 - 20,000 years of performance, with modified gradients resulting from the thermal loading. As the magnitude of the assumed downward vertical gradient is unknown, it is not currently possible to predict if an upward gradient will prevail as a result of thermal loading or if the downward gradient will remain at lesser magnitude. Regardless of the magnitude of the thermal effect on the gradient, the flow direction is expected to be predominantly vertical because aquitards are characterized by vertical flow and this character would be accentuated by the assumed prevalence of continuous vertical fractures.

Once waste is released from the repository, if upward movement does occur, it will be temporary and it is possible that the flow regime will return to the initial configuration before waste is discharged. Such a scenario would increase the transit time.

BETTER DEFINE THE PHENOMENA INVOLVED HERE, ESPECIALLY THAT CAUSING VERTICAL FLOW APART FROM THE THERMAL LOADING.

repository without contacting the waste package, over the years, enough water may contact the package to cause ultimate failure. Also, such water could carry waste exposed by other potential modes of package failure. Alternatively, if some event (possibly a climatic change) caused the repository to become inundated (an unlikely but possible scenario) the waste packages would be immediately saturated.

The above considerations suggest a layered backfill design which takes advantage of fine and coarse grained materials. A three layer design is suggested: fine grained, coarse grained, fine grained (Figure 3-2). A fine grained material adjacent to the host rock takes on water but the water cannot enter the next coarse grained layer because capillary pressures prevent this and no fractures exist in the fine grained layer to allow entry, as was the problem with having coarse material near the host rock. Hence, the intermediate coarse layer keeps the waste package dry. The central fine layer slows water contact in the event of inundation.

Such a complex fill design could not be constructed with high quality assurance in horizontal emplacement holes. In-room emplacement has typically been ruled out elsewhere for operational safety and retrievability matters. Procedures can be defined to surmount the problem of in-room emplacement. However, in-room placement offers no performance related benefit when compared with vertical hole emplacement. Therefore, in-room and horizontal emplacement are not discussed.

WHAT IS THE AFFECT ON THIS STUDY OF NOT CONSIDERING HORIZ EMPLACEMENT? BOTH BWIP AND NTS ARE CONSIDERING HORIZ. EMPLACEMENT IN THEIR DESIGNS.

One problem with such a layered design is that usually clays and gravels are used for fill material and the multilayer design may result in unacceptably high temperatures. The solution to this is to use high thermal conductivity material. Possibly a relatively inexpensive and abundant metal like copper or iron formed into appropriate grain sizes. These could also be meshed into annular cylinders for ease of emplacement. The inner fine grained layer should be clay since its purpose is to impede water entry in a saturated environment.

LBL DID EXPERIMENTS WHERE 1 PHASE OF A 2 PHASE SYSTEM MOVED TOWARD THE REPOSITORY

ALSO - HOW ABOUT CONVECTION CELLS

Ck w/ HYDRO PEOPLE.

3.4.5 Effects of Thermal Loading

If the repository is designed to maintain temperatures below about 125°C near the waste package, then chemical alteration of the tuff (which likely causes decreased strength and sorption potential) should not be a problem and the waste package can easily be designed to withstand such temperatures. Then, during the thermal period (first 10,000 plus years) the heat will provide two hydrologic benefits. First, moisture flows from areas of high temperature to areas of low temperatures in the unsaturated zone. Therefore, as long as the temperature in the repository is significantly higher than the surrounding rock, unsaturated flow will be in the direction away from the repository. Secondly, water that will be present in the repository will probably exist in a vapor phase due to the high temperature and low pressure. Water movement in the vapor phase cannot transport nuclides.

Not correct.

Tritium + C-14 and some ionic elements will escape.

3.5 HYDROGEOLOGIC SUMMARY

Quantitative estimates of time and level of nuclide release from a repository at the NTS is not possible because there is not enough information to determine the nature of the flow regime. Qualitative discussion of repositories located in the saturated and unsaturated zone of Yucca Mountain suggest groundwater travel time from the two repositories may be quite similar but the level of nuclide release from the unsaturated zone repository would be relatively lower due to the reduced water flux past the waste. A repository located in unfractured, unsaturated tuff would exhibit substantially longer travel times to the phreatic zone than a repository in fractured unsaturated tuff. However, conditions expected to prevail at the Yucca Mountain site are more closely modeled by fractured unsaturated conditions.

Effective engineered barriers in a saturated tuff repository are similar to those suggested in basalt with rooms backfilled with high hydraulic conductivity, high porosity, sorping material placed down gradient of the waste. Effective barriers in an unsaturated tuff repository are those designed to

Because of the difficult topography at Yucca Mountain, it is possible that some of the facilities may not be located at the repository entry, but may be sited some distance away, though within the Nevada Test Site. In particular, the waste receiving and spent fuel packaging facilities might be so located. It is also possible that major facilities at the repository entries may be located at the base of Yucca Mountain, and not on top of it.

4.3 ENTRIES

The unique topography of Yucca Mountain may not lend itself to the development of vertical shafts from the top of Yucca Mountain. Thus, it is possible that sloped entries or inclines from the surface or base of Yucca Mountain into the repository horizon may serve as the major access routes.

It is also likely that at least one entry will be a vertical shaft from Yucca Mountain. The precise number of entries is a design variable which has not been resolved. Recent repository conceptual designs have had 4, 5 and 6 shafts, depending on waste receipts, ventilation philosophy and material handling.

4.4 UNDERGROUND DEVELOPMENT

The underground development at the repository horizon will be a function of the geology the structural characteristics of the target host rock, and the design philosophy, particularly as it relates to waste package placement. At present, DOE is exploring both horizontal and vertical waste emplacement schemes (Scully and Rothman, 1982). DOE appears to favor a horizontal emplacement shceme in which a 4-foot diameter horizontal waste emplacemen hole is drilled 600 to 700-feet long off of secondary subsurface entries (Scully and Rothman, 1982; Peters, 1983). This design scheme reduces tuff extraction for repository development, in contrast to more traditional vertical emplacement schemes.

No discussion of all the construction related rock damage, support system (rock bolt or concrete lining) - and interaction of waste package with liner if used.

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A likely engineered barrier design strategy is to avoid surrounding waste forms with materials which have high tendency to attract moisture such as finely divided solids (small pore-size, therefore, high capillary potential). These will cause moisture to migrate toward waste forms rather than aid in the exclusion of water. Provision for drainage in the repository may be a practical approach to keeping the waste package dry in the vadose zone during the operational period at least.

5.1.2 Creep Deformation

The strain characteristics for tuff, based on limited data, show a possible plastic component indicating that some time-dependent deformation will result (Golder Associates, 1983b).

The creep characteristic could be important to package life. The protection of the waste form from crushing is a significant issue in salt but could also be important for tuff. The waste package is a primary component of the barrier system which functions to delay or prevent water intrusion and to delay or prevent migration of radionuclide to the environment. Thus, an important goal for the waste form and associated package it to provide defense against crushing due to rock deformation by creep. It should be noted this phenomena is distinct from displacement along faults as a reusit of seismic activity.

5.1.3 Backfill Degradation

Selction procedures should lead to designs including backfills which will not be susceptiple to processes which might significantly alter the desirable properties of the backfill. If a backfill is used because of an unique property, such as high sorption or swelling properties, but subsequently looses such properties through diogenesis then clearly its effectiveness is lost. At issue are the undefined hydrothermal conditions which influence the diogenesis of backfills.

Horizontal flow in the repository horizon is not likely unless induced flow by capillary action results from high capillary potential materials as discussed above. Vertical flow induced by heat, infiltration or water table rise is a more realistic scenario. Barriers to horizontal flow may not be needed in a repository located in unsaturated tuff.

6.0 WASTE PACKAGE PERFORMANCE

The hydrogeology, geochemistry and hydrochemistry of the repository environment, and the response of that environment to engineered materials, heat and radiation will influence repository performance in the vicinity of the waste package. These fundamental system data, combined in a comprehensive engineered system performance model will allow the calculation of waste package life, nuclide release from the waste package, and nuclide transport in the vicinity of the package.

As previously discussed in Section 3, there is considerable current uncertainty surrounding the data and model of hydrogeology of the fractured unsaturated tuff horizons. More is known about the hydrogeology of tuff below the phreatic surface. Also, there is currently very little data describing the geochemistry and hydrochemistry of the unsaturated tuff horizon. The use of the limited hydrochemical and geochemical data which has been measured for the purpose of calculating radionculde transport is quite uncertain, partially due to system complexity and variability, as well as to problems of scale (Gillham and Cherry, 1982).

~~It~~ If data were available, defensible hydrogeologic models existed for an unsaturated tuff horizon, the calculation of near-field performance would be done in three steps. Initially, waste package lifetime would be calculated. A waste package model which incorporated corrosion as well as possible crushing forces would calculate a predicted waste package breach time. This calculation is, of course, closely linked to the hydrogeologic model. Corrosion is expected to be much slower and possibly non-existent in the unsaturated zone due to the minimal or nil flux of water. The second performance phase would predict nuclide release from the waste forms. Geochemical, hydrochemical and hydrgeologic data would again serve to describe the release environment, along with the respone of that environment to repository conditions. The result of this modeling phase would be a nuclide flux from the waste form as a function of time. Again this flux is expected to be low in the unsaturated zone where

WE SHOULD NOT MAKE STATEMENTS LIKE THIS. THIS IS FOR DOE TO TELL US.

7.1.2 Assessment of Transport in the Geologic Setting

Far-field waste transport, at present, is as uncertain as waste transport in the engineered system. Estimates of groundwater travel times to the accessible environment (10 km away from the repository) range from 10^2 to 10^5 years (Dove, et al., 1982). Because of the strong sorption properties of the zeolitized tuff, many radionuclides can be expected to reach the accessible environment only at times much greater than 10,000 years. Nuclides which may reach the accessible environment in significant quantities at earlier times are long-lived, weakly sorbed, high solubility nuclides. These would probably include Tc-99, I-129, and C-14.

The effect of retardation in tuff could be significantly enhanced as a result of matrix diffusion. Matrix diffusion is migration of solute into the surrounding porous rock during transport through rock fractures. Neretnieks has shown that this process could be very significant in retarding transport in granite (Neretnieks, 1979). However, no field data has yet been produced to validate this concept in any hard rock media. One would nevertheless hypothesize this process to be important in tuff, due to its relatively high matrix porosity.

7.1.3 Conclusions and Summary of Important Issues in the Saturated Zone

Based on the available data it appears that backfill barriers are likely to be an important part of the engineered barrier system in saturated tuff. A good waste package backfill would be a low hydraulic conductivity, non-smectite clay. An adequate room backfill would appear to be the crushed tuff from the excavation process. The need for tunnel seals within the repository is uncertain. By analogy to the results for basalt, such tunnel seals appear to be unnecessary if no detrimental to performance. However, this conclusion is dependent upon assumed repository flow scenarios. Scenarios involving horizontal flow in repository tunnels followed by transport to the accessible environment have not been analyzed in tuff. Flow scenarios are, however,

8.0 CONCLUSIONS AND RECOMMENDATIONS

The effectiveness of engineered barriers in a repository must be measured by their contribution to overall repository performance requirements. At present, these requirements include:

- o nuclide transport to the accessible environment (Draft EPA,1982)
- o waste package life (NRC,1983)
- o nuclide transport from the engineered system to the geologic setting (NRC, 1983)

Demonstration of the effectiveness and necessity of engineered barriers requires defensible models of:

- o waste package lifetime
- o nuclide release from waste form
- o nuclide transport through engineered system (including package and room backfills, if present)
- o nuclide transport through geologic setting

Construction of these defensible models, in turn, requires a fundamental understanding of the hydrogeology, geochemistry and hydrochemistry, as well as of the response of these to man-induced environmental changes in the repository, including heat, radiation, repository construction, and engineered materials.

At present, the data and models necessary to evaluate engineered barrier performance in an unsaturated tuff repository do not currently exist.

As a result, a defensible and conclusive statement on barrier and repository performance cannot be made at this time. Current indications are that the partially saturated repository environment currently favored by DOE may offer significant performance advantages when compared to a saturated repository environment. It is cautioned, however, that such speculations are based on a desirable but currently indefensible hydrogeologic models.