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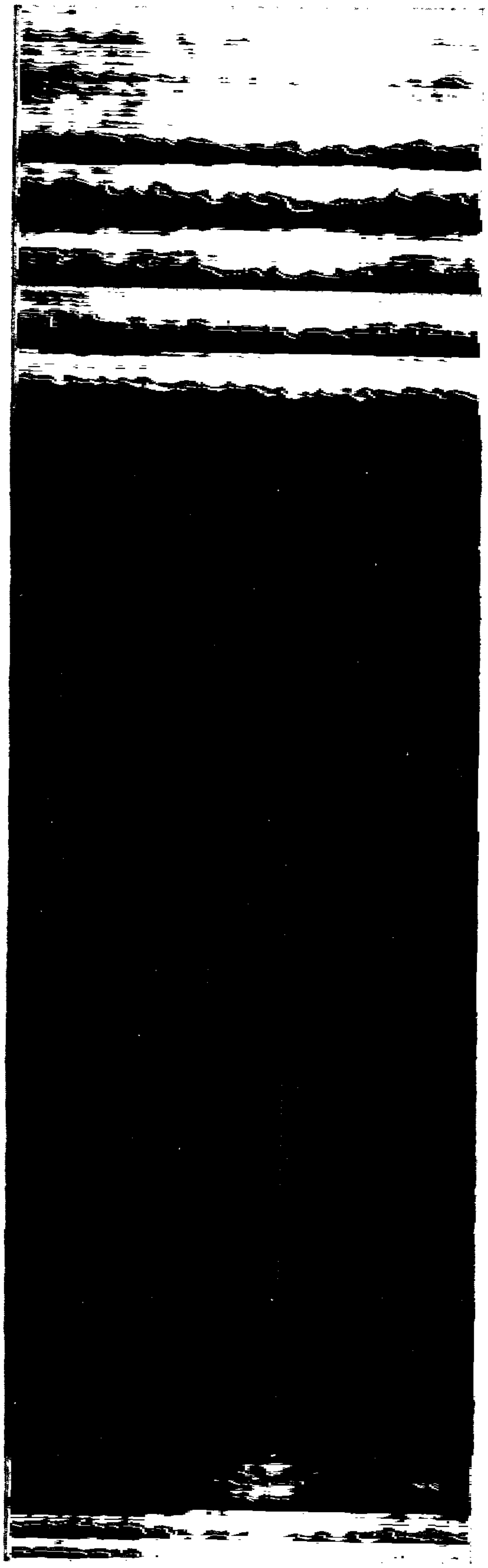

Nevada Nuclear Waste Storage Investigations Exploratory Shaft Facility Fluids and Materials Evaluation

Los Alamos

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The computer codes used in the generation of data for this report have not been verified or validated in accordance with the requirements of NUREG-0856 and the Los Alamos National Laboratory procedure for computer software documentation. Data could be subject to revision upon completion of the verification and validation process.

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by

Karen A. West

ABSTRACT

The objective of this study was to determine if any fluids or materials used in the Exploratory Shaft Facility (ESF) of Yucca Mountain will make the mountain unsuitable for future construction of a nuclear waste repository. Yucca Mountain, an area on and adjacent to the Nevada Test Site in southern Nevada, USA, is a candidate site for permanent disposal of high-level radioactive waste from commercial nuclear power and defense nuclear activities.

To properly characterize Yucca Mountain, it will be necessary to construct an underground test facility, in which *in situ* site characterization tests can be conducted. The candidate repository horizon at Yucca Mountain, however, could potentially be compromised by fluids and materials used in the site characterization tests. To minimize this possibility, Los Alamos National Laboratory was directed to evaluate the kinds of fluids and materials that will be used and their potential impacts on the site. A secondary objective was to identify fluids and materials, if any, that should be prohibited from, or controlled in, the underground.

The methodology used in this study consisted of (1) collecting data on fluids and materials that will be used in the ESF, (2) developing a decision tree analysis to screen the fluids and materials for deleterious interactions, (3) evaluating potential changes to groundwater chemistry, (4) evaluating effects of microorganisms, and (5) reviewing transport analyses of the fluids and materials to the waste packages. Fluids and materials were analyzed by type (inorganic, organic, metal), physical form (solid, liquid, gas), solubility/miscibility, reactivity with rock, quantity, time of use, location of use, and loss to the environment.

Based on the information currently available, the conclusion of this study is that the use of fluids and materials during construction and testing of the ESF will not have a significant impact on the site characterization data or on the ability of the site to isolate nuclear waste from the environment. However, in the vicinity of selected site characterization tests, the use of water will have to be controlled to minimize adverse hydrological effects. Also, the use of hydrocarbons and solvents underground should be minimized. As the start of ESF construction and testing approaches, the inventory of fluids and materials will become more definitive. At that time, a more quantitative analysis of the subject should be conducted to ensure that assumptions used in this report are still valid.

1.0 INTRODUCTION

Yucca Mountain, an area on and adjacent to the Nevada Test Site (NTS) in southern Nevada, is a candidate site for construction of a mined geologic disposal system (MGDS) for the permanent disposal of high-level radioactive waste (HLW) from commercial power and defense nuclear activities. To determine its suitability as an MGDS, investigators must first obtain conclusive site data. The Nuclear Waste Policy Act of 1982 directs that this task be accomplished by a combination of surface and underground investigations.[1] The Act also requires construction of an Exploratory Shaft Facility (ESF) to facilitate underground investigations by providing access for *in situ* testing, which is believed essential to achieving the objectives of the site characterization phase. These activities are the responsibility of the Nevada Nuclear Waste Storage Investigations (NNWSI) Project, which is managed by the Waste Management Project Office (WMPO). The candidate repository location and test data could potentially be compromised, however, by materials used to construct the ESF. To minimize this possibility, Los Alamos National Laboratory (LANL) was directed to evaluate the fluids and materials proposed for use in the ESF and their potential impacts on the site.

Unsaturated rock of the Topopah Spring Member of the Paintbrush Tuff, a rhyolite formation that underlies Yucca Mountain, is the preferred formation to host the underground facilities of the repository [Fig. 1; also shown in Fig. 1 is the conceptualized flow regime used by the US Geological Survey (USGS) to illustrate suspected groundwater flow paths]. Underground facilities are expected to occupy about 1850 acres, at a depth of approximately 1315 ft (400 m).

A system of multiple barriers, both natural and engineered, are planned to contain, within the repository boundary, the radionuclide components of any HLW. Natural barriers consist of the existing geologic, hydrologic, and geothermal features of the site. These features constitute the primary barriers to mid- and long-term (1000- to 10,000-yr and greater than 10,000-yr) movement of radionuclides to the accessible environment. The engineered barriers will be composed of the waste form, container, borehole liner, packing, and the adjacent (or near-field) host rock, or some combination thereof. Collectively, the engineered barriers would limit any groundwater circulation around the waste packages and impede the subsequent short-term (300- to 1000-yr) transport of radionuclides from the repository to the environment. Identification and characterization of the natural barriers and development of the engineered barriers are objectives of the current phase of the NNWSI Project.

Located in the northeast portion of the candidate repository site at Yucca Mountain, the ESF would occupy only a small fraction of the total repository area (Fig. 2). An enlargement of the ESF portion is given in Fig. 3. The ESF consists primarily of (1) the main exploratory shaft (ES-1), which will provide a primary scientific test bed for site characterization testing, will transport people, materials, and equipment from the surface to the subsurface test area, and will provide additional ventilation capacity to the long exploratory drifts; (2) a secondary exploratory shaft (ES-2), which will be used for ventilation, materials handling, and emergency egress; (3) an underground dedicated testing area; and (4) long exploratory drifts.[2] As currently planned, ES-1 will

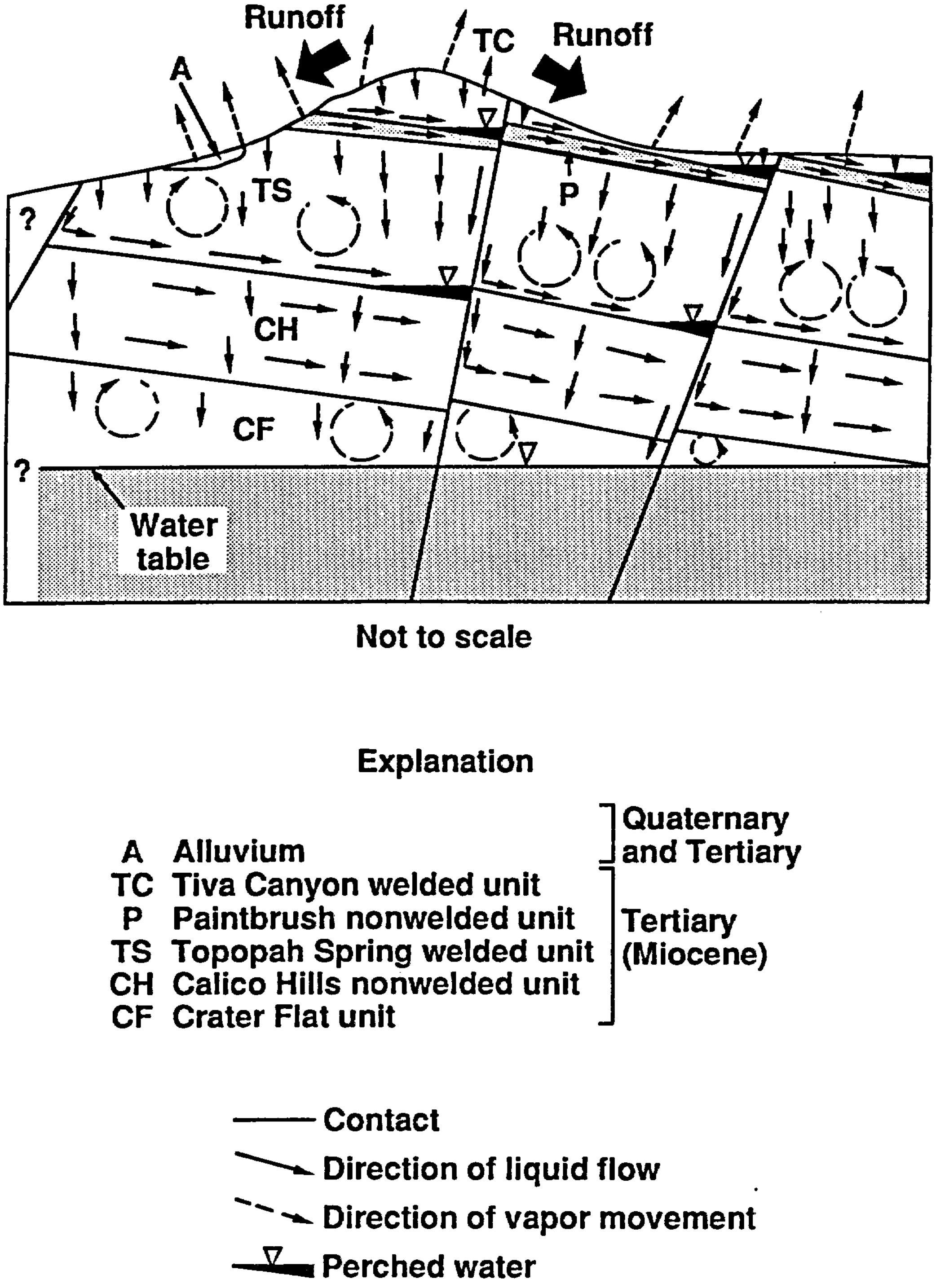


Fig. 1. Generalized cross section of Yucca Mountain showing conceptualized flow regime. Lengths of solid arrows show relative magnitudes of fluxes (redrawn from Montazer and Wilson, Ref. 19).

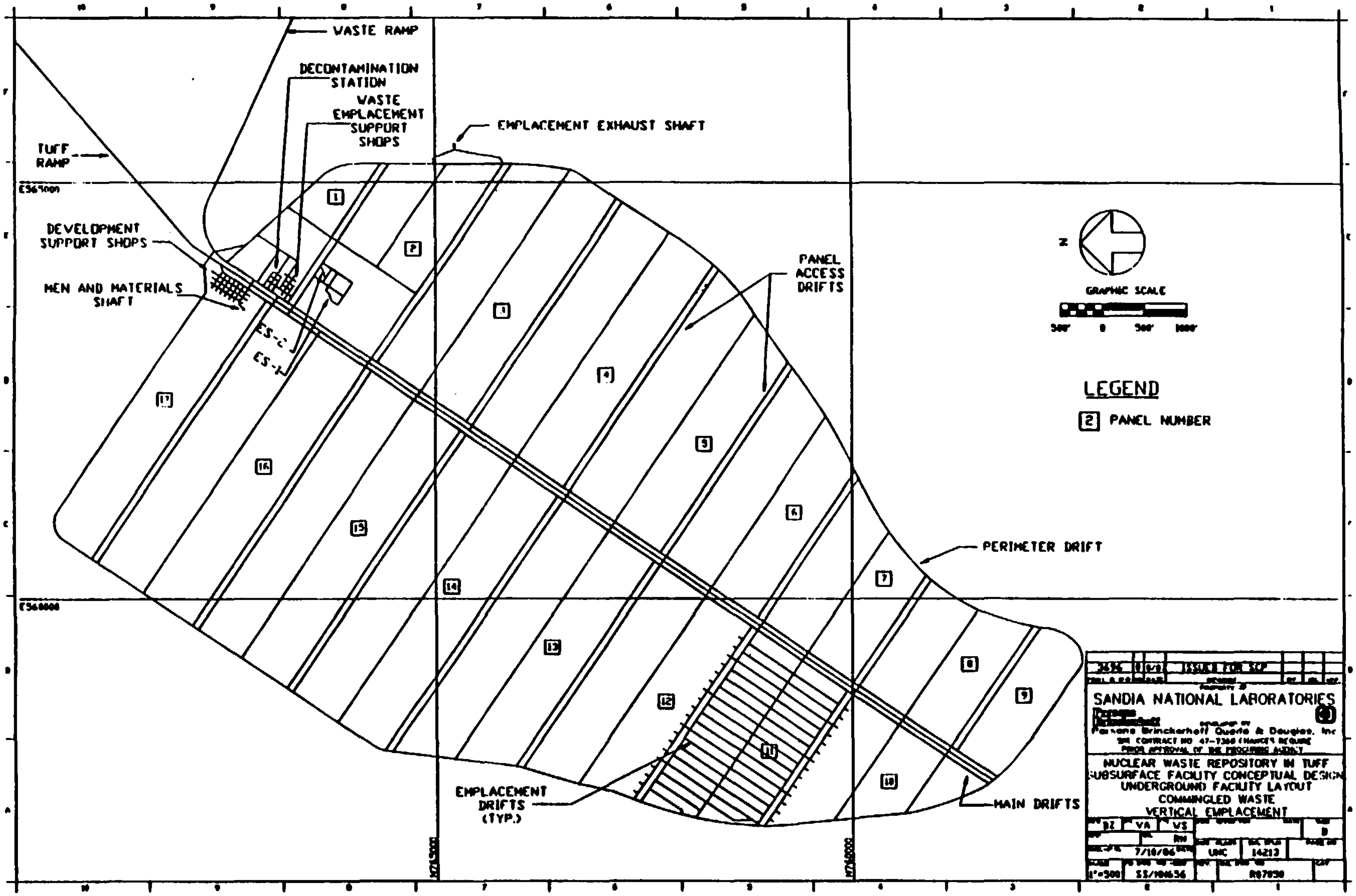
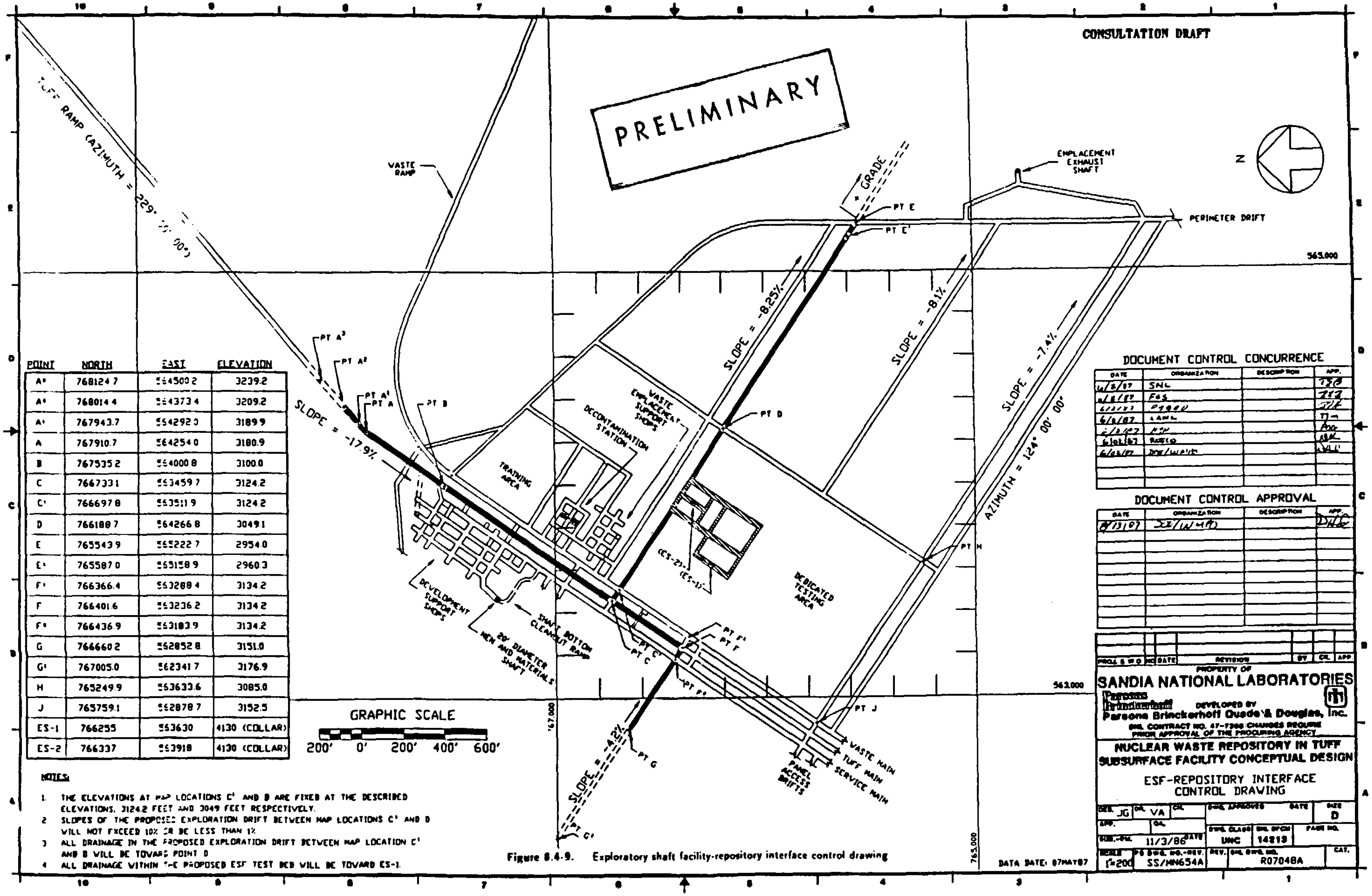


Fig. 2. Repository underground facility layout for commingled waste vertical emplacement (from the Consultation Draft of the Site Characterization Plan, Chapter 8.4).



POINT	NORTH	EAST	ELEVATION
A³	768124.7	564500.2	3239.2
A²	768014.4	564373.4	3209.2
A¹	767943.7	564292.0	3189.9
A	767910.7	564254.0	3180.9
B	767535.2	564000.8	3100.0
C	766733.1	563459.7	3124.2
C¹	766697.8	563511.9	3124.2
D	766188.7	564266.8	3049.1
E	765543.9	565222.7	2954.0
E¹	765587.0	565158.9	2960.3
F¹	766366.4	563288.4	3134.2
F	766401.6	563236.2	3134.2
F²	766436.9	563183.9	3134.2
G	766660.2	562852.8	3151.0
G¹	767005.0	562341.7	3176.9
H	765249.9	563633.6	3085.0
J	765759.1	562878.7	3152.5
ES-1	766255	563630	4130 (COLLAR)
ES-2	766337	563918	4130 (COLLAR)

NOTES:

1. THE ELEVATIONS AT MAP LOCATIONS C¹ AND D ARE FIXED AT THE DESCRIBED ELEVATIONS, 3124.2 FEET AND 3049 FEET RESPECTIVELY.
2. SLOPES OF THE PROPOSED EXPLORATION DRIFT BETWEEN MAP LOCATIONS C¹ AND D WILL NOT EXCEED 10% OR BE LESS THAN 1%
3. ALL DRAINAGE IN THE PROPOSED EXPLORATION DRIFT BETWEEN MAP LOCATION C¹ AND D WILL BE TOWARD POINT D
4. ALL DRAINAGE WITHIN THE PROPOSED ESF TEST BED WILL BE TOWARD ES-1.

Figure 8.4-9. Exploratory shaft facility-repository interface control drawing

Fig. 3. Exploratory Shaft Facility/Repository interface control drawing (from the Consultation Draft of the Site Characterization Plan, Chapter 8.4).

penetrate to the unsaturated portion of the Calico Hills formation beneath the Topopah Spring unit. ES-2 will extend only slightly beneath the proposed level of the repository in the Topopah Spring unit. The dedicated test area will be located at the repository level. As shown in Fig. 3, the ESF boundary will be physically separated from any waste emplacement panels by a minimum of approximately 100 ft (30 m) of rock, with the dedicated testing area generally separated from the panels by at least 200 ft (60 m). Long exploratory drifts will allow access to the Ghost Dance Fault and the Drill Hole Wash and Imbricate Fault zones. The ESF shafts and drifts are configured so that they can be incorporated into the design of the repository underground facilities. Isolation of the test area will prevent physical interference of the area and test activities with the underground repository facilities.

During construction of the surface facilities, shafts, and underground facilities, some millions of gallons of water will be used for drilling and dust control. Numerous other fluids such as antifreeze, hydraulic fluid, and diesel fuel, and materials such as experimental instrumentation, concrete, and other construction materials will be introduced into the host rock in varying quantities. Although these materials are essential to construction, the possibility exists that they could affect (1) site characterization data or (2) the ability of the site to isolate waste from the environment. The ESF is designed to drain any fluids that might enter the shafts or drifts toward ES-1 (see Fig. 4) and away from the emplacement areas, but this design feature alone may not prevent the possible adverse effects of these essential fluids and materials on site characterization data and on subsequent repository performance.

Failure to contain fluids or control materials may compromise results during the operating phase of the ESF. For example, saturation of the host rock with drilling fluid could result in erroneous interpretations of characterization data relevant to postclosure groundwater travel time. Transport of any one or a combination of these materials from the ESF to the proposed emplacement locations for waste packages could compromise waste package performance. Alteration of the groundwater chemistry as a result of reaction with these materials could affect waste package corrosion rates or mechanics. Host rock properties might be degraded by reactions with these fluids and materials. The Nuclear Regulatory Commission (NRC) has recognized these and other possibilities and included the following requirements in technical criteria developed for the disposal of HLW in geologic repositories.

1. "DOE has described the proposed geologic repository including but not limited to:...(iv) construction procedures which may affect the capability of the geologic repository to serve its intended function;..."[3]

2. "Materials and placement methods for seals shall be selected to reduce, to the extent practicable: (1) The potential for creating a preferential pathway for groundwater, or (2) radioactive waste migration through existing pathways."[4]

LANL, as part of its overall effort to support the NNWSI Project, undertook the specific task of evaluating materials proposed for use in the ESF in terms of

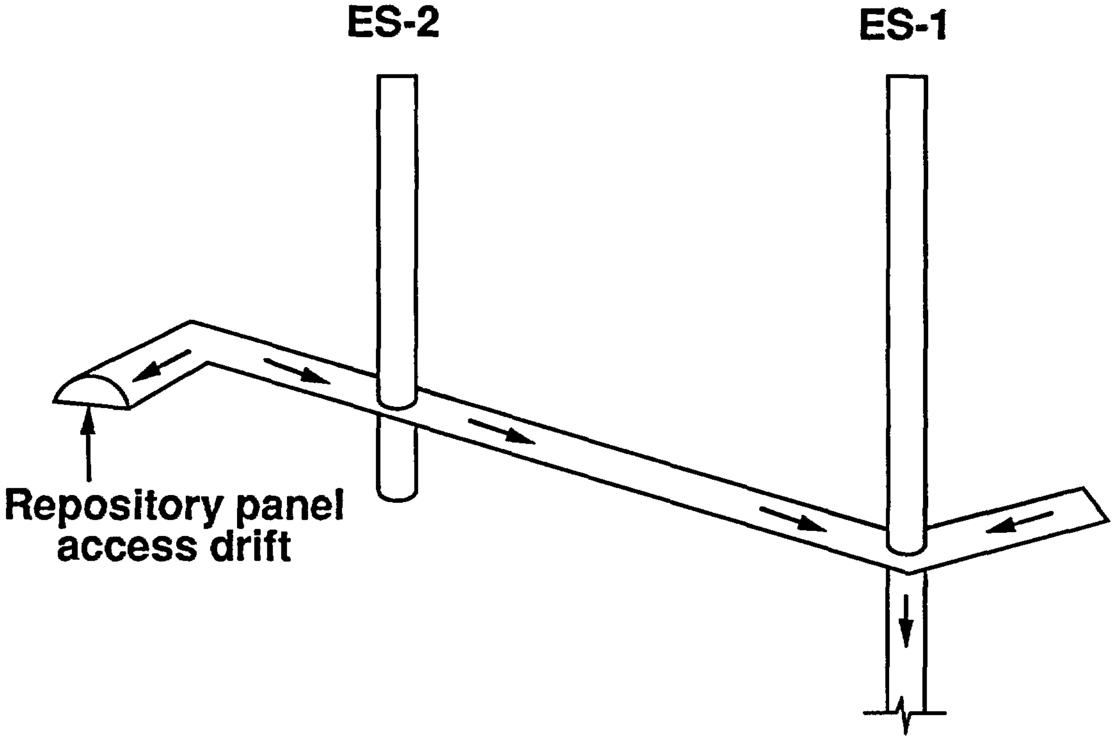


Fig. 4. Planned drainage pattern towards Exploratory Shaft 1 in the Exploratory Shaft Facility (redrawn from the Consultation Draft of the Site Characterization Plan, Chapter 8.4).

their threat to the characterization investigations and repository performance. We evaluated the use of the materials under normal operating conditions only: accident scenarios were not addressed.

The objective of the LANL task was to identify materials, fluids, and dry chemicals, hereafter referred to as materials, proposed for use in the ESF construction, operation, maintenance, and testing. A further objective was to evaluate the materials identified and assess whether the use of any should be prohibited or controlled. We sought to categorize materials as one of the following:

1. approved for use without restriction;
2. approved for use with restrictions on amounts, locations, or applications;
3. prohibited from use.

To the extent possible, substitutes were to be identified for those materials categorized as "prohibited from use."

The Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA) also regulate the use of certain hazardous materials. Materials identified as such, by their inclusion on one of the following three lists, were specifically labeled but, for the purpose of analyzing interactions, were treated just as any other material:

1. EPA List of Hazardous Substances and Reportable Quantities,[5]
2. EPA List of Extremely Hazardous Substances and Their Threshold Planning Quantities,[6]
3. OSHA-Regulated Substances.[7]

The regulations of the EPA and OSHA will govern the use, in the ESF, of any materials on these lists. Recommendations or conclusions resulting from the LANL task should not be interpreted as superseding these regulations. The results of this work are expected to be used by designers in the preparation of specifications for construction, by ESF management in the preparation of operation and maintenance procedures, and by ESF experimentalists in the preparation of test procedures.

This report describes the method used to collect the information required for evaluating the materials proposed for use in ESF construction, operation, maintenance, and testing. It documents the assumptions used concerning groundwater chemistry and rock properties and the procedure used to sort and screen materials for more intensive analysis. Finally, it summarizes the results of this analysis and those of supplementary studies that were used to support further its conclusions and recommendations.

2.0 PROCEDURE

The procedure used in this study consisted of (1) collecting data and estimates concerning the anticipated use of materials in the ESF, (2) developing a decision tree analysis to screen the materials for deleterious interactions, (3) evaluating potential changes to groundwater chemistry, (4) evaluating effects of microorganisms, and (5) analyzing fluid transport and pertinent rock properties.

2.1 Fluids and Materials Database

The evaluation of materials usage began with the collection of information about the types and quantities of materials that were expected to be used. In October 1986, with input from the Project participants and with information from the Exploratory Shaft Test Plan,[8] LANL developed the NNWSI Fluids and Materials Database, which lists materials known or proposed for use during construction of the ESF. The results of that survey, augmented with estimates from LANL personnel, are listed in Table A-I.

Detailed information about the chemical composition of each item is useful, but not absolutely necessary, when analyzing chemical reactions between specific materials. Wherever possible, the exact composition of the material was listed, but in some cases the primary interest was in reactions occurring with the contacting component. "Contacting" refers to the part of the item that is exposed to the surroundings. A specific example from the materials to be used in the ESF is a neutron probe. Because the probe is enclosed in a stainless steel case, the contacting component is stainless steel, and the specific composition of the internal components is not relevant to the discussion. So, for hardware and instrumentation, only the composition of the contacting surface was listed in Table A-I.

For the subsequent screening procedure, the materials data in Table A-I were rearranged and combined as shown in Table A-II, "NNWSI Condensed Fluids and Materials Database." The purpose of the rearrangement was to obtain the total mass of a given material for a specific time of use, location of use, and potential for recovery at the conclusion of the ES site characterization activities. The phases used for this separation (construction or *in situ*) were defined according to DOE Headquarters guidance for the SCP: "construction" encompasses activities that occur before mining the underground connection between ES-1 and ES-2, and "*in situ*" includes all activities subsequent to the construction phase.[9] These categories were further subdivided according to location of use (surface or underground) and recovery (recovered or permanent). For convenience, there is a column labeled "Item Numbers" in Table A-II. Numbers in this column correspond to the item numbers in Table A-I that have been grouped in Table A-II. The information in the column labeled "Box No." is the result of a later analysis, which is explained in Section 2.2.1. Initially, this information does not appear in Table A-II; only after completing Table A-III can this information be added to Table A-II.

For comparison of detail, the chemical inventory from the Waste Isolation Pilot Plant (WIPP) is included in Appendix A.[10] The NNWSI inventory of materials has not reached the level of detailed planning (for example, "cans of spray paint" instead of the specific brands of paint) that eventually will be needed.

2.2 Decision Tree Analysis

The number of possible combinations of materials proposed for use in the ESF (Table A-II) is in the thousands. Clearly, some way was needed to narrow the list to only those reactions that could have a significant impact on the site. Statistically, the screening problem is more than just a sampling problem because there is no representative sample. Since the reaction between each pair of materials is unique, the results of examining a small sample cannot be used to make inferences about the entire population. Statistically, then, the problem has no solution. Recognizing this, LANL needed a method of screening materials that would give the best comprehensive analysis.

To develop an approach for screening potentially deleterious reactions, LANL worked with Dan Brooks, a decision analyst from Arizona State University who specializes in decision and information systems. Brooks assisted with the development of a decision tree analysis method for evaluating the synergistic effects; based on criteria developed by Brooks and LANL, this method eliminates materials in a sieve-like manner, until only those materials of significance remain. The procedures outlined below were directed by Brooks' independent analysis of the situation. He had no preconceptions about the study, and because his services were acquired by another group at LANL, his analysis was unbiased.

LANL believes that the structure of this methodology allows additional materials to be evaluated in the future. When, as the Project design matures, additional materials that will be needed underground are identified, this same procedure can be used to determine how their use will affect the site.

Before the screening process could begin, it was necessary to develop a set of criteria by which to eliminate materials from further consideration. Panel members, all with a background in materials science or chemistry, were selected by the LANL Technical Project Officer to assist with the development of these criteria. This panel determined that the following reasons would be sufficient for eliminating a material:

1. generally nonreactive (inert),
2. insufficient quantity,
3. lack of catalyst,
4. separation by distance (for example, materials are too far apart),
5. separation by time of use (construction or testing),
6. speed of reaction (for example, reaction kinetics too slow).

Criteria for the decision tree are an extension of these reasons for elimination. The following are examples of criteria questions.

1. Does the interaction affect radionuclide release?

2. Does the combination of X and Y require a catalyst Z to react? Is Z present?

3. Is the distance between the materials great enough that the possibility of their coming into contact with each other is slight?

For simplification, the analysis of chemical interactions was done in three stages: materials sorting, chemical reactivity, and conditions for reaction. Each of these is discussed below.

2.2.1 Materials Sorting

The first stage, summarized in Table A-III, "Materials Sorting," eliminated materials strictly on the basis of their physical properties. This table is basically a decision tree, developed by LANL, stating conclusions about major materials categories. The methodology for using this table is as follows:

1. On an individual basis, pass each material from the NNWSI Condensed Fluids and Materials Database through the decision tree.

2. Appropriately answer all criteria questions for each material, until a decision is obtained.

3. Record that decision and proceed as instructed.

The decision tree process shown in this table was based on criteria for type (inorganic, organic, metal), physical form (solid, liquid, gas), solubility/miscibility, reactivity with the rock, quantity, and time of use (construction, testing, or permanent). Each of these criteria is discussed in "Instructions for Using Table III: Materials Sorting," which is designed to lead the reader through Table A-III.

The criteria used in the first table were defined and ranked. Panel members collectively assigned one of the following rankings to each of the 216 unique categories: not a problem, problem of low concern, or problem of high concern. Table A-III shows the decisions that were assigned to each category. The justification for the ranking of each category is shown in Appendix A.6.

All solid and liquid materials were screened through this process. Gaseous materials in Table A-II were considered at a later stage of the decision tree analysis because transport properties of gases are distinctly different from those of solids and liquids. This segregation into gaseous and nongaseous materials allowed greater attention to reactions of gases than could be attained if they were combined with nongaseous materials at the start.

The results of passing each material through Table A-III were recorded in Table A-II under the heading "Box No." This entry shows the number of the box (from Table A-III) into which the material finally was assigned after being sorted. Materials identified as no concern were recorded as such, and then were eliminated from the interaction analysis. The rest were subjected to further decision tree analysis.

2.2.2 Chemical Reactivity

The second stage of the synergistic effects study analyzed the interactions between pairs of materials. This stage of the analysis is concerned only with the potential for reaction. That is, do Compound A and Compound B react? Should we be concerned about this reaction? If they come together under any conditions, will they react (regardless of whether these conditions actually exist in the ESF)? Clearly, some pairs of materials will not react with each other at all and, therefore, do not need additional study. Others will react, but only under "certain" conditions, so we may want to study them further. Other pairs may react strongly with one another; they will be of high concern and will have to be studied further. The purpose of this stage was to determine which reactions needed to be evaluated in more detail.

Again, this analysis was designed to identify pairs of compounds that react with one another. Although not specifically concerned with location, this stage of the analysis did address the location to some extent because the tables separated materials used on the surface from materials used underground. In addition, the time aspect was addressed because the surface and underground tables are further divided into phases of usage. The following six tables were used to analyze the interactions between pairs of materials:

Table A-IV-a: Surface- Construction
Table A-IV-b: Surface- Testing
Table A-IV-c: Surface- Permanent
Table A-IV-d: Underground- Construction
Table A-IV-e: Underground- Testing
Table A-IV-f: Underground- Permanent

After the materials sorting process, each material that was ranked as being of concern (either high concern or low concern) in Table A-III was added to the appropriate table here. "Instructions for Using Table A-III: Materials Sorting" describes how Table A-III is used to assign materials to a specific Table A-IV. Then, the determination was made as to whether pairs of materials would react. "Instructions for Using Table A-IV: Chemical Reactivity" explains how Table A-IV was used to aid in analyzing of pairs of materials.

Tables A-IV-a through A-IV-f, developed as a result of our chemical interaction analysis, appear in Appendix A. A bullet indicates a potentially significant reaction between the pair of materials intersecting at that point. Those pairs denoted by an asterisk were not considered significant and so were eliminated from further analysis.

2.2.3 Conditions for Reaction

The third stage of the synergistic effects study analyzed whether the potentially significant reactions identified in Table A-IV could and would actually occur in the ESF. This analysis specifically examined the conditions for reaction, including such things as location (specific location of each material), temperature, pressure, and presence of a catalyst. The purpose of this analysis was to determine whether the pair of materials would actually react in the ESF environment. It is possible that although both materials are present, they will not react because conditions, such as those shown in the following examples, are not conducive to reaction.

1. The distance between them is too great, so they will not contact with each other.
2. The temperature is not high enough.
3. The pressure is too low.
4. The catalyst for this reaction is missing.

To decide whether a reaction will actually take place in the ESF, it was first necessary to determine all the conditions required for reaction and then to determine whether all of those conditions will actually be present in the ESF. In some cases, analysis of ESF conditions indicates that the reaction in question will not take place in the ESF, and, therefore, the use of either material is not a problem (as far as this interaction is concerned). For example, two materials that are physically separated by 165 vertical ft (50 vertical m) will not come into contact for approximately 50,000 yr [assuming a 0.04 in./yr (1 mm/yr) groundwater flux, Section B.3]. Therefore, we conclude that neither material will pose a hazard to the site. A reaction requiring a temperature of 500°C to "go" also results in a decision that neither material is a problem because this temperature is not likely in the ESF. If, on the other hand, a pair of materials has the potential for reacting (that is, all the necessary conditions exist) in the ESF, restrictions or limitations need to be placed on their use.

2.3 Evaluating Effects of Groundwater and Microorganisms

The procedure for evaluating the effects of groundwater and microorganisms involved meeting with specialists to discuss the ramifications that added materials could have in these areas. LANL met with Lawrence Livermore National Laboratory (LLNL) to discuss the natural variation in groundwater chemistry as it related to waste package performance criteria and this evaluation. Larry E. Hersman, from LANL, was consulted concerning the effects of shaft construction materials on microbial activity.

2.4 Analyzing Fluid Transport and Rock Properties

At LANL's request, several organizations studied groundwater transport in order to model groundwater flow. The objective was to obtain a representative set of calculations showing the movement of groundwater in the fractures and in the matrix so that conclusions could be made about the likelihood of groundwater transport at Yucca Mountain.

The analysis of fluid transport began with meetings between LANL and modelers from Sandia National Laboratories (SNL) and the USGS to define reasonably comparable sets of calculations to be run at each organization. Parameters to be used in the computer codes were also established during these meetings so that, though done independently with different codes and modeling techniques, all results had the same basis and so could be readily compared.

SNL performed calculations to model groundwater flow primarily in the matrix. The SNL calculations were used to analyze the distance that the retained water from construction could move from the surface of the shaft wall (or drift) into the rock, for both shaft and drift geometries. Based on our meeting, SNL developed a problem definition memo (PDM) describing all the parameters required for the calculations. SNL used information contained in the revised PDM, which incorporated LANL comments on the draft version, to perform the calculations.

Modelers from the USGS, in conjunction with Lawrence Berkeley Laboratory (LBL), calculated groundwater transport in the fractures. In addition to these calculations, the USGS was asked to finalize their rationale for dry mining portions of the ESF.

3.0 DISCUSSION OF RESULTS

This chapter discusses the results of the decision tree analysis, followed by results of the biological degradation/transport study and the water transport analysis. The results of the water transport analysis are subdivided into the following categories:

1. discussion of conductivity vs rock saturation properties,
2. transport of drilling fluid using matrix flow models,
3. transport of drilling fluid using fracture-matrix models,
4. transport of hydrocarbons,
5. effects of solvents,
6. transport of other chemicals.

3.1 Results of Decision Tree Analysis

The decision tree analysis did not identify any materials or pairs of materials whose presence will significantly impact the candidate repository location; therefore no materials were prohibited from use. However, the results of our materials sorting study (Table A-III) identified two major categories of materials that could have potentially significant effects: hydrocarbons and solvents. Because most of the materials fell into one of these categories, LANL was able to draw conclusions at the category level, thus eliminating the need for detailed analysis of specific interactions between hydrocarbons and/or solvents.

Hydrocarbons will have a tendency to remain in the proximity of the ESF, although mechanisms can be postulated for their transport. According to Hunter,[11] the loss of organics underground, near possible waste emplacement, could affect the transport characteristics of certain radionuclides (such as uranium) in the long term. But from a hydrologic perspective, the quantities of organics (oil, grease, etc.) lost at the surface appear to be negligible. Even if the organics are concentrated, Hunter does not think they would subtract from the ability of the site to isolate and contain radionuclides because the influence of any of the organics lost on the surface of the repository or below should not be felt for at least 10,000 yr.

Compared with the millions of gallons of drilling fluids that are proposed for use, solvents will primarily be present in small localized quantities. In the overall scheme of things, then, the volume of rock affected by solvents will also be small, and the depth of penetration will be minimal. Though not specifically addressed in this study, intuitively we know that solvents will evaporate, leaving an even smaller amount of the solvent to penetrate the rock. By inspection, then, we can conclude that the solvents will probably not have a significant effect on the site.

Interactions between hydrocarbons and solvents will tend to lower the viscosity of liquid hydrocarbons, enabling them to be carried deeper into the formation. But, in all likelihood, the depth of penetration will not amount to more than a few centimeters. Again, solvents will gradually evaporate. From the standpoint of the decision tree analysis, all materials categorized as hydrocarbons or solvents are, therefore, approved for use but will be restricted to the surface when possible.

One assumption used in performing this analysis was that instrumentation, such as gauges and extensometers, would be removed after fulfilling their intended function. LANL recommends that this reasonable assumption be implemented as a mandatory procedure.

3.2 Biological Degradation/Transport

Organic materials may be used as growth substrates by large numbers of microorganisms, which may in turn influence the transport of radioactive elements from the repository. Hersman investigated the effect of added fluids and materials on microbial behavior and found that microorganisms can affect transport in one or more of the following ways:[12,13]

1. alter the composition of the groundwater chemistry through changes in pH or Eh,
2. produce chelating agents that make radioactive elements soluble,
3. transport the radionuclide by biological movement,
4. transport the radionuclide by colloidal dispersion,
5. retard the transport of the radionuclide by sorption onto a nonmotile solid phase.

Microbial activity is a function of nutrients and will occur only when nutrients exist. Hersman believes that water from any of the Yucca Mountain wells contains ample amounts of the salts necessary to support microbial growth.[12] His studies indicate that the drilling fluids used at Yucca Mountain, primarily Nalco ASP-700 and Turco 5622, are also biodegradable by a variety of microorganisms and will support a large population of microorganisms that use measurable amounts of oxygen. Because these bacteria can survive for a long period of time, significant and long-term microbial activity may occur in the groundwater at Yucca Mountain.

In addition to biodegrading chemical compounds, microbial growth may affect the chemical environment by changing the pH and oxidation-reduction potential of the system. Although Hersman's investigations show no evidence that microbial activity will change the pH of the groundwater, there is a strong possibility that microbiological activity could result in reducing (conditions at present are oxidizing) conditions.[13] For example, 1 gal (3.8 L) of drilling fluid diluted 1/42 with water--the dilution used by drillers at Yucca Mountain--contains 0.24 lb (90 g) of polymer. For every gallon (3.8 L) of polymer, 7.31 moles of oxygen are consumed, which results in reducing conditions. Hersman believes that the most important effect of microorganisms on the groundwater chemistry is the removal of oxygen and the concomitant drop in oxidation-reduction potential. Such a drop may be beneficial in retarding the migration of radioactive species.

Bacteria are known to sorb many different metals from solution. Although Hersman has not demonstrated that sorption is actually occurring, he has observed that the actinide $^{239}Pu^{4+}$ is being removed from the solution.[12] Hersman found that these results are consistent with the findings of Strandberg *et al.*, who reported a strong intercellular uptake of uranium by microorganisms, specifically *Pseudomonas aeruginosa.*[12] By depositing metals, internally or externally, microorganisms are not only protecting themselves from the toxic effects of the metal ions, but are also, in effect, concentrating the metal in the biosphere. What remains to be determined is the overall effect that this biological sorption has on the movement of radioactive wastes from a high-level nuclear waste repository. As Hersman points out, studies show that bacteria will be removed from suspension by soil or rock, but the specific influences of saturated or unsaturated fracture flow conditions have yet to be determined.

It is now known that significant microbial activity can occur to depths of 100 ft (30 m) or more. Studies performed at Savannah River Laboratory have found microorganisms at depths to approximately 1000 ft (300 m) and LANL has found microorganisms at depths of 175 ft (53 m). Still, little information exists regarding the extent of microbial activity in the deep subsurface environment.

Although the organic fluids that have been or will be introduced into the repository block appear to be biodegradable and capable of supporting large numbers of microorganisms, Hersman selected representative materials from Table A-I and notes that the data indicate that organic matter, including hydrocarbons and ethylene glycol, biodegrade slowly.[13] Table I, taken from Hersman,[13] lists the constituents of both the drilling fluids and those fluids expected to be used during the construction of the ESF. Also included in the table is a brief comment regarding the availability of the given constituent for biodegradation.

Hersman's results indicate that microorganisms can exist in the Yucca Mountain environment, but at this time, LANL is unable to identify an area where this actually constitutes a problem. Although the introduction of organic substances and the presence of suitable water chemistry, along with a source of oxygen (ventilation air), will promote biological activity, the consequences have not been identified as detrimental. Overall, however, the amounts of degradation would be so small that they would be ranked as "No Concern" in the decision tree analysis. Specifically, the sorption/concentration of the actinide $^{239}Pu^{4+}$ by microorganisms could potentially help isolate the plutonium and thus enhance the barrier between the radionuclides and the accessible environment. Movement of significant quantities of materials caused by microbial activity will probably depend on fluid transport. As discussed in Section 3.3, the quantities of fluids and the properties of the rock combine to limit the distances of significant effect.

TABLE 1

BIODEGRADATION OF SELECTED MATERIALS PROPOSED FOR USE IN THE EXPLORATORY SHAFT FACILITY

(from Hersman, Ref. 13)

Constituent	Comments
Ammonia	Biodegradable
Antifreeze (ethylene glycol)	Biodegradable
Brake fluid (ethylene glycol)	Biodegradable
Diesel fuel, fuel oil, gasoline, kerosene, grease, engine oil, lube oil: all hydrocarbons derived from petroleum.	Biodegradable
Emulsifier (polyethylene glycol p-isooctylphenyl ether)	Biodegradable
Gelatin	Biodegradable
Hydraulic fluids (ethylene glycol)	Biodegradable
Isopropyl alcohol	Biodegradable
Light hydrocarbons (hexane)	Biodegradable
Linear dodecyl benzene sulfonic acid	Biodegradable
Polymer (acrylamide copolymer with sodium acrylate)	Indirectly biodegradable, may leach nitrogen that is utilized by microorganisms
Sodium nitrate	Biodegradable in dilute concentrations
Torque converter fluid (ethylene glycol)	Biodegradable
Tracers:	
fluorescein dye	Biodegradable
lithium bromide lithium chloride sodium bromide sodium chloride	Not biodegradable (may be utilized as salts)
sulfur hexafluoride perfluorinated benzoic acid	Unknown
Transmission fluid (petroleum distillates, hydrocarbons)	Biodegradable

3.3 Water Transport and Associated Effects on Rock Properties

The materials transport analysis was specifically designed to determine whether the fluids and materials used in construction of the ESF could penetrate the repository block and/or come into contact with the closest waste package container, approximately 100 ft (30 m) away. The methodology used was to investigate the transport of drilling fluid (modeled as water) and then, based on those results, make inferences about the transport of other materials (all of which are present in much smaller quantities than drilling fluid).

The USGS is concerned that the introduction of drilling fluids into the host rock at the ESF will distort the results of two of their experiments, the Infiltration Test and the Bulk Permeability Test, whose primary purposes are to determine bulk-rock characteristic curves (saturation and hydraulic conductivity as functions of water potential).[14-21] The USGS also needs to collect data for use in confirming various conceptual and numerical models that interpret and describe flow processes in the unsaturated zone at Yucca Mountain. The USGS believes that the introduction of drilling fluid may seriously jeopardize these efforts by changing the *in situ* fluid saturations, which would then substantially change the rock mass properties derived from the data. Their position regarding the introduction of drilling fluids is described in a report by Montazer *et al.*[15]

In their report, the USGS discusses the effect of wet mining on hydrologic conditions. The basic premise is that wet mining operations in or near the tests may seriously impact their ability to understand the ambient conditions of the test block, assess the shape and hysteresis of characteristic curves, and verify conceptual and numerical models.[15] They believe tests can be performed only when saturation levels are carefully measured under controlled conditions. Controlled conditions refer not only to limiting the volume of water applied, but also to limiting the rates of water infiltration, the volumes of rock affected, and the location of that rock. If these types of limitations are not employed during wet mining, they believe that their test results may be meaningless. Although, admittedly, it may be possible for ventilation air to remove the moisture introduced during wet drilling and mining operations, Montazer believes the water that penetrates deeply into the fractures may never be recovered because of low air circulation in these regions. Therefore, the USGS believes that measures must be taken at the onset to preserve the *in situ* conditions of the host rock for these two tests.

For comparison, the USGS evaluated the effect of dry mining on hydrologic conditions.[15] Dry drilling could be accomplished in two ways (assuming that these methods are successful in the welded tuff):

1. by dry drilling and blasting, and

2. by adapting of mechanical tunnel miners or boring machines to dry working conditions.

During dry drilling, compressed air enters the matrix through the borehole cavity and causes two types of disturbances in the moisture content.[15] The first type is a result of compressed air displacing the water that is held as a pendular network in the fracture and matrix. This disturbance is temporary, and, as soon as the air pressure is removed, the water returns to occupy the small pores, thus restoring equilibrium. Simulation of this phenomena indicates that throughout most of the fracture, the return to initial conditions occurs within the first hour. Montazer observed that the pressure disturbance caused by the injection of air into fractured metamorphic rock dissipated, and initial conditions were restored within less than 1 month.

The second type of disturbance described by the USGS results when moisture is removed from exposed surfaces of the drill hole and open fractures.[14] When this occurs, dry air replaces the nearly vapor-saturated air of the formation; this replacement creates a vapor pressure that lowers the water-potential and saturation states of the matrix and fractures. In this case, total recovery may require a much longer time than that required by transient water displacement because water may be lost as vapor, which may cause a decrease in saturation.

Based on their analysis, the USGS recommended using dry drilling with a noncontaminating gas that is conditioned and tagged.[15] Specifically, they recommended using dry mining techniques both in the Infiltration and the Bulk Permeability Test rooms and in the adjacent portions of the access drift within 100 ft (30 m) from the center of either room. They also recommended that minimal-water techniques, such as air-mist drilling, be used in excavating any underground opening that falls within a spherical radius of 300 ft (90 m) from the center of the Bulk Permeability Test room or within 200 ft (60 m) from the center of the Infiltration Test room.

Project evaluation of this recommendation was a major factor in the Waste Management Project Office (WMPO) assignment of the preparation of this report to LANL.

3.3.1 Discussion of Conductivity vs Rock Saturation Properties

Figure 5, from Klavetter and Peters 1987,[22] shows that pressure head for unsaturated rock matrix varies with saturation. Because of this variation, and with techniques discussed in SAND85-0855 that take into account fracture conductivity, a composite conductivity can be developed as a function of pressure head.[23] Therefore, given typical data for the repository horizon rock, matric suction head varies as a function of saturation. Figure 6, from SAND85-0855, illustrates that hydraulic conductivity also varies with pressure head and that a large difference exists between fracture and matrix conductivity. The SNL model uses a composite conductivity to account for both fracture and matrix flow. The question that remains to be answered is how much change in saturation will result when water from drilling and other activities is added, and how this change in saturation will affect the conductivity.

Because some of the experiments attempt to measure the saturation, which relates to conductivity, an error in the *in situ* saturation measurement can create an error in selecting the conductivity to be used in repository performance analysis. Because of this error, it is desirable to have the rock in the pristine state. Figure 7, reproduced from Bodvarsson *et al.*,[20] illustrates the

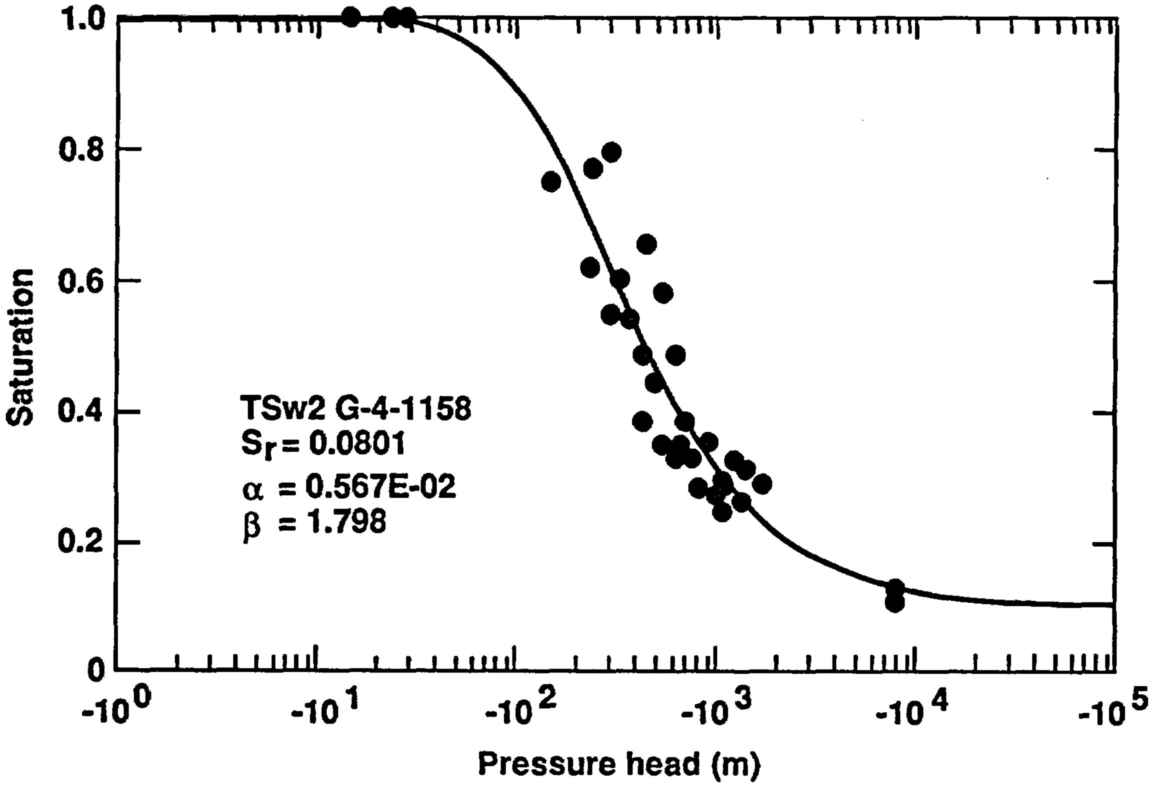


Fig. 5. Saturation as a function of pressure head for sample G4-1158. See original reference (redrawn from Klavetter and Peters, Ref. 22) for symbols and terminology.

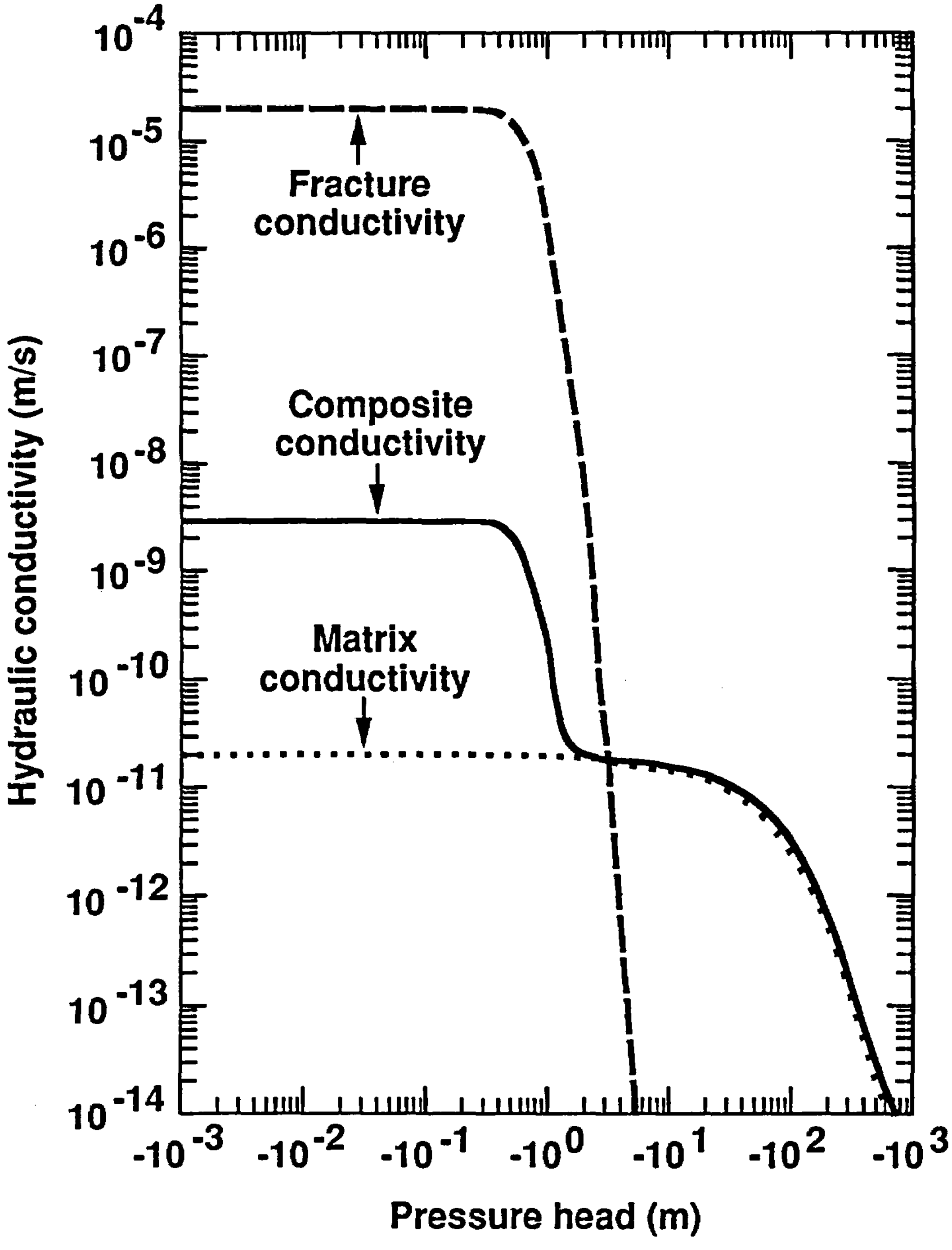


Fig. 6. Conductivity curve for Unit TSw2 (redrawn from Klavetter and Peters, Ref. 23).

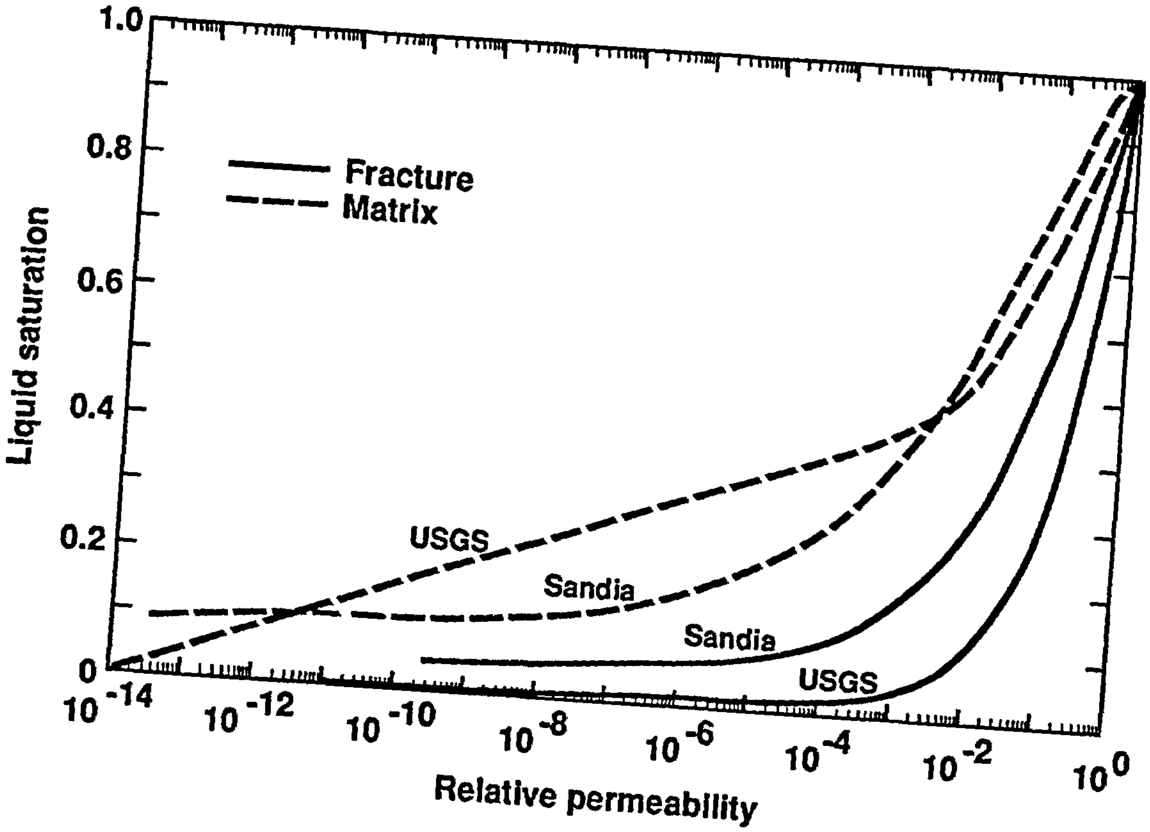


Fig. 7. Relative permeability/liquid saturation curves used in the simulations (redrawn from Bodvarsson *et al.*, Ref. 20).

difference in data that occurs as a result of using different methods for generating curves such as the curve in Fig. 5 (see Appendix B.2 for additional details).

Several of the tests in the ESF attempt to measure permeabilities. Therefore, the liquid saturation levels should not be allowed to change without knowledge of the pristine state. For example, the difference in permeability, for a change in saturation from 70 to 72%, is small, approximately 10%. Thus, for a 2% change in saturation, errors in interpretation of the relative permeability are approximately 10%. A 2% change in saturation, such as the one described, might be expected from liquid drilling activities after a relaxation time of 1 month (see Bodvarsson *et al.*, Section 3.3.3).

3.3.2 Transport of Drilling Fluid Using Matrix Flow Models

The purpose of this set of calculations was to determine whether the drilling fluid, and other sources of water, used in ESF shaft sinking and drifting could be transported through the adjacent rock in such a manner as to compromise the repository site or affect the results of the tests to be performed.

SNL performed calculations for the shaft and drift geometries to determine the distance that the retained water from construction could move from the surface of the shaft wall into the rock.[24-27] For these analyses, it was assumed that the fractures had a small initial residual saturation and that the initial saturation of the matrix was low enough that, when the water moved from the fractures to the matrix, the matrix did not become fully saturated. This analysis was strictly a geometrical argument that compared volumes of water with volumes of void available. Typical results are shown in Figs. 8 and 9. The results of these analyses illustrate that if the water initially flowed primarily into the fractures and was then absorbed into the matrix, the change in matrix saturation would be small. Figure 8 summarizes the results of putting a given amount of water (from 0 to 10% of the total drill water) into the rock and measuring the volume of rock required to contain all of that water while simultaneously keeping all the fractures (within that rock) full. For the Topopah Spring lithophysae-poor (labeled "Topopah Rep" in the figures) strata, whose fracture porosity is 1.8×10^{-4}, an annular volume with a radius of approximately 66 ft (20 m) would be required to contain a volume of water equal to 10% residual drilling water. Figure 9 shows the increase in matrix saturation assuming all residual drilling water was originally in the fractures. For these calculations, the volume of water used in Fig. 8 was put into the fractures. That volume of water was then absorbed from the fractures into the matrix by capillary pressure. The resulting change in matrix saturation, for various porosities, is shown in Fig. 9. The actual matrix porosity for each strata is circled. For the Topopah Rep strata, the increase in matrix saturation was about 0.0015 (dimensionless). For all the strata, the change in matrix saturation would be less than 0.0017 (dimensionless).

Additional calculations performed by Eaton and Peterson[27] determined the increase in saturation when the same volume of water (10% residual drilling water) was put into the rock, but in these calculations the fill radius was held constant. It was assumed that the water in this region was at constant saturation. Of all the strata, the highest saturation increase (0.013) occurred

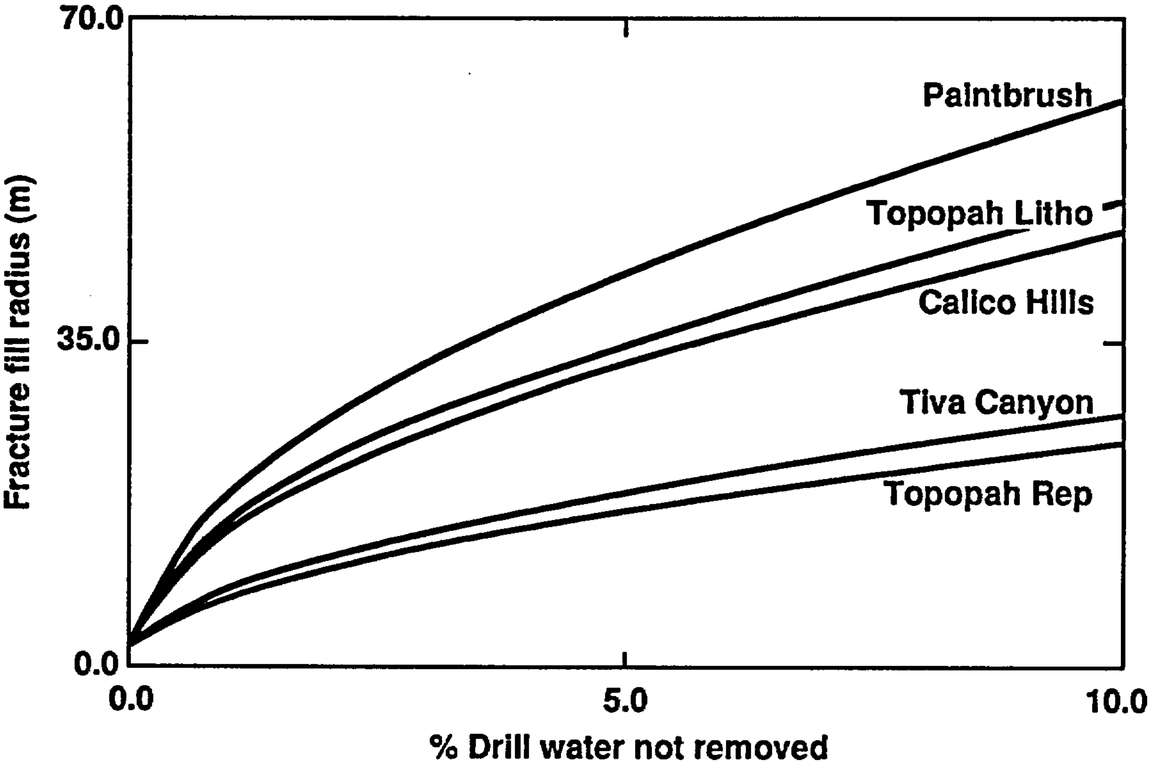


Fig. 8. Radius to which fractures would fill to accommodate all residual drilling water, Case 1a (redrawn from Eaton and Peterson, Ref. 27).

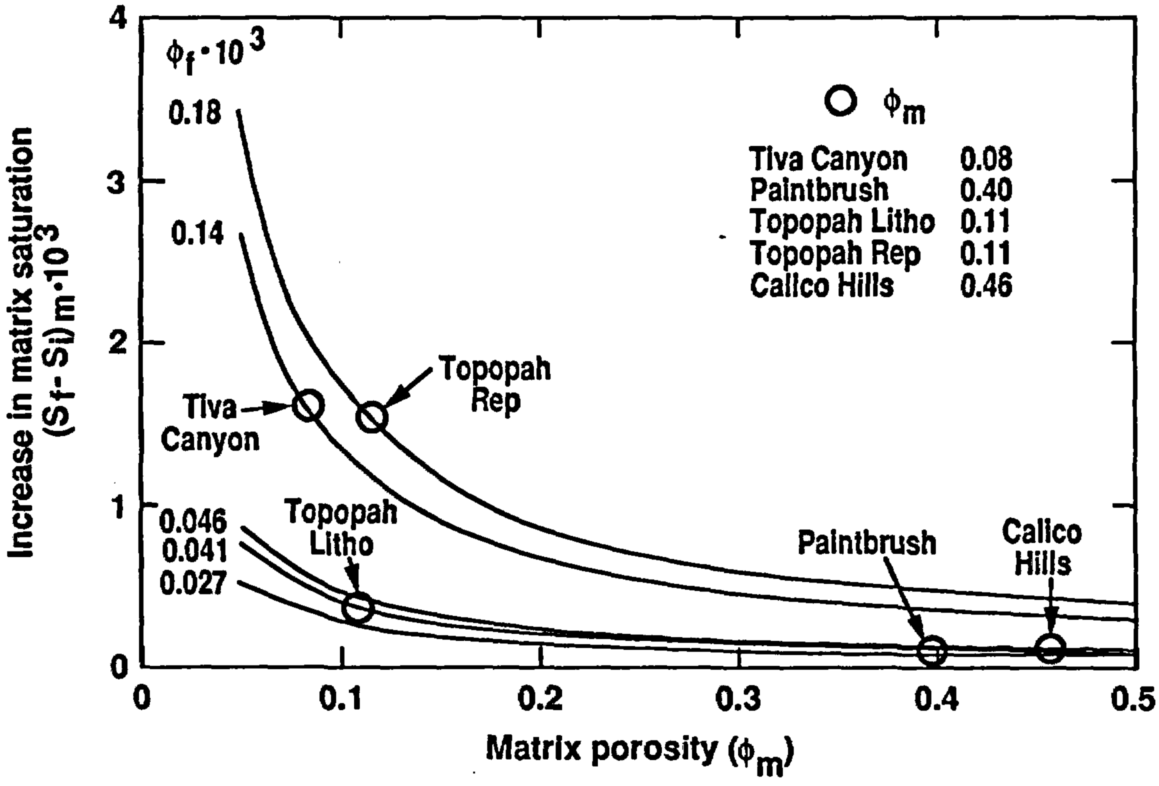


Fig. 9. Increase in matrix saturation assuming all residual drilling water was originally in fractures, Case 1b (redrawn from Eaton and Peterson, Ref. 27).

in the Tiva Canyon strata (whose matrix porosity is 8×10^{-2}) when 10% of the residual water was put into a volume of rock that had a fill radius of 33 ft (10 m). The Topopah Rep strata, whose matrix porosity is 0.11, had a saturation increase of 9.2×10^{-3} when 10% of the residual water was put into a volume of rock that had a fill radius of 33 ft (10 m). In general, as fill radius increased, the saturation decreased. These results indicated that, for the conditions investigated, the expected change in saturation would be quite small. After performing these calculations, the investigators decided that further calculations should be done using the NORIA computer code.

NORIA is a finite element computer program that simultaneously solves four nonlinear, parabolic, partial differential equations.[28] The four equations describe the transport of water, water vapor, air, and energy through partially saturated porous media. NORIA is intended to solve nonisothermal problems in which large gradients are expected in the gas pressure.

Specifically, SNL used NORIA to calculate the one-dimensional, time-dependent radial movement of the residual mining water in the rock matrix adjacent to the shaft liner.[29] Water was assumed to be in isothermal matrix/fracture equilibrium at all times. Other initial conditions were the following:

1. R_o = 7.25 ft (2.21 m) (outside radius of concrete shaft liner).

2. R = 82 ft (25 m) (radial distance).

3. 3.02 m^3/m of water is added to the rock (see Section B.7, Drilling Fluids).

4. Initial pressure head and saturation values are obtained by assuming one-dimensional, vertical, steady-state infiltration of Q = 0.004 in./yr (0.1 mm/yr).

5. The retained water was initially distributed in the modified permeability zone (MPZ).[30] (The MPZ is that portion of the rock surrounding the excavation that exhibits increased permeability caused by either blast damage or stress relaxation. Figure 10 shows the expected MPZ for Topopah Spring welded tuff at a depth of 310 m.[30])

Again, results indicate that the change in saturation would be quite small.[29] Figure 11 shows typical results for the Topopah Spring welded tuff. These calculations show the increases in saturation for computational times of 1 to 1000 yr, from the shaft centerline to a radius of 82 ft (25 m). In the Topopah Spring unit, at time zero, the saturation in the MPZ was approximately 86%. The initial change in saturation in the MPZ was 0.060 (dimensionless), from approximately 86 to 92%. At 1 yr, the saturation in the MPZ was about 89.3% (approximately 0.035 above the nominal value), and changes in saturation out to about 26 ft (8 m) from the shaft centerline were calculated. At 2 yr, the saturation in the MPZ had fallen to about 89% (0.03 higher than the nominal value), and changes in saturation out to about 33 ft (10 m) from the shaft centerline were calculated. However, at 2 yr, the changes in saturation were less than 1% at radii greater than 19.5 ft (6 m) from the shaft centerline [5.25 ft (1.6 m) from the outer edge of the MPZ]. At 1000 yr, the calculated

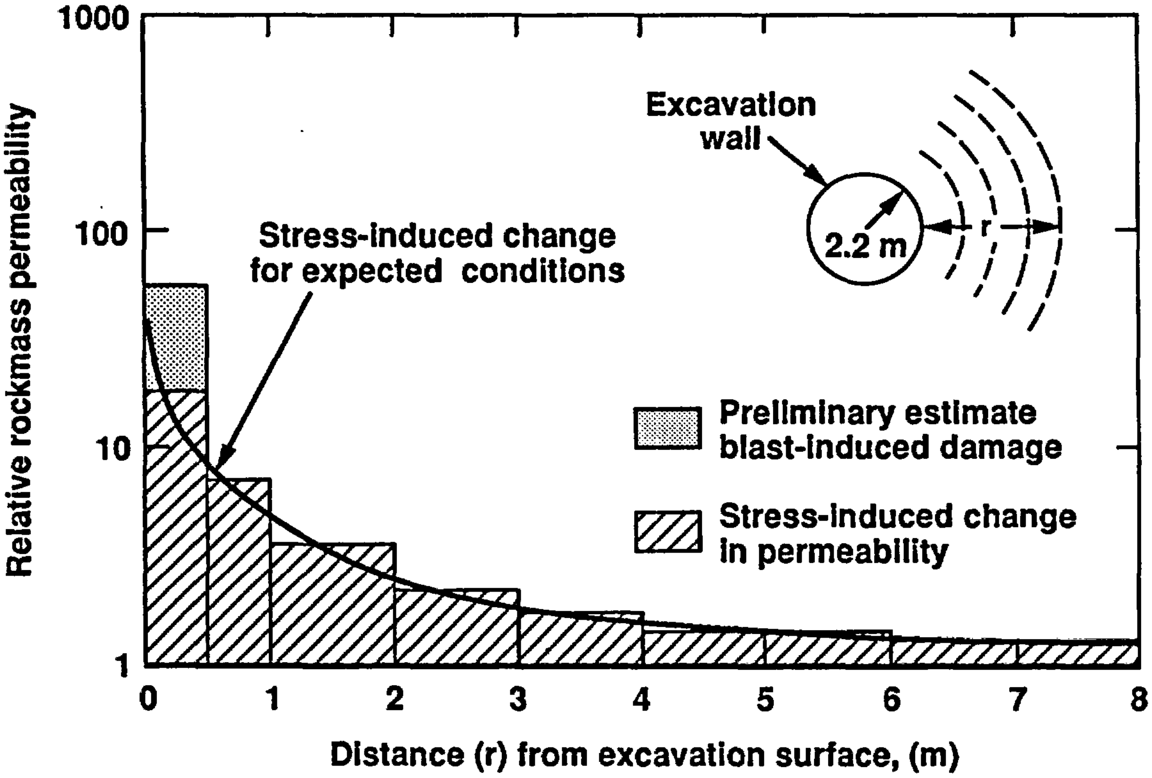


Fig. 10. Modified permeability zone model for Topopah Spring welded tuff for expected conditions at 310-m depth (redrawn from Fernandez *et al.*, Ref. 30).

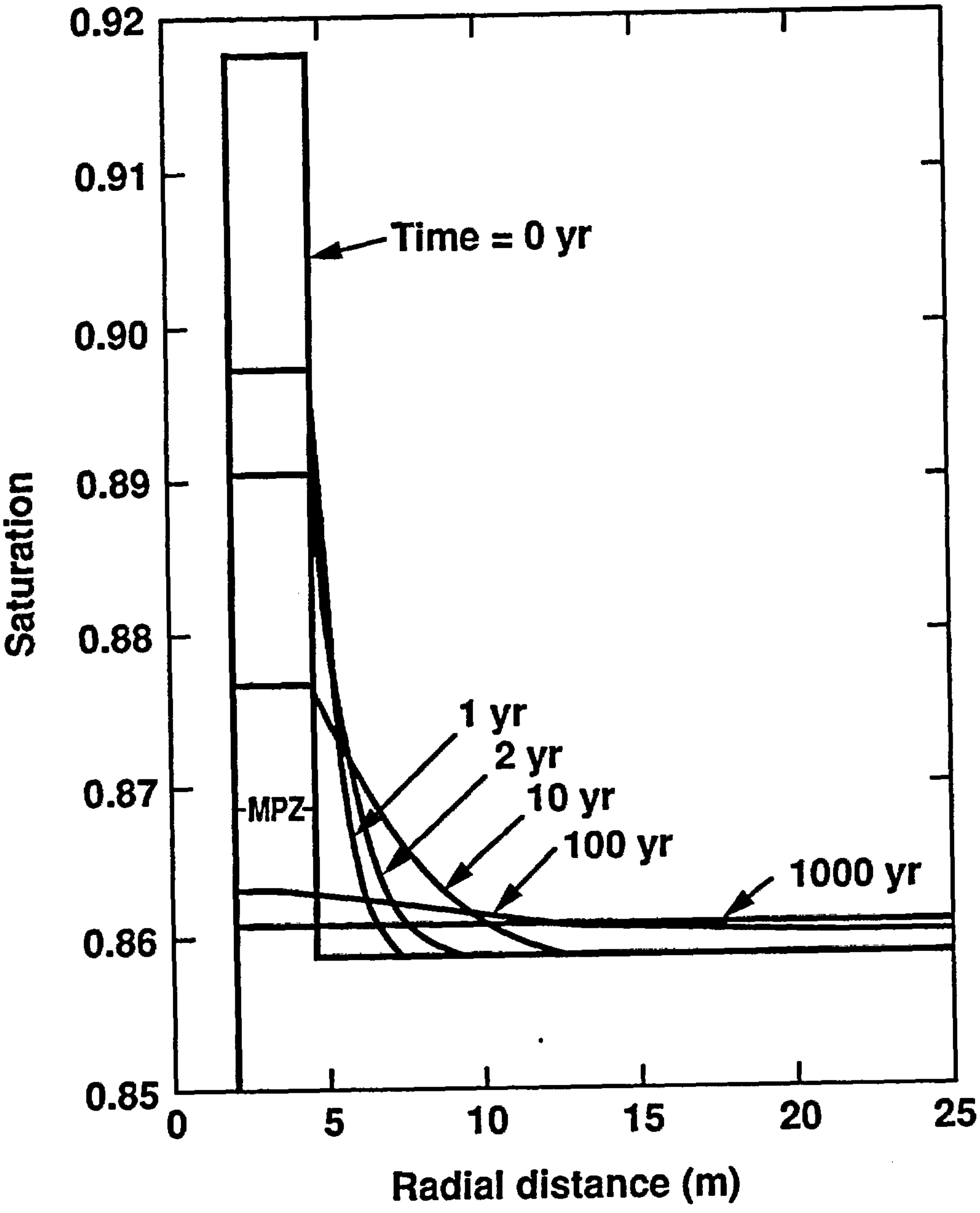


Fig. 11. Saturation profiles for Topopah Spring for 1, 2, 10, 100, and 1000 yr (redrawn from Eaton and Peterson, Ref. 29).

saturation was uniform throughout the unit at about 86%. For all strata, the saturation increase at radial distances greater than 16 ft (5 m) from the shaft centerline [2 ft (0.6 m) from the MPZ] was less than 3%.

Although these calculations applied directly to the shaft geometry, Eaton and Peterson expect similar types of saturation increases in the vicinity of the drifts.[29] From the problems investigated, Eaton and Peterson concluded that the appreciable increases in rock saturation that result from wet mining procedures are, in general, confined to a small region in the vicinity of the walls.[29]

Fernandez *et al.* performed preliminary analyses to determine whether construction of the two shafts associated with the ESF could influence the long-term isolation capabilities of the candidate high-level nuclear waste repository.[30] Their report focuses primarily on the shaft liner and the increased rock damage around the shaft, the sorptivity of zeolites, and the enhanced radionuclide releases. From their calculations, Fernandez *et al.* conclude that the presence of the shafts, the shaft liner, and the associated MPZ does not significantly impact the long-term isolation capability of the repository. This conclusion was reached on the basis of the following:

1. Water entering the shaft can be dissipated effectively at the base of the shaft.
2. Air flow out of the shaft can be controlled effectively by emplacement of shaft fill.
3. Deposition of solids from the interaction of the shaft liner with the groundwater will be a localized phenomenon and should not decrease the drainage capability of the rock at the base of the shaft.
4. Increases in the temperature of the groundwater reaching the base of the shaft will not significantly impact the sorptivity of the Calico Hills zeolites.

Peters and Gauthier investigated the response of a matrix block to the high-pressure introduction of water drilling fluid.[31] Figure 12, adapted from the Peters and Gauthier report, is a typical example of how water penetrates the matrix block. The results indicate that the application of high-pressure water to matrix material like that found in the repository zone will not cause water penetration to large depths [it is expected that depths will be less than 1.3 in. (5 cm)]. Furthermore, water quickly redistributes, so the increase in matrix saturation is small. Thus, it appears that pervasive flooding of the fractures will not significantly affect the matrix saturation.

Daily and Ramirez performed dye penetration studies to determine the extent to which drill water might be expected to penetrate the matrix of core samples in a densely welded tuff.[32] Their experiment was conducted in the G-Tunnel complex at the NTS because the welded tuffs in G-tunnel have bulk, thermal, and mechanical properties similar to those at Yucca Mountain. The samples were drilled according to standard coring procedures; however, the drill water contained methylene chloride, a dye that stains the rock a dark blue. During this drilling activity,

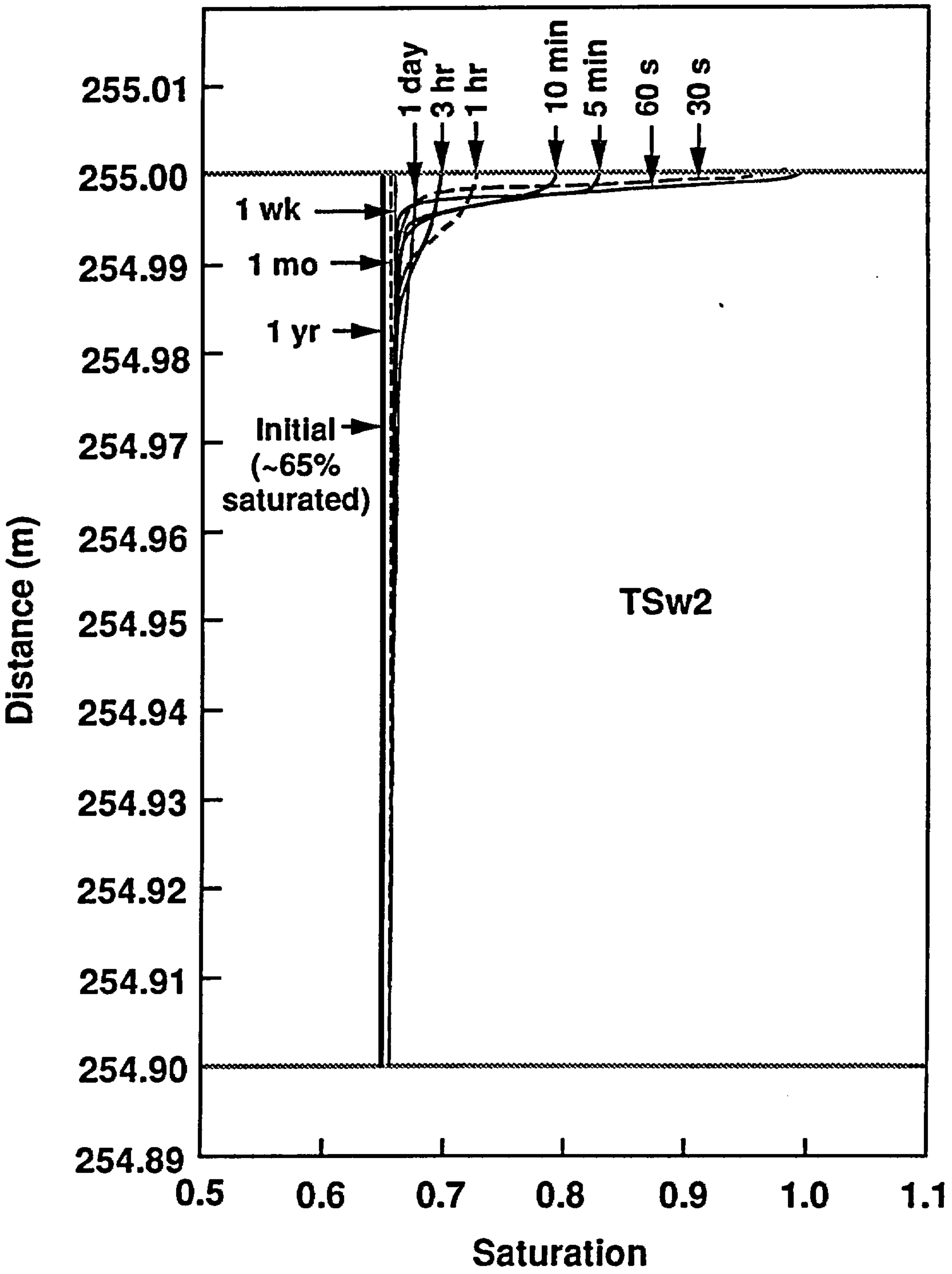


Fig. 12. Matrix-block water penetration; initial condition - no flow, 20-m pressure head for 1 minute (redrawn from Peters and Gauthier, Ref. 31).

the borehole wall and core were first exposed to water that might alter its pristine state.

Six pieces of core were examined; the extent to which the rock matrix imbibed the drill water was determined by observing the depth of dye penetration.[32] In general, drill water was imbibed approximately 0.08 in. (0.2 mm) into the matrix. Imbibition occurred further into the matrix where larger crystals were near the core boundary, but dye penetration was less than 1 mm even at these locations. Based on their observations, Ramirez and Daily estimated the amount of drill water that might be imbibed into the rock matrix directly from the borehole wall. By assuming that the average penetration depth is 1 mm and the borehole wall and core imbibe water similarly, they estimate that the rock will imbibe approximately 1.7 in.^{3} (28 cm^3) [or 0.0074 gal. (0.028 L)] of drill water per meter of NX hole length (at an initial porosity of 15% and saturation of 60%).[32]

The results of this experiment have been questioned because some people feel that the dye was not conservative (nonreactive, nonsorbing). However, the observations are consistent with the calculations discussed in this section, which predict that water in contact with unfractured matrix rock does not penetrate very far.

3.3.3 Transport of Drilling Fluid Using Fracture-Matrix Models

The impact of drilling with water on the hydraulic behavior of a fracture-matrix system in welded tuff was investigated by Kwicklis and Hoxie, who numerically simulated a hypothetical infiltration test.[16] A 65.6-ft (20.0-m) head of water was imposed for 1 hour at the top of a column containing a single fracture, whose hydraulic aperture was 24 mm, to analyze moisture redistribution. This simulated the introduction of water into the system during drilling. At the end of this 1-hour period, the head was removed, the upper boundary was assigned a no-flow condition, and the water was allowed to redistribute for 24 hours. Initially, the fracture was assigned a residual saturation of 0.159. Results (Fig. 13) show a return to this initial value, with an average value of approximately 0.20 being obtained after only 10 hours. The propagation of the moisture front in the fractures nearly ceased after the imposed head was removed because of the nearly zero longitudinal hydraulic conductivity of the unsaturated fractures. Drainage from the matrix block to the fracture probably would not have occurred unless the matrix block had become completely saturated.

To analyze the effect of a perturbation, Kwicklis and Hoxie then modeled a system that had initial conditions similar to those described above, but which, following the 1-hour drilling period, introduced an additional 0.66-ft (0.2-m) head for 1 hour.[16] Results (Fig. 14) showed that if this had been the actual test, the infiltration test would have overestimated the extent of water movement in the fracture. The amount of overestimation varies with the initial conditions. For example, if the test had been run after the drilling and after a 10-hour redistribution period, the overestimate would have been approximately 6 in. (15 cm) (20-25%). If the redistribution period had been 24 hours, the overestimate would have been 4 in. (10 cm) (15-20%). Although the amount of moisture in the fracture at the end of the 24-hour redistribution period is

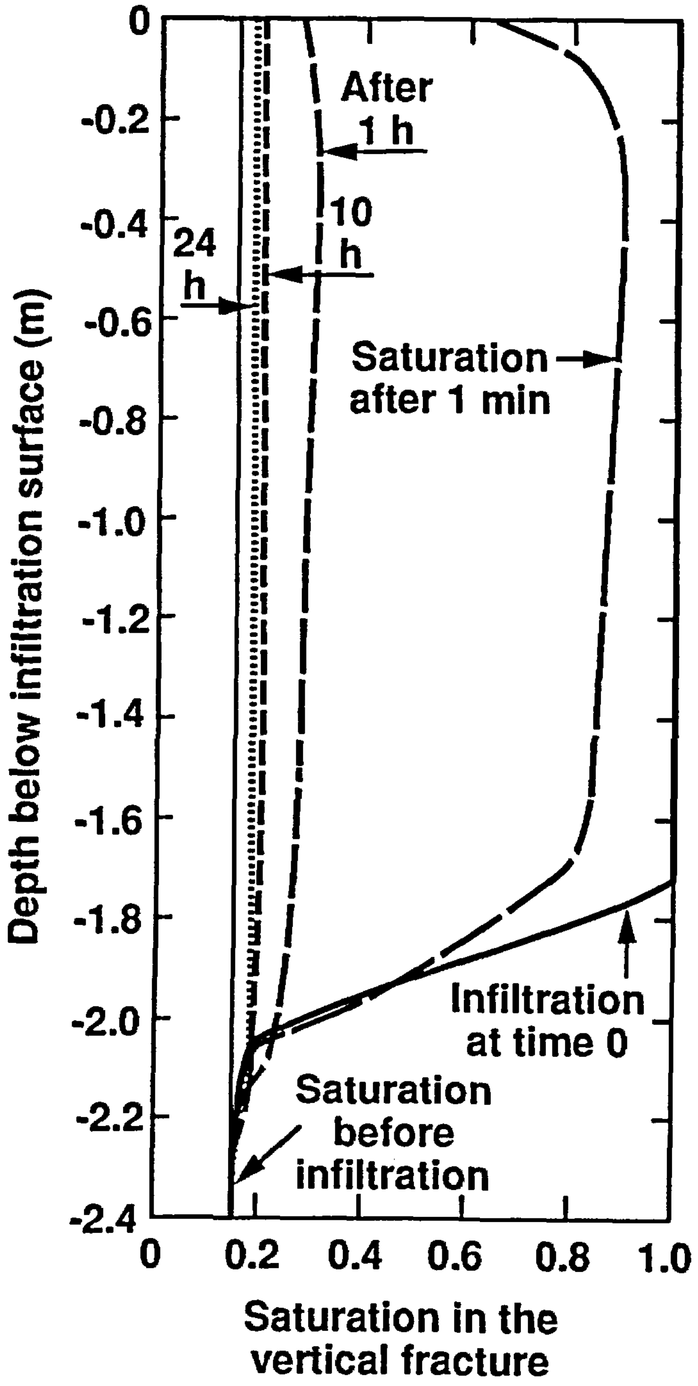


Fig. 13. Saturation as a function of depth and time for the hypothetical infiltration test (redrawn from Kwicklis and Hoxie, Ref. 16).

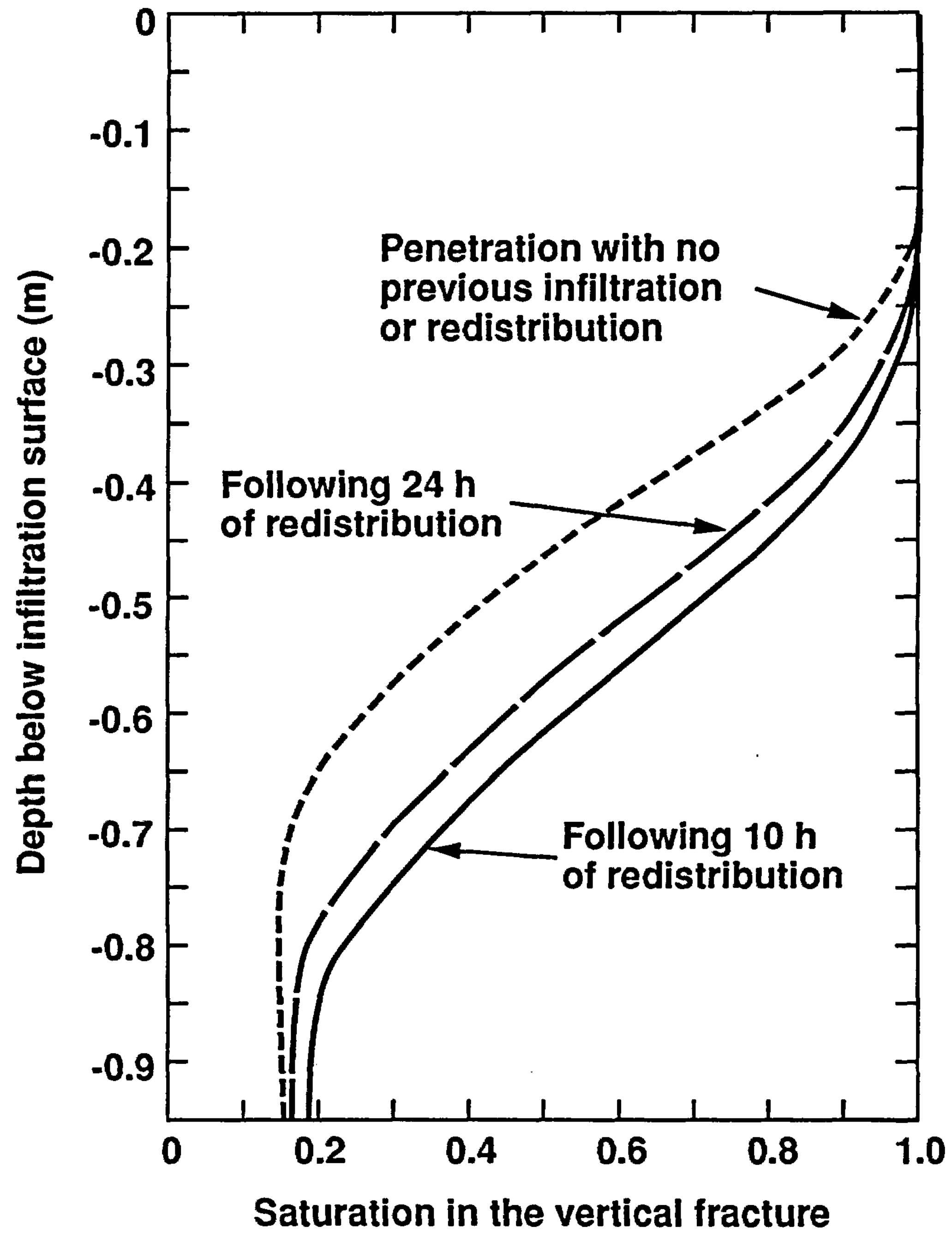


Fig. 14. Effect of a perturbation on the extent of water movement in a vertical fracture of the hypothetical infiltration test for various redistribution times (redrawn from Kwicklis and Hoxie, Ref. 16).

close to residual saturation, accelerated movement of water was observed in the fractures.

Kwicklis and Hoxie point out that the distance that the water may travel within the fractures depends on the imposed boundary head and on the largely unknown hydraulic properties of the fractures.[16] Table II, "Effect of Hydraulic Fracture Aperture on Water Penetration Distance," demonstrates this point.

TABLE II

EFFECT OF HYDRAULIC FRACTURE APERTURE
ON WATER PENETRATION DISTANCE

Imposed Boundary Head (ft)	(m)	Hydraulic Fracture Aperture (μm)	Time (min)	Water Penetration Distance (ft)	(m)
+ 0.66	+ 0.2	24	60	1.6	0.5
+65.6	+20.0	24	60	6.6	2
+ 0.66	+ 0.2	250	30	180.5	55

Kwicklis and Hoxie conclude that, although the present results suggest that the introduction of drilling fluids may not produce a significant impact locally on the matrix *in situ* condition, a pronounced effect could be produced within a hydraulically well-connected fracture system.[16] They do note, however, that these numerical simulations do not allow for air displacement and the entrapment that may impede the movement of water in both the fractures and matrix.

Numerical simulations carried out by Bodvarsson *et al.* at LBL address the effect of air and liquid water drilling on the time-dependent moisture conditions of nearby fractures and rock matrix blocks.[20] Bodvarsson *et al.* found that the most sensitive parameters are the apertures of the fractures and the corresponding fracture permeability. Figure 15 from the Bodvarsson report is a typical example of liquid saturation in the fracture for various recovery times. In the assumed fracture, the water front corresponding to complete (100%) saturation penetrates only to a depth of about 12 m. The water is absorbed from the fracture into the matrix, which then conducts the water into the adjoining rock, as shown in Figs. 16 and 17. These figures show that after 1 month the change in saturation resulting from wet drilling is only about 2%. If the SNL permeability curves shown in Fig. 7 had been used instead of the USGS permeability curves, Bodvarsson predicts a comparable change in saturation, again, only about 2%. If the effective fracture aperture was approximately 10 microns rather than the assumed value of 100 microns, the moisture front in Fig. 15 would likely be much less than the tens of meters predicted from the Bodvarsson *et al.* simulation.

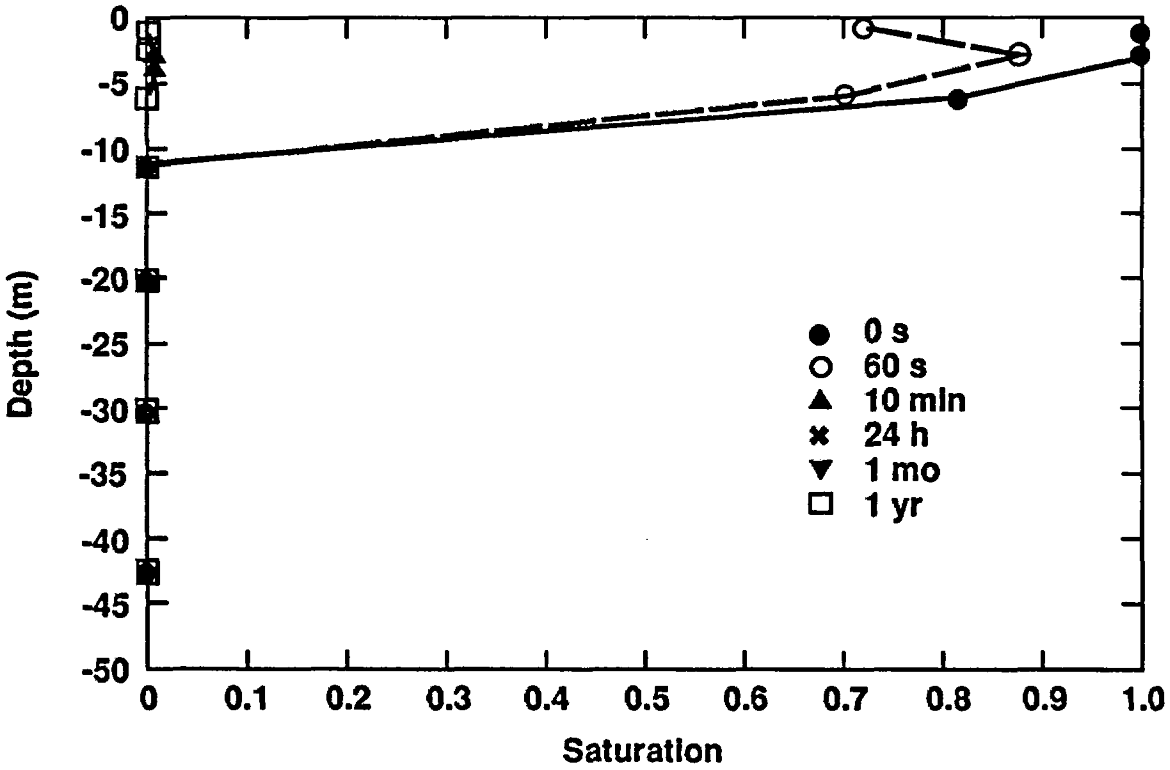


Fig. 15. USGS characteristic curves: liquid saturation in the fracture for various recovery times (redrawn from Bodvarsson *et al.*, Ref. 20).

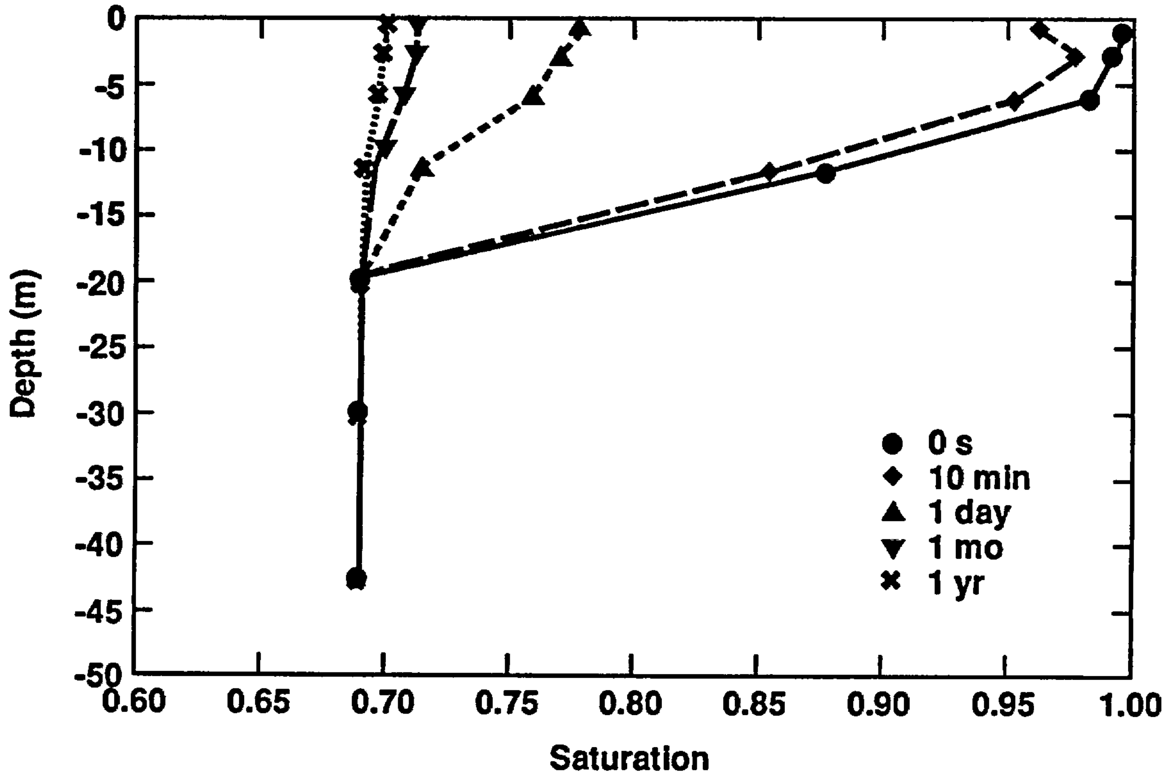


Fig. 16. USGS characteristic curves: liquid saturation in the matrix (0.5 mm from the fracture) for various recovery times (redrawn from Bodvarsson *et al.*, Ref. 20).

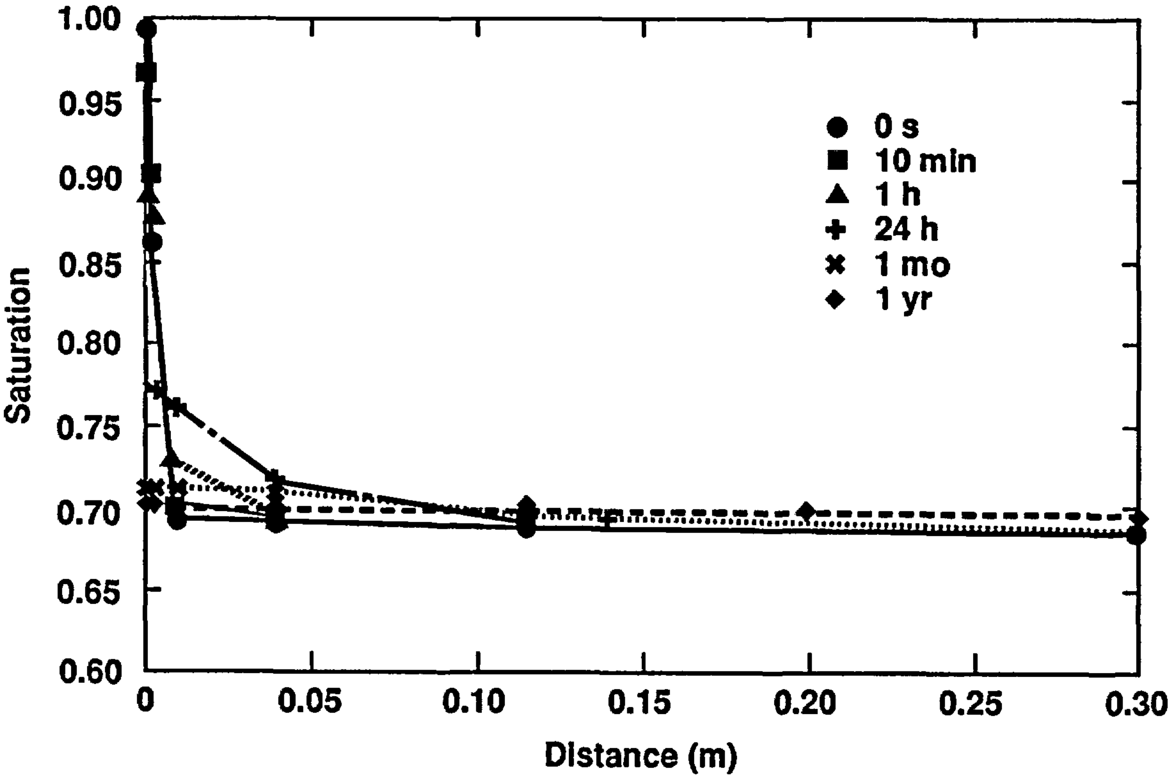


Fig. 17. USGS characteristic curves: liquid saturation in the matrix at a depth of 0.75 m for various recovery times (redrawn from Bodvarsson *et al.*, Ref. 20).

3.3.4 Transport of Hydrocarbons and Solvents

Hydrocarbon and solvent transport was not calculated to support this study, primarily because (1) the expected quantities are small compared with water, and (2) the water is not expected to saturate a large volume of rock.

3.3.5 Transport of Other Chemicals

As described earlier, the approach for analyzing the transport of other chemicals was to first analyze the transport of drilling fluid, and then to make inferences about other chemicals. The results of the drilling fluid transport calculations indicated that drilling fluid would not penetrate the repository block. This conclusion eliminated the need for additional transport calculations studying the transport of other elements and chemicals because it was assumed that they would be carried only as far as the drilling fluid was transported.

The issue of the transport of calcium from the shaft liner is addressed in Section B.6 of this report. There it is concluded that the calcium will precipitate as a result of a change in pH caused by the buffering capacity of the rock. Once out of solution, because it is no longer soluble, it will not be transported by groundwater.

4.0 RECOMMENDATIONS

The results of the ESF fluids and materials evaluation have not identified any fluids or materials that should be restricted during construction of the ESF. However, because a conservative approach should be taken with respect to the use of fluids and materials, LANL advocates using the techniques discussed in this section.

4.1 General Usage

For general usage, follow these guidelines.

1. As much as possible, use and remove instrumentation.
2. Clean up spills. Intuitively, proper administrative controls with respect to spills should mitigate the effects of accidents.
3. LANL recommends that hydrocarbons and solvents be limited to above ground areas as much as possible.
4. Limit the drilling fluid flow to the minimum practicable.
5. Avoid drilling into known large-aperture fractures.

4.2 Alternate Materials

Because we have not identified any materials that need to be restricted, the question of alternate materials is moot.

4.3 Mining of Infiltration and Bulk Permeability Rooms

Until more definitive information on fracture and matrix properties or advances in calculational techniques become available, LANL supports the USGS recommendations for preparation of the Infiltration and Bulk Permeability rooms. These include using dry mining techniques for the rooms and the adjacent portions of the access drifts within 100 ft (30 m) from the center of either room. Minimal-water techniques, such as air-mist drilling, should be used in the excavation of any underground opening that falls within a spherical radius of 300 ft (90 m) from the center of the Bulk Permeability Test room or within 200 ft (60 m) from the center of the Infiltration Test room. In addition, the bulkheads should be approved or planned with the intention of preserving the natural conditions.

4.4 Use of Tracers

Do not use tracers containing chlorine in Well J-13 water during the mining of the ESF; bromide ions can be used as a tracer during this phase of construction.

If bromide is used as a tracer for the Diffusion Test, do not use it as a tracer for drilling or for overcoring holes. In this case, use lithium chloride or sodium chloride.

Additional recommendations about the usage of tracers cannot be made until the details of the tracer system have been decided. At that point, this issue should be revisited.

4.5 Data from Prototype Testing

LANL believes that this study should be an ongoing process in which conclusions are updated as new information becomes available from sources such as prototype testing and early shaft testing. For instance, data obtained from prototype testing should be compared with calculations used in this study to ensure that the conclusions are consistent. If there are major inconsistencies, this whole issue will need to be revisited and the assumptions and conclusions revised accordingly.

Early shaft testing data should also be used as they become available. As Hunter points out, information for the repository horizon is sparse, especially where rock property data are concerned, making it difficult to draw quantitative conclusions about materials usage effects.[11] He notes, however, that almost 80% of the possible water loss occurs during the *in situ* phase. Therefore, he concludes that better estimates of how much water will actually be lost could be obtained based on the first 2-3 yr of shaft sinking experience.

4.6 Application of Results

As the design progresses, these results should be applied to the preparation of the following:

1. specifications for construction,
2. procedures for operation,
3. preparation of position papers for issues resolution, and
4. procedures for introduction of new materials.

4.7 Future Work

As mentioned earlier, the magnitude of the fluids and materials question necessitated that this evaluation address only normal operating and maintenance procedures. Accident scenarios have not been addressed. Accident prevention/mitigation is another important factor that must be considered at some future time.

5.0 CONCLUSIONS

The decision tree analysis methodology used to evaluate the chemical interactions between fluids and materials did not identify any reactions that have a significant impact on the candidate repository location. It did identify two classes of materials, hydrocarbons and solvents, whose use may have a minor impact on the site. Although we do not anticipate any effects more significant than those described here, LANL recommends that the use of hydrocarbons and solvents be limited to the surface whenever possible. It may even be worthwhile to develop procedures for cleaning up spills.

Analysis of the effect of added fluids and materials on microbial behavior revealed that organic fluids may be biodegradable and capable of supporting large numbers of microorganisms. This conclusion only strengthens our position that the materials identified in the chemical interaction analysis should be limited to the surface. Though the activity of microorganisms does promote changes in oxidation-reduction potential, LANL does not feel that this is necessarily a negative effect because the sorption of actinides by microorganisms may actually enhance the barrier between the repository and the accessible environment.

As far as groundwater chemistry is concerned, LANL believes that any variations introduced by added fluids and materials will be within the limits established in the water characterization goals for water contacting waste packages. Therefore, LANL concludes that the introduction of fluids and materials will not have a noticeable impact on the groundwater chemistry near the waste package.

Experts predict that of the nearly 33 million gallons (1.25×10^8 L) of drilling fluid used in ESF construction, only about 10% will be lost to the surroundings. Numerous reports on the use of drilling fluid in the construction of the ESF indicate that in the quantities proposed, drilling fluid will not have a significant impact on the long-term isolation capability of the repository. Though different models and different properties were used in the various calculations, the basic water penetration distances were similar and showed that the water would not penetrate very far. Perturbations were localized (in geometry). However, two of the tests proposed for the ESF, the Infiltration and the Bulk Permeability Tests, would be affected by the use of drilling fluid. Therefore, until more definitive information on fracture and matrix properties becomes available, LANL has recommended that the areas surrounding these tests be mined by using a combination of dry and minimal-water techniques.

Based on the results of drilling fluid calculations, we concluded that the transport of other materials would also have a minimal impact on the site. This is primarily attributed to their much smaller quantities relative to drilling fluid. The transport of calcium from the shaft liner was considered separately. This transport is not a problem because calcium will precipitate as the result of a change in pH caused by the buffering capacity of the rock. Once out of solution and therefore no longer soluble, the calcium will not be transported by groundwater.

Finally, LANL's analysis of the effect of the ventilation system indicates that the system will not have a significant drying effect in the short term (over a period of several months). Therefore, drying by ventilation cannot be expected to counteract the effects of wet mining the Infiltration and Bulk Permeability rooms. However, over a period of years, the ventilation system can be expected to remove more water than was added during construction.

The overall conclusion of this evaluation is that the use of fluids and materials during ESF construction will not have a significant impact on the site characterization data or on the ability of the site to isolate waste from the environment. Therefore, no materials have been prohibited from use. Restrictions have been placed on the use of hydrocarbons, solvents, chlorine, and instrumentation. The use of water in the vicinity of the Infiltration and Bulk Permeability rooms has also been restricted. All other materials are approved for use without restriction.

Again, extensive analyses of the effects of drilling fluid on saturation and transport were performed. For all other materials, the conclusions are based on a decision tree analysis, which resulted from the consensus of a panel. As more detailed identification and analysis of materials become available, the chemical interactions between the materials should be reevaluated by a more quantitative approach to ensure that assumptions used in this report are still valid.

APPENDIX A

ANCILLARY ATTACHMENTS

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
ACOUSTIC SENSORS						
1. Acoustic emission sensors	Slope Indicator Geomonitor MS_2	TBD	Canister-Scale Heater Experiment	Main Test level	8	1
2. Acoustic sensors	TBD	TBD	Plate Loading Test	Upper Demonstration Breakout Room (UDBR)	6	1
3. Acoustic sensors	TBD	TBD	Plate Loading Test	Main Test level	6	1
4. Acoustic sensors	TBD	TBD	Slot Strength Test	UDBR level	4	1
5. Acoustic sensors	TBD	TBD	Slot Strength Test	Main Test level	4	1
ANCHORS						
6. Anchor	Five per multiple-point borehole extensometer (MPBX)	Steel	Plate Loading Test	UDBR level	50	1
7. Anchor	Five per MPBX	Steel	Plate Loading Test	Main Test level	50	1
8. Anchor	TBD	Steel	Sequential Drift Mining Test	Main Test level	TBD	1
9. Anchor	Six per MPBX	Steel	Small-Scale Heater Experiment	UDBR level	12	1
10. Convergence anchor	TBD	Stainless steel	Sequential Drift Mining Test	Main Test level	TBD	1
11. Drift convergence anchor	TBD	Stainless steel	Demonstration Breakout Room Test	UDBR level	3	1
12. Drift convergence anchor	TBD	Stainless steel	Demonstration Breakout Room Test	Main Test level	3	1
13. MPBX anchor	TBD	Stainless steel	Canister-Scale Heater Experiment	Main Test level	TBD	1

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
14. Rock mounted anchors	TBD	Steel	Shaft Convergence Test	TBD	TBD	1,2
AUTOMOTIVE FLUIDS						
15. Antifreeze	Ethylene-glycol type; nonvolatile antifreeze cmpnd. for use in automobiles, trucks, & tractors; Fed. Spec. 0-A-548	Ethylene-glycol	Site Preparation	Surface	108 gal[a]	3,15
16. Antifreeze	same as above	Ethylene-glycol	Facilities construction	Surface	90 gal[a]	3,15
17. Antifreeze	same as above	Ethylene-glycol	Collar, headframe	Surface	75 gal	3
18. Antifreeze	same as above	Ethylene-glycol	Shaft sinking and testing	Surface	170 gal[a]	3,15
19. Antifreeze	same as above	Ethylene-glycol	Station construction and changeover	Surface	130 gal	3
20. Antifreeze	same as above	Ethylene-glycol	ES-2 shaft sinking	Surface	200 gal[a]	3,15
21. Antifreeze	same as above	Ethylene-glycol	Excavation	Surface	260 gal	3
22. Antifreeze	same as above	Ethylene-glycol	Test construction	Surface	60 gal	1
23. Antifreeze	same as above	Ethylene-glycol	Test support	Surface	220 gal	1
24. Brake fluid	Liquid	Petroleum-based oil (hydrocarbon)	Construction	Surface Underground	300 gal (50 gal)[b] 30 gal (5 gal)	3
25. Hydraulic fluid	Mobil 300 Hydrostatic Trnsmssn Fluid. Mobil P/N UA1911211711B. Liquid, bulk	Petroleum-based oil (hydrocarbon)	Construction	Surface Underground	500 gal (100 gal) 50 gal (10 gal)	3
26. Torque converter fluid	Three-stage torque converter fluid. For use on Moran 5 drill rig. Twin Disc Co.	Petroleum-based oil (hydrocarbon)	Construction	Surface Underground	100 gal (10 gal) 10 gal (1 gal)	3

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
27. Transmission fluid	Automatic transmission fluid	Petroleum-based oil (hydrocarbon)	All	Surface	600 gal (100 gal)	3
28. Transmission fluid	Automatic transmission fluid	Petroleum-based oil (hydrocarbon)	All	Underground	60 gal (10 gal)	3
29. Tanner gas	Liquid	TBD	Construction	Underground	10 gal	16
<u>BLASTING AGENTS</u>						
30. Detonator	IRECO Superdet/Milledet	Al, Cu, polyolefin	Construction underground	Surface and	TBD	16
31. Blasting Agents[c]	Same as above, ANFO, solid bulk	Prilled ammonium nitrate + 6% diesel oil, $3NH_4NO_3^+ (CH_2)_n$	Construction	Underground	TBD	16
32. High explosives	IRECO POWERGEL/IRESPLIT	NG, SN, AN, CCM	Construction	Underground	TBD	16
33. High explosives	DETAPRIME TYPE-UA	TBD	Construction	Underground	TBD	16
<u>CABLES/ TUBING</u>						
34. Air sampling tubes	With shutoff valve and connector for sampling flask, solid	Plastic	Canister-Scale Heater Experiment	Main Test level	4	1
35. Heat probe cable	Eight-conductor	Neoprene	Radial-Boreholes Test	Main shaft	2500 ft	4
36. Heat probe cable	TBD	Neoprene	Calico Hills Test	Main Test level	5000 ft	5
37. Heat probe cable	TBD	Neoprene	Calico Hills Test Drill Room	Calico Hills	1400 ft	5
38. Logging cable	TBD	Neoprene	Calico Hills Test	Main Test level	5000 ft	5

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
39. Logging cable	TBD	Neoprene	Calico Hills Test Drill Room	Calico Hills	5000 ft	5
40. Logging cable	Four-conductor	Neoprene	Radial-Boreholes Test	Main shaft	2500 ft	4
41. Thermocouple psychrometer cable	TBD	Neoprene	Calico Hills Test	Main Test level	5000 ft	5
42. Thermocouple psychrometer cable	TBD	Neoprene	Calico Hills Test	Calico Hills Drill Room	5000 ft	5
43. Thermocouple psychrometer cable	TBD	Neoprene	Radial-Boreholes Test	Main shaft	2500 ft	4
44. Tubing	Nylon	Nylon	Calico Hills Test	Main Test level	5000 ft	5
45. Tubing	Nylon	Nylon	Calico Hills Test	Calico Hills Drill Room	5000 ft	5
46. Tubing	Nylon, 1.27 cm	Nylon	Radial-Boreholes Test	Main shaft	2500 ft	4
47. Well screen	TBD	Stainless steel	Calico Hills Test	Main Test level	25	5
48. Well screen	TBD	Stainless steel	Calico Hills Test	Calico Hills Drill Room	25	5
49. Well screen	TBD	Stainless steel	Radial-Boreholes Test	Main shaft	80	4
<u>CONCRETE MATERIALS</u>						
50. Accelerator concrete	Sigunite, silka chemical or MDT enterprise. Pozolith. (wt: 5 lb/truckload)	Tricalcium silicate, calcium chloride, sodium chloride, or sodium hydroxide	TBD	At surface/ underground interface (shaft)	TBD	3
51. Bonding agent	Sta-crete, formula #15, for grout or mortar. Consists of epoxy base and hardener.	Polyether resin	Permanent	TBD	10 gal (10 gal)	3,16

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
52. Cement	Bulk type II, low alkali, must conform to ASTM Spec. C-150-70.	TBD	All	TBD	TBD	3
53. Cement	Por rock; fast setting	TBD	TBD	TBD	TBD	3
54. Cement	Portland ASTM C-150	Calcium silicate, tricalcium aluminum hydrate, tetracalcium aluminoferrite hydrate	TBD	TBD	TBD	3
55. Cement anchor	Sulphaset. For anchor bolt F-181. S/P 300 lb. drum. Randustrial Corp.	Sulfur	TBD	TBD	TBD	3
56. Cement grout	Celtite 10-35, 10-45, 10-50, or 10-60	Concrete, sand (SiO_2), water (H_2O)	TBD	TBD	TBD	6
57. Concrete plug	To seal heater hole at the collar; removeable	TBD	Canister-Scale Heater Experiment	Main Test level	1	1
58. Concrete plug	To seal radon monitoring hole at the collar	TBD	Canister-Scale Heater Experiment	Main Test level	1	1
59. Epoxy grout	Celtite 42-60 or 42-76	Epoxy (polyether resin)	TBD	TBD	TBD	7
60. Grout pre-mix	Nonshrink grout, metallic premix in 50 lb. moisture resistant bag. Embeco.	TBD	TBD	TBD	TBD	3
61. Retarder	Concrete retarder, shelf life 18 months, no substitutions. Pozolith #80.	TBD	TBD	TBD	TBD	3
62. Rockbolts	Solid, rebar type	Steel, ASTM-A 615-68 GR60 ASTM-A-307	TBD	TBD	TBD	7,16

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
63. Resin	R.B. Cartridge by DuPont Faslock or Celtite	Benzoyl peroxide, polyester resin, and inert fillers	TBD	Underground	TBD	16
DEFORMATION GAUGES						
64. Borehole deformation gauge	USBM model or Geochem three-component; wt. 1-3/4 lb (w/70-ft cable = 8 lb) each	Stainless steel	Excavation Effects Test	UDBR level	20	1,8
65. Borehole deformation gauge	Three-component	Stainless steel	Excavation Effects Test	Main Test level	20	1,8
66. Borehole deformation gauge	TBD	Stainless steel	Yucca Mountain Heated Block Experiment	Main Test level	2	1
67. Borehole deformation gauge	TBD	Stainless steel	Canister-Scale Heater Experiment	Main Test level	3	1
68. Borehole deformation gauge	Three-component	Stainless steel	Overcore Stress Test	UDBR level	1	1
69. Borehole deformation gauge	same as above	Stainless steel	Overcore Stress Test	Main Test level	1	1
70. Borehole deformation gauge	same as above	Stainless steel	Overcore Stress Test	Calico Hills Drill Room	1	1
DILATOMETERS						
71. Borehole dilatometer	Size EX -Menard pressuremeter. Measures thermal expansion and dilation of liquids or solids. (wt. 1 lb each)	Stainless steel	Overcore Stress Test	UDBR level	1	9
72. Borehole dilatometer	Size EX (same as above)	Stainless steel	Overcore Stress Test	Main Test level	1	9

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
73. Borehole dilatometer	Size EX (same as above)	Stainless steel	Overcore Stress Test	Calico Hills Drill Room	1	9
74. Borehole dilatometer	Size NX (same as above)	Stainless steel	Overcore Stress Test	UDBR level	1	9
75. Borehole dilatometer	Size NX (same as above)	Stainless steel	Overcore Stress Test	Main Test level	1	9
76. Borehole dilatometer	Size NX (same as above)	Stainless steel	Overcore Stress Test	Calico Hills Drill Room	1	9
ELECTRICAL ACCESSORIES						
77. Connection boxes	TBD, solid (2'x2'x8" @ 10 lb each)	Painted Steel	All tests	Main Test level	30	1
78. Ground bus	Copper, solid cable 3/8" diam.	Copper	All tests	Main Test level	500 ft	1
79. Grounded cable Tray	5" x 18"	Galvanized steel	All tests	Main Test level	2500 ft	1
80. Wiring	For transducers; 300 ft for each of 8000 channels (but multiplexed) so 500 conductors	TBD	All tests; removed after testing	Main Test level	TBD	1
EXTENSOMETERS						
81. Borehole extensometer	TBD - Slope Indicator or Mathak 89 mm	Stainless steel	Waste Package Environment Test	Main Test level	TBD	1
82. Horizontal surface extensometer	TBD - USBM-BDG	Stainless steel	Yucca Mountain Heated Block Experiment	Main Test level	8	1
83. MPBX	Multiple-point borehole extensometer; 89-mm IRAD or GeoCon (wt 10 lbs each)	Stainless steel	Canister-Scale Heater Experiment	Main Test level	3	1

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
84. MPBX	Multiple-point borehole extensometer; 73-mm Slope Indicator or MATHAK	Stainless steel	Demonstration Breakout Room Test	UDBR level	12	1
85. MPBX	Multiple-point borehole extensometer; 73-mm Slope Indicator or MATHAK	Stainless steel	Demonstration Breakout Room Test	Main Test level	12	1
86. MPBX	Multiple-point borehole extensometer	Stainless steel	Plate Loading Test	UDBR level	10	1
87. MPBX	Multiple-point borehole extensometer	Stainless steel	Plate Loading Test	Main Test level	10	1
88. MPBX	Multiple-point borehole extensometer	Stainless steel	Sequential Drift Mining	Main Test level	TBD	1
89. MPBX	Multiple-point borehole extensometer; rated sensitivity of 30 uM or better; installed in the liner	Stainless steel	Shaft Convergence Test	260 level	3	1,2
90. MPBX	same as above	Stainless steel	Shaft Convergence Test	650 level	3	1,2
91. MPBX	same as above	Stainless steel	Shaft Convergence Test	Main Test level	3	1,2
92. MPBX	Multiple-point borehole extensometer	Stainless steel	Small-Scale Heater Experiment	UDBR level	2	1
93. MPBX	Multiple-point borehole extensometer	Stainless steel	Yucca Mountian Heated Block Experiment	Main Test level	2	1
94. Rod extensometer	TBD	Stainless steel	Shaft Convergence Test	TBD	TBD	1
FLAT JACKS						
95. Flat jack and/or loading cells	GeoCon IRAD (4-1/2 x 11-1/2 x 1-1/4") (wt 1.75 lb each)	Steel	Excavation Effects Test	UDBR level	40	8

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
96. Flat jack and/or loading cells	TBD	Steel	Excavation Effects Test	Main Test level	40	8
97. Flat jacks	TBD (wt. 3 lb each)	Steel	Plate Loading Test	UDBR level	2	1
98. Flat jacks	TBD	Steel	Plate Loading Test	Main Test level	2	1
99. Flat jacks	TBD	Steel	Slot Strength Test	UDBR level	TBD	1
100. Flat jacks	TBD	Steel	Slot Strength Test	Main Test level	TBD	1
101. Flat jack	TBD	Steel	Yucca Mountain Heated Block Experiment	Main Test level	TBD	1
FLOW METERS						
102. Flow meter	TBD	Glass & steel	Excavation Effects Main Test levels & UDBR	Underground	15	1,8
FUELS						
103. Diesel fuel	Liquid	Hydrocarbon	TBD	Surface Underground	280,000 gal 280,000 gal	3
104. Fuel oil	Stove oil, grade FS#1, Fed. Spec. VV-F-815.	TBD	TBD	Surface	TBD	3
105. Gasoline	Automotive, regular unleaded (minimum Octane 87) that meets the requirement for Group 1 Distribution IAW Fed. Spec. VV-6-1690C and all amendments thereto.	TBD	All	Surface	10,000 gal	3
106. Kerosene	Low sulphur, Grade No. 1K	TBD	Construction	Surface	1000 gal	3

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
GASES						
107. Halon	(extinguishers)	Fluorinated hydrocarbon	TBD	TBD	TBD	
108. Acetylene	Used for metal welding and cutting	C_2H_2	Construction	Surface and underground	TBD	
109. Carbon dioxide	Fire extinguisher gas Air	CO_2	TBD	Surface and underground	TBD	
110. Carbon monoxide	Combustion by-product, air	CO	TBD	TBD	TBD	
111. Oxygen	Welding and first aid gas, air	O_2	TBD	In air	TBD	
112. Nitrogen dioxide[c]	Product of explosion (blasting agent combustion)	NO_2	TBD	TBD	TBD	
113. Nitrogen	N_2	N_2	TBD	In air	TBD	
114. Nitrogen	N_2	N_2	Packers	Underground	180 kg	10
115. Nitrogen	N_2; for injection into cored hole	N_2	Radial-Boreholes Test	Main shaft	TBD	1
GAUGES (Other)						
116. Displacement gauge	TBD	Stainless steel	Waste Package Environment Test	Main Test level	TBD	1
117. Gauge	TBD	Stainless steel	Plate Loading Test	UDBR level	TBD	1
118. Gauge	TBD	Stainless steel	Plate Loading Test	Main Test level	TBD	1
119. Moisture-sensing device	TBD	Stainless steel	Canister-Scale Heater Experiment	Main Test level	4	1
120. Permeability-measuring device	TBD	Stainless steel	Yucca Mountain Heated Block Experiment	Main Test level	3	1

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
121. Pressure gauge	TBD	Stainless steel	Small-Scale Heater Experiment	UDBR level	2	1
122. Radon-monitoring device	TBD	Stainless steel	Canister-Scale Heater Experiment	Main Test level	1	1
123. Relative humidity gauge	TBD	Stainless steel	Small-Scale Heater Experiment	UDBR level	2	1
HEAT DISSIPATION PROBES						
124. Heat dissipation probes	Standard, (wt. 2-3 lb each)	Stainless steel	Calico Hills Test	Main Test level	10	5
125. Heat dissipation probes	Same as above	Stainless steel	Calico Hills Test	Calico Hills Drill Room	10	5
126. Heat dissipation probes	TBD	Stainless steel	Radial-Boreholes Test	Main Shaft	100	1,4
HEATERS						
127. Heater	TBD	Stainless steel	Canister-Scale Heater Experiment	Main Test level	1	1
128. Heater unit	1200 W	Stainless steel	Small-Scale Heater Experiment	UDBR level	1	1
129. Heater	TBD	Stainless steel	Waste Package Environment Test	Main Test level	1	1
130. Heater	1000 W	Stainless steel	Yucca Mountain Heated Block Experiment	Main Test level	14	1
HYDRAULIC PRESSURE CELLS						

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
131. Hydraulic pressure cells (HPC)	Rated sensitivity of 7 KP (wt. 5 lb each)	Stainless steel	Shaft Convergence Test	260 level	6	1,2
132. HPC	same as above	Stainless steel	Shaft Convergence Test	650 level	6	1,2
133. HPC	same as above	Stainless steel	Shaft Convergence Test	Main Test level	6	1,2
LUBRICANTS						
134. Gear lubricant	Straight mineral, SAE 90. For heavy duty trucks w/Fuller Roadrunner transmissions.	Petroleum-based oil	TBD	Surface	50 gal (2 gal)	3
135. Gear lubricant	Universal SAE 90 EP API-GL 5 type in accordance with MIL. Spec. MIL-L-2105.	Petroleum-based oil	TBD	Surface and underground	500 gal (20 gal)	3
136. Grease	Multipurpose, extreme pressure, KLGI grade 2, lithium base, Timken load ok, 40 lb. minimum. Continuous operating range -25 to +250°F, minimum dropping point 370°F, IAW SAEJ310 (1216-6000 for hand grease gun.)	Petroleum-based oil	Site preparation	Surface	376 lb.[a]	3,15
137. Grease	same as above	Petroleum-based oil	Facilities construction	Surface	171 lb.[a]	3,15
138. Grease	same as above	Petroleum-based oil	Collar, headframe	Surface	295 lb.	3
139. Grease	same as above	Petroleum-based oil	ES-1 shaft sinking	Surface and underground	799 lb.[a]	3,15
140. Grease	same as above	Petroleum-based oil	Station construction and changeover	Surface Underground	611 lb. 465 lb.	3 3
141. Grease	same as above	Petroleum-based oil	ES-2 shaft sinking	Surface Underground	940 lb.[a] [a]	3,15 3,15

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
142. Grease	same as above	Petroleum-based oil	Excavation	Surface Underground	1357 lb. 1628 lb.	3 3
143. Grease	same as above	Petroleum-based oil	Test construction	Surface Underground	288 lb. 208 lb.	3 3
144. Grease	same as above	Petroleum-based oil	Test support	Surface Underground	1232 lb. 858 lb.	3 3
145. Silicon lubricant	Liquid aerosol	Silicon-based	Waste Package Environment Test	Underground	TBD	6,7
146. Water pump grease	McKay P/N 410.	Petroleum-based oil	TBD	Underground	15 gal	3
147. Rope dressing	Containing moly disulfide. Jet Lube WLD. Liquid 35# bulk.	MoS_2	Construction-testing (1 & 2 sh. hoist ropes)	Surface and underground.	1000 lbs	3
148. Wheel bearing lubricant	Heavy duty, KLGI Gr. 2, Timkin OK, 40 lb. load, dropping point 475°F minimum, oil viscosity 85 at 210°F. For misc. vehicles with disc brakes.S/P 35 lb/cn.	Petroleum-based oil	TBD	Surface	75 lb	3
NEUTRON PROBES						
149. Neutron probe	TBD. Assume: 1' diam. x 2' long (5 lb each)	Stainless steel	Canister-Scale Heater Experiment	Main Test level	2	1
150. Neuron probe	TBD	Stainless steel	Small-Scale Heater Experiment	UDBR level	1	1
151. Neutron probe	TBD	Stainless steel	Yucca Mountain Heated Block Experiment	Main Test level	1	1
152. Neutron probe	TBD	Stainless steel	Diffusion test	Main Test level	1	1
153. Neutron probe	TBD	Stainless steel	Diffusion test Drill Room	Calico Hills	1	1

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
OILS						
154. Engine oil	20W40	Petroleum-based oil	TBD	Surface	200 gal (20 gal)	3
155. Hydraulic oil	Light grade,anti-wear,150 SUS.	Petroleum-based oil	Site preparation	Surface	290 gal[a]	3,15
156. Hydraulic oil	same as above	Petroleum-based oil	Facilities construction	Surface	166 gal[a]	3,15
157. Hydraulic oil	same as above	Petroleum-based oil	Collar, headframe	Surface	255 gal	3
158. Hydraulic oil	same as above	Petroleum-based oil	ES-1 shaft sinking	Surface	558 gal[a]	3,15
159. Hydraulic oil	same as above	Petroleum-based oil	Station construction and changeover	Surface Underground	452 gal 109 gal	3 3
160. Hydraulic oil	same as above	Petroleum-based oil	ES-2 shaft sinking	Surface Underground	656 gal[a] [a]	3,15 3,15
161. Hydraulic oil	same as above For LHD & Jumbos	Petroleum-based oil	Excavation	Surface Underground	884 gal 884 gal	3 3
162. Hydraulic oil	same as above	Petroleum-based oil	Test construction	Surface Underground	154 gal 84 gal	3 3
163. Hydraulic oil	same as above	Petroleum-based oil	Test support	Surface Underground	616 gal 308 gal	3 3
164. Hydraulic transmission oil	John Deere Hy-Gard # AR-69445.	Petroleum-based oil	TBD	Surface	50 gal (2 gal)	3
165. Light lubricating oil	TBD	Petroleum-based oil	TBD	Surface	TBD	6
166. Lubricating oil	15W-40, approved for Detroit, Caterpillar, Mack truck EO-J, Cummins, International Harvester diesels. G/M No. 6136M, Ford	Petroleum-based oil	Construction	Surface and underground	750 gal (30 gal)	3

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
	No. M2C153A, IAW Specs. API CD, SF, MIL-L-2104C, MIL-L-46152.					
167. Lubricating oil	For compressors with automatic oilers. No substitute due to safety reasons. Compressed air.	Petroleum-based oil	TBD	Surface	200 gal	3
168. Lubricating oil	Series 3, SAE 30 per MIL SPEC. MIL 2104C.	Petroleum-based oil	Construction and test support	Surface and underground	10 gal	3
169. Road oil	Chip-seal to cover ESF pad and 800-1000 ft of road	Petroleum-based oil	TBD	Surface	4,000,000 gal	3
170. Rock drill oil	Molubaloy oil for rock drill.	Petroleum-based oil	Site preparation	Surface	65 gal[a]	3,15
171. Rock drill oil	same as above	Petroleum-based oil	ES-1 shaft sinking	Underground	238 gal[a]	3,15
172. Rock drill oil[a]	same as above	Petroleum-based oil	ES-2 shaft sinking	Underground	280 gal	15
173. Rock drill oil	same as above	Petroleum-based oil	Station construction and changeover	Underground	312 gal	3
174. Water soluble oil mixture	Texaco, soluble oil-D with water, Ratio 1:5	Petroleum-based oil	Overcore Stress Test	Underground	20-30 gal	11
PACKERS						
175. Packer	Standard - LYNES	Rubber (Neoprene)	Calico Hills Test and Calico Hills Drill Room	Main Test level	2	5
176. Packer	Standard	Rubber (Neoprene)	Diffusion Test and Calico Hills Drill Room	Main Test level	2	12
177. Packer	Standard	Rubber (Neoprene)	Excavation Effects Test	UDBR and Main Test levels	9	8
178. Packer	Standard	Rubber (Neoprene)	Radial-Boreholes Test	Main Shaft	80	4

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
PAINTS						
179. Cleaning solvents	Liquid	Turpentine	TBD	Surface	30 gal (5 gal)	3,6
180. Spray paint	Liquid enamel	TBD	TBD	Surface and underground	1000 cans	13
181. Galvanized metal coating	Shaft	Steel	TBD	Surface and underground	TBD	
182. Machine parts cleaning solvent	Liquid H_2O solution	TBD	TBD	Surface and underground	50 gal	
183. Steam cleaning compound	Biodegradable detergent	TBD	TBD	Surface and underground	TBD	
PIEZOMETERS						
184. Piezometers	TBD	Stainless steel	Perched-Water Test	TBD	TBD	1,14
ROCK BOLT LOAD CELLS						
185. Rock bolt load cell	TBD (wt. 25 lb each)	Stainless steel	Demonstration Breakout Room Test	UDBR level	40	1
186. Rock bolt load cell	TBD	Stainless steel	Demonstration Breakout Room Test	Main Test level	40	1
187. Rock bolt load cell	TBD	Stainless steel	Plate Loading Test	UDBR level	24	1
188. Rock bolt load cell	TBD	Stainless steel	Plate Loading Test	Main Test level	24	1

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
SEISMOMETERS						
189. Seismometer	With self-contained oscillographic recorders	TBD	Demonstration Breakout Room Test	UDBR level	1	1
190. Seismometer	With self-contained oscillographic recorders	TBD	Demonstration Breakout Room Test	Main Test level	1	1
STRESSMETER						
191. Borehole stressmeter	TBD (wt. 10 lb each)	Stainless steel	Sequential Drift-Mining Test	Main Test level	TBD	1
192. Borehole stressmeter	TBD	Stainless steel	Slot Strength Test	UDBR level	2	1
193. Borehole stressmeter	TBD	Stainless steel	Slot Strength Test	Main Test level	2	1
THERMOCOUPLES						
194. Thermocouples	TBD (wt. 2 lb each)	Pt, Cu, Ni, Al in Neoprene sheath	Canister-Scale Heater Experiment	Main Test level	6	1
195. Thermocouples	TBD	Pt, Cu, Ni, Al in Neoprene sheath	Radial-Boreholes Test	Main shaft	100	1,4
196. Thermocouples	TBD	Pt, Cu, Ni, Al in Neoprene sheath	Small-Scale Heater Experiment	UDBR level	59	1
197. Thermocouples	TBD	Pt, Cu, Ni, Al in Neoprene sheath	Waste Package Environment Test	Main Test level	486	1
198. Thermocouples	TBD	Pt, Cu, Ni, Al in Neoprene shealth	Yucca Mountain Heated Block Experiment	Main Test level	16	1

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
THERMOCOUPLE PSYCHROMETERS						
199. Thermocouple psychrometers	TBD (wt. 10 lb each)	Pt, Cu, Ni, Al in Neoprene sheath	Radial-Boreholes Test	Main shaft	100	1,4
200. Thermocouple psychrometers	Standard	Pt, Cu, Ni, Al in Neoprene sheath	Calico Hills Test	Main Test level	10	5
201. Thermocouple psychrometers	Standard	Pt, Cu, Ni, Al in Neoprene sheath	Calico Hills Test	Calico Hills Drill Room	10	5
THERMAL PROBES						
202. Thermal probe	30 cm long, 0.3 cm diameter	Stainless steel	Yucca Mountain Heated Block Experiment	Main Test level	1	1
TRACERS (Known Canidates)						
203. Fluorescein dye	TBD	Organic compound	Testing	Surface and underground	10 lb	10
204. Lithium bromide	LiBr	LiBr	Water supply/testing	Surface and underground	3000 lb	10,13
205. Lithium chloride	LiCl	LiCl	Testing	Underground	100 lb	10
206. Perfluorinated benzoic acid[c]	Organic compound	(Ring structure)	Testing	Underground	1 lb	10
207. Sodium bromide	NaBr	NaBr	Testing	Surface and underground	3000 lb	10
208. Sodium chloride	NaCl	NaCl	Testing	Underground	TBD	10
209. Sulfur hexafluoride	SF_6	SF_6	Testing	Underground	50 lb	1

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
TRANSDUCERS						
210. Pressure transducer	Used at UDBR and Main Test levels (wt. 2 lb each)	Stainless steel	Excavation Effects Test	TBD	15	1,8
211. Pressure transducer	0.001 psi sensitivity	Stainless steel	Calico Hills Test	Main Test level	15	5
212. Pressure transducer	0.001 psi sensitivity	Stainless steel	Calico Hills Test	Calico Hills Drill Room	15	5
213. Pressure transducer	TBD	Stainless steel	Diffusion Test	Main Test level	1	12
214. Pressure transducer	TBD	Stainless steel	Diffusion Test	Calico Hills Drill Room	1	12
215. Semiconductor pressure transducers	TBD	Stainless steel	Radial-Boreholes Test	Main shaft	100	1,4
216. Strain-Gauge pressure transducers	TBD	Stainless steel	Radial-Boreholes Test	Main shaft	100	1,4
217. Transducers	TBD	Stainless steel	Waste Package Environment Test	Main Test level	TBD	1
TRANSFORMERS						
218. Transformer	Linear variable (Variac) (wt. 50 lb)	Steel and copper	Yucca Mountain Heated	Main Test level Block Experiment	1	1
ULTRASONICS						
219. Ultrasonics	TBD (wt. 10 lb)	Stainless steel	Yucca Mountain Heated Block Experiment	Main Test level	4	1

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
VALVES						
220. Valve	As needed to monitor perched water (wt. 2 lb)	Iron (steel)	Perched-Water Test	Underground	TBD	1,14
WATER (With Tracers)						
221. Water	Compaction	H_2O	Site preparation	Surface	4,611,600 gal[a]	3,15
222. Water	Dust control	H_2O	Site preparation	Surface	2,160,000 gal[a]	3,15
223. Water	Dust control and compaction	H_2O	Facilities construction	Surface	2,160,000 gal[a]	3,15
224. Water	Drilling and dust control	H_2O	Collar, headframe	Underground	1,050,000 gal	3
225. Water	Dust control and misc.	H_2O	Shaft sinking and testing	Surface	4,760,000 gal[a]	3,15
226. Water	Drilling and wetdown	H_2O	Shaft sinking and testing	Underground	74,200 gal	3
227. Water	Concrete washdown & cleanup	H_2O	Shaft sinking and testing	Underground	14,840 gal	3
228. Water	Drilling and wetdown	H_2O	Station construction and changeover	Underground	129,200 gal	3
229. Water	Rockbolt drilling	H_2O	Station construction and changeover	Underground	12,920 gal	3
230. Water	Concrete and construction washdown and cleanup	H_2O	Station construction and changeover	Underground	42,500 gal	3
231. Water	Dust control and misc.	H_2O	Station construction and changeover	Surface	1,820,000 gal	3
232. Water	Dust control and misc.	H_2O	ES-2 shaft sinking	Surface	2,800,000 gal[a]	3,15

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
233. Water	Drilling and wetdown[a]	H_2O	ES-2 shaft sinking	Underground	55,000 gal[a]	3,15
234. Water[a]	Concrete washdown & cleanup	H_2O	ES-2 shaft sinking	Underground	11,000 gal[a]	15
235. Water	Dust control and misc.	H_2O	Excavation	Surface	7,280,000 gal	3
236. Water	Drift drilling and wetdown	H_2O	Excavation	Underground	985,720 gal	3
237. Water	Rockbolting	H_2O	Excavation	Underground	98,572 gal	3
238. Water	Water bath scrubbers[a]	H_2O	Excavation	Underground	546,000 gal	3,15
239. Water	Dust control and misc.	H_2O	Test construction	Surface	420,000 gal	3
240. Water	Concrete and construction washdown and cleanup	H_2O	Test construction	Underground	63,000 gal	3
241. Water	Dust control and misc.	H_2O	Test support	Surface	3,850,000 gal	3
242. Water	Misc. cleanup and wetdown	H_2O	Test support	Underground	77,000 gal	3
MISC.						
243. Air foam, air soap	Detergent drilling fluid siponate 301-50	Sodium alpha-olefin sulfonate $NaCl_3$ and $NaCHO_3$	TBD	Underground	TBD	16
244. Aluminum pins	20 cm. In a rosette pattern consisting of 3 pins per rosette; 6 rosettes	6061 Al, solid Si, Cr, Mg, Cu	Yucca Mountain Heated Block Experiment	Main Test level	18	1
245. Aluminum pins	Row of pins.	Al, Si, Cr, Mg, Cu	Yucca Mountain Heated Block Experiment	Main Test level	TBD	1
246. Borehole deflectometer conduit	TBD	TBD	Sequential Drift-Mining Experiment	Main Test level	TBD	1
247. $CaCl_2$ - tire ballast	Liquid	H_2O and $CaCl_2$	TBD	Surface	2000 lbs	3

A.1. TABLE A-1. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
248. Fire extinguishing chemicals	Liquid, powder	Potassium bicarbonate	TBD	Surface and underground	450 lbs	3
249. Chemical toilet deodorizers	TBD	TBD	Construction/testing	Surface and underground	300 lbs	3
250. Plastic sheeting/ plastic lining	Impermeable - Kynarfilm or polyethylene film or Porter 003-13 woven filament nylon	Solid	Infiltration Test	Underground	100 lbs	1
251. Restraint column	TBD (wt. 200 lb each)	Steel	Plate Loading Test	UDBR level	2	1
252. Restraint column	TBD. (wt. 200 lb each)	Steel	Plate Loading Test	Main Test level	2	1
253. Rubber from tires	TBD	Rubber: Butadiene or latex	TBD	TBD	4000 lb (1000 lb)	
254. Sand	To fill a frame 13 ft long by 13 ft wide by 1-1.6 ft deep.	SiO_2	Infiltration Test	Main Test level (wt. 27,000 lb)	169-270 cu. ft.	1
255. Silica flour	Used to couple heat dissipation probes with the rock matrix.	SiO_2	Radial-Boreholes Test	Underground	300 lb	4
256. Soldering and welding fluxes	TBD	Tin, lead, arsenic, silver	TBD	Surface and underground	10 lb	6,7
257. Steel casing for vertical boreholes	2-1/2" Diameter. Outside diameter 2-7/8 inches. ASTM A53 type E or S, Grade B	Iron (steel)	Infiltration Test	Underground	100 ft	1
258. Wire mesh (ground support)	Chain link, 9 ga, 2" mesh x 84" wide	Galvanized steel	TBD	Surface and underground	TBD	1
259. Wooden sand-bed frame	13 ft long by 13 ft wide and approx. 1-1.6 ft deep.	Pine (cellulosic lignin)	Infiltration Test	Underground	250 lb	1
260. UPS w/flywheel	2500 lb flywheel	Steel	Testing	Underground	2500 lb	

A.1. TABLE A-I. NNWSI FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	DESCRIPTION	CHEMICAL COMPOSITION	WHEN USED	WHERE USED	QUANTITY	INFORMATION SOURCE
261. Emergency lighting battery	wt. 50 lb	Lead and sulfuric acid	Testing	Underground	30	
262. IDS equipment	TBD	TBD	TBD	TBD	TBD	TBD

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[a] Revision

[b] Gallons in parentheses are lost to formation.

[c] EPA Extremely Hazardous Materials List.

Information Sources

1. Los Alamos National Laboratory, Nevada Nuclear Waste Storage Investigations (NNWSI) Exploratory Shaft Facility (ESF) Subsystem Design Requirements document, Appendix B.

2. NNWSI Exploratory Shaft Test Plan, Revision 1, August 1985 (Edited January 1986), pages 3.2-5 through 3.2-18.

3. V. Gong, "Useable Fluids on Exploratory Shaft Facility Project," Reynolds Electrical & Engineering Co., Inc. memorandum 540-01-41, to M. P. Kunich (December 19, 1985).

4. NNWSI Exploratory Shaft Test Plan, Revision 1, August 1985 (Edited January 1986), pages 4.6-10 through 4.6-15.

5. NNWSI Exploratory Shaft Test Plan, Revision 1, August 1985 (Edited January 1986), pages 4.8-5 through 4.8-15.

6. J. L. Yow, Jr., "Fluids and Dry Chemicals for ESF Test Operations," Lawrence Livermore National Laboratory memorandum WP: 2-86, to T. Merson (January 7, 1986).

7. J. L. Yow, Jr., "Fluids and Dry Chemicals for ESF Test Operations," Lawrence Livermore National Laboratory memorandum WP: 3-86, to V. Gong (January 7, 1986).

8. NNWSI Exploratory Shaft Test Plan, Revision 1, August 1985 (Edited January 1986), pages 4.7-1 through 4.7-10.

9. NNWSI Exploratory Shaft Test Plan, Revision 1, August 1985 (Edited January 1986), page 3.3-15.

10. A. E. Norris, "Fluid Requirements for Exploratory Shaft Facility Test Operations," Los Alamos National Laboratory memorandum TWS-INC7-01/86-2, to T. J. Merson (January 6, 1986).

11. W. L. Ellis, "ESF Overcore Stress Tests- Fluid Usage Information," United States Department of the Interior Geological Survey memorandum, to T. J. Merson (January 7, 1986).

12. NNWSI Exploratory Shaft Test Plan, Revision 1, August 1985 (Edited January 1986), page 4.12-19.

13. R. B. Scott, United States Department of the Interior Geological Survey memorandum, reference: fluids and tracers to be used in shaft and drift mapping, to T. Merson and J. Tegtmeier (January 13, 1986).

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15. P. C. Hulse, "NNWSI ESF Project Updated Estimate of the Types of Fluids and Quantities Expected to be Exposed to the Site Environment by REECo and REECo's Subcontractor During Construction and Operation of the ESF," Reynolds Electrical & Engineering Co., Inc. (April 7, 1987).

16. Database submission from Fenix and Scisson, A.I. #87-450, J. Scott to K. A. West (June 29, 1987).

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A.2. TABLE A-II. NNWSI CONDENSED FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	PHASE	ITEM NUMBERS	WHERE USED	RECOVERY	QUANTITY (wt in kg)	BOX NO.
ACOUSTIC SENSORS						
Acoustic emission sensors	In situ	1	Underground	Recovered	8	10N or 10Q--No Concern
Acoustic sensors	In situ	2,3	Underground	Recovered	12	10N or 10Q--No Concern
Acoustic sensors	In situ	4,5	Underground	Recovered	8	10N or 10Q--No Concern
ANCHORS						
Anchor	In situ	6,7	Underground	Permanent	100	10L--No Concern
Anchor	In situ	8	Underground	Permanent	TBD	10L--No Concern
Anchor	In situ	9	Underground	Permanent	12	10L--No Concern
Convergence anchor	In situ	10	Underground	Permanent	TBD	10L--No Concern
Drift convergence anchor	Construction	11	Underground	Permanent	3	10L--No Concern
	Construction	12			3	
MPBX anchor	In situ	13	Underground	Permanent	TBD	10L--No Concern
Rock mounted anchors	Construction	14	Underground	Permanent	TBD	10L--No Concern
AUTOMOTIVE FLUIDS						
Antifreeze	Construction	15-21	Surface	Recovered	1033 gal ($4.34x10^3$ kg)	7M
	In situ	22,23	Surface	Recovered	280 gal ($1.18x10^3$ kg)	7N
Brake fluid	Construction	24	Surface	Recovered	300 gal (1022 kg)	8M
				Permanent	50 gal (170 kg)	8O
	In situ	24	Underground	Recovered	30 gal (102 kg)	8N
				Permanent	5 gal (17 kg)	8R
Hydraulic fluid	Construction	25	Surface	Recovered	500 gal (1703 kg)	8M
				Permanent	100 gal (341 kg)	8O
	In situ	25	Underground	Recovered	50 gal (170 kg)	8N
				Permanent	10 gal (34 kg)	8R

A.2. TABLE A-II. NNWSI CONDENSED FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	PHASE	ITEM NUMBERS	WHERE USED	RECOVERY	QUANTITY (wt in kg)	BOX NO.
Torque converter fluid	Construction	26	Surface	Recovered	100 gal (341 kg)	8M
				Permanent	10 gal (34 kg)	8R
			Underground	Recovered	10 gal (34 kg)	8P
				Permanent	1 gal (3 kg)	8R
Transmission fluid	Construction	27	Surface	Recovered	600 gal (2043 kg)	8M
				Permanent	100 gal (341 kg)	8O
	In situ	28	Underground	Recovered	60 gal (204 kg)	8N
				Permanent	10 gal (34 kg)	8R
Tanner gas	Construction	29	Underground	TBD	10 gal	TBD
BLASTING AGENTS						
Detonator	Construction	30	Surface	TBD	TBD	TBD
			Underground	TBD	TBD	TBD
Blasting agents	Construction	31	Underground	TBD	TBD	TBD
High explosives	Construction	32	Underground	TBD	TBD	TBD
High explosives	Construction	33	Underground	TBD	TBD	TBD
CABLES/ TUBING						
Air sampling tubes	In situ	34	Underground	Recovered	4	TBD
Heat probe cable	Construction	35	Underground	Recovered	2500 ft	TBD
Heat probe cable	In situ	36,37	Underground	Recovered	10,000 ft	TBD
Logging cable	In situ	38,39	Underground	Recovered	10,000 ft	TBD
	Construction	40			2500 ft	TBD
Thermocouple psychrometer cable	In situ	41,42	Underground	Recovered	10,000 ft	TBD
	Construction	43			2500 ft	TBD
Tubing	In situ	44,45	Underground	Recovered	10,000 ft	TBD
	Construction	46			2500 ft	TBD

A.2. TABLE A-II. NNWSI CONDENSED FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	PHASE	ITEM NUMBERS	WHERE USED	RECOVERY	QUANTITY (wt in kg)	BOX NO.
Well screen	In situ	47,48	Underground	Permanent	50	TBD
	Construction	49	Underground	Permanent	80	TBD
CONCRETE MATERIALS						
Accelerator concrete	Construction	50	At surface/ underground interface (shaft)	TBD	TBD	TBD
Bonding agent	TBD	51	TBD	TBD	10 gal (10 gal)	6R
Cement	TBD	52,53,54	TBD	TBD	TBD	TBD
Cement anchor	TBD	55	TBD	TBD	TBD	TBD
Cement grout	TBD	56	TBD	TBD	TBD	TBD
Concrete plug	In situ	57,58	Underground	TBD	2	TBD
Epoxy grout	TBD	59	Underground	TBD	TBD	TBD
Grout pre-mix	TBD	60	Underground	TBD	TBD	TBD
Retarder	TBD	61	Underground	TBD	TBD	TBD
Rockbolts	Construction	62	Underground	Permanent	(probably large)	10L--No Concern
Resin	TBD	63	Underground	TBD	TBD	TBD
DEFORMATION GAUGES						
Borehole deformation gauge	Construction	64,65,68,69,70	Underground	Recovered	43 (156 kg)	10M--No Concern
Borehole deformation gauge	In situ	66,67	Underground	Recovered	5 (18 kg)	10Q--No Concern
DILATOMETERS						
Borehole dilatometer	Construction	71-76	Underground	Recovered	6 (3 kg)	10P--No Concern

A.2. TABLE A-II. NNWSI CONDENSED FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	PHASE	ITEM NUMBERS	WHERE USED	RECOVERY	QUANTITY (wt in kg)	BOX NO.
ELECTRICAL ACCESSORIES						
Connection boxes	In situ	77	Underground	Recovered	30 (136 kg)	10N--No Concern
Ground bus	In situ	78	Underground	Recovered	500 ft (13,892 kg)	10K--No Concern
Grounded cable tray	In situ	79	Underground	Recovered	2500 ft (prob. large)	10K--No Concern
Wiring	In situ	80	Underground	Recovered	TBD (prob. large)	10K--No Concern
EXTENSOMETERS						
Borehole extensometer	In situ	81	Underground	Recovered	TBD	TBD
Horizontal surface extensometer	In situ	82	Underground	Recovered	8	TBD
MPBX	In situ	83,86,87,88,92,93	Underground	Recovered	27 (122 kg)	10N--No Concern
	Construction	84,85,89,90,91	Underground	Recovered	33 (150 kg)	10M--No Concern
Rod extensometer	Construction	94	Underground	Recovered	TBD	TBD
FLAT JACKS						
Flat jack and/or loading cells	Construction	95-96	Underground	Recovered	80 (64 kg)	10P--No Concern
	In situ	97-98	Underground	Recovered	4 (3 kg)	10Q--No Concern
Flat jacks	In situ	99,100	Underground	Recovered	TBD	TBD
Flat jack	In situ	101	Underground	Recovered	TBD	TBD
FLOW METERS						
Flow meter	Construction	102	Underground	Recovered	15 (less than 100 kg)	10P--No Concern
FUELS						
Diesel fuel	Construction	103	Surface	Recovered	280,000 gal	8J

A.2. TABLE A-II. NNWSI CONDENSED FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	PHASE	ITEM NUMBERS	WHERE USED	RECOVERY	QUANTITY (wt in kg)	BOX NO.
					(9.5 x 10^5 kg)	
			Underground	Recovered	280,000 gal (9.5 x 10^5 kg)	8K
Fuel oil	Construction	104	Surface	TBD	TBD	TBD
Gasoline	Construction	105	Surface	Recovered	10,000 gal (3.4 x 10^4 kg)	8J
	In situ	105	Underground	Recovered	10,000 gal (3.4 x 10^4 kg)	8K
Kerosene	Construction	106	Surface	Recovered	1000 gal (3.4 x 10^3 kg)	8M
GASES						
Halon	TBD	107	TBD	TBD	TBD	GAS
Acetylene	Construction	108	Surface and underground	TBD	TBD	GAS
Carbon dioxide	TBD	109	Surface and underground	TBD	TBD	GAS
Carbon monoxide	TBD	110	TBD	TBD	TBD	GAS
Oxygen	TBD	111	TBD	TBD	TBD	GAS
Nitrogen dioxide	TBD	112	TBD	TBD	TBD	GAS
Nitrogen	TBD	113	TBD	TBD	TBD	GAS
Nitrogen	In situ	114	Underground	TBD	180 kg	GAS
Nitrogen	Construction	115	TBD	TBD	TBD	GAS
GAUGES (Other)						
Displacement gauge	In situ	116	Underground	Recovered	TBD	TBD
Gauge	In situ	117,118	Underground	Recovered	TBD	TBD

A.2. TABLE A-II. NNWSI CONDENSED FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	PHASE	ITEM NUMBERS	WHERE USED	RECOVERY	QUANTITY (wt in kg)	BOX NO.
Moisture sensing device	In situ	119	Underground	Recovered	4	10Q--No Concern
Permeability measuring device	In situ	120	Underground	Recovered	3	10Q--No Concern
Pressure gauge	In situ	121	Underground	Recovered	2	10Q--No Concern
Radon monitoring device	In situ	122	Underground	Recovered	1	10Q--No Concern
Relative humidity gauge	In situ	123	Underground	Recovered	2	10Q--No Concern
HEAT DISSIPATION PROBES						
Heat dissipation probes	In situ	124,125	Underground	Recovered	20 (28 kg)	10Q--No Concern
	Construction	126	Underground	Recovered	100 (140 kg)	10M--No Concern
HEATERS						
Heater	In situ	127,128,129	Underground	Recovered	3 (less than 400 kg)	10N--No Concern
Heater	In situ	130	Underground	Recovered	14 (less than 10 kg)	10N--No Concern
HYDRAULIC PRESSURE CELL						
Hydraulic pressure cells (HPC)	Construction	131,132,133	Underground	Recovered	18 (42 kg)	10P--No Concern
LUBRICANTS						
Gear lubricant	Construction & In situ	134	Surface	Recovered	50 gal (170 kg)	8M
			Surface	Permanent	2 gal (6.8 kg)	8R
Gear lubricant	Construction	135	Surface	Recovered	250 gal (850 kg)	8M
				Permanent	10 gal (34 kg)	8R
	In situ	135	Surface	Recovered	200 gal (680 kg)	8N
				Permanent	8 gal (27 kg)	8R

A.2. TABLE A-II. NNWSI CONDENSED FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	PHASE	ITEM NUMBERS	WHERE USED	RECOVERY	QUANTITY (wt in kg)	BOX NO.
			Underground	Recovered	50 gal (170 kg)	8N
				Permanent	2 gal (7 kg)	8R
Grease, total	Construction	136-142	Surface	Recovered	4150 lb (1.4 x 10^4 kg)	8J
		139-142	Underground	Recovered	2893 lb (1080 kg)	8M
Grease, total	In situ	143,144	Surface	Recovered	1520 lb (567 kg)	8N
		143,144	Underground	Recovered	1066 lb (398 kg)	8N
Silicone lubricant	In situ	145	Underground	TBD	TBD	TBD
Water pump grease	In situ	146	Underground	Recovered	15 gal (51 kg)	8Q
Rope dressing	Construction	147	Surface	Recovered	250 lb (93 kg)	8P
			Underground	Recovered	250 lb (93 kg)	8P
	In situ	147	Surface	Recovered	250 lb (93 kg)	8Q
			Underground	Recovered	250 lb (93 kg)	8Q
Wheel bearing lubricant	Construction	148	TBD	Recovered	37 lb (14 kg)	8P
	In situ	148		Recovered	37 lb (14 kg)	8Q
NEUTRON PROBES						
Neutron probe	In situ	149-153	Underground	Recovered	6 (12 kg)	10Q--No Concern
OILS						
Engine oil	Construction	154	Surface	Recovered	100 gal (341 kg)	8M
				Permanent	20 gal (68 kg)	8R
	In situ	154	Surface	Recovered	100 gal (341 kg)	8N
				Permanent	20 gal (68 kg)	8R
Hydraulic oil	Construction	155-160	Surface	Recovered	2377 gal (8.1 x 10^3 kg)	8M
		159,160	Underground	Recovered	109 gal (371 kg)	8M
	In situ	161-163	Surface	Recovered	1654 gal (5.6 x 10^3 kg)	8N
		161-163	Underground	Recovered	1276 gal (4.3 x 10^3 kg)	8N
Hydraulic transmission oil	Construction	164	Surface	Recovered	25 gal (85 kg)	8P
				Permanent	1 gal (3 kg)	8R
	In situ	164	Surface	Recovered	25 gal (85 kg)	8Q
				Permanent	1 gal (3 kg)	8R

A.2. TABLE A-II. NNWSI CONDENSED FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	PHASE	ITEM NUMBERS	WHERE USED	RECOVERY	QUANTITY (wt in kg)	BOX NO.
Light lubricating oil	TBD	TBD	Surface	TBD	TBD	TBD
Lubricating oil	Construction	165-168	Surface	Recovered	700 gal (2.4×10^3 kg)	8M
				Permanent	30 gal (102 kg)	8O
			Underground	Recovered	50 gal (170 kg)	8M
	In situ		Surface	Recovered	100 gal (340 kg)	8N
			Underground	Recovered	100 gal (340 kg)	8N
Road oil	Construction	169	Surface	Recovered	3,000,000 gal (1.02×10^7 kg)	8J
	In situ	169	Surface	Recovered	1,000,000 gal (3.4×10^6 kg)	8K
Rock drill oil	Construction	170	Surface	Recovered	65 gal (221 kg)	8M
		171-173	Underground	Recovered	830 gal (2.8×10^3 kg)	8M
Water soluble oil mixture	Construction	174	Underground	Recovered	20-30 gal (68-102 kg)	7P
PACKERS						
Packer	In situ	175-176	Underground	Recovered	80 lb (30 kg)	6Q
	Construction	177-178	Underground	Recovered	1780 lb (667 kg)	6M
PAINTS						
Cleaning solvents	Construction	179	Surface	Recovered	15 gal (51 kg)	8P
				Permanent	5 gal (17 kg)	8R
	In situ	179	Surface	Recovered	15 gal (51 kg)	8Q
				Permanent	TBD	TBD
Spray paint	Construction	180	Surface	Recovered	250 cans (93 kg)	8P
			Underground	Recovered	250 cans (93 kg)	8P
	In situ	180	Surface	Recovered	250 cans (93 kg)	8Q
			Underground	Recovered	250 cans (93 kg)	8Q
Galvanized metal coating	TBD	181	TBD	TBD	TBD	TBD

A.2. TABLE A-II. NNWSI CONDENSED FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	PHASE	ITEM NUMBERS	WHERE USED	RECOVERY	QUANTITY (wt in kg)	BOX NO.
Machine parts cleaning solvent	Construction	182	Surface	Recovered	15 gal (57 kg)	7P
			Underground	Recovered	10 gal (38 kg)	7P
	In situ	182	Surface	Recovered	15 gal (57 kg)	7Q
			Underground	Recovered	10 gal (38 kg)	7Q
Steam cleaning compound	TBD	183	Surface	TBD	TBD	TBD
			Underground	TBD	TBD	TBD
PIEZOMETERS						
Piezometers	Construction	184	Underground	Recovered	TBD	TBD
ROCK BOLT LOAD CELLS						
Rock bolt load cell	Construction	185-186	Underground	Recovered	80 (746 kg)	10M--No Concern
Rock bolt load cell	In situ	187-188	Underground	Recovered	48 (448 kg)	10N--No Concern
SEISMOMETERS						
Seismometer	Construction	189,190	Underground	Recovered	TBD	TBD
STRESSMETER						
Borehole stressmeter	In situ	191-193	Underground	Recovered	at least 4 (14 kg)	10N or 10Q: No Concern
THERMOCOUPLES						
Thermocouples	In situ	194	Underground	Recovered	6 (5 kg)	6Q--No Concern
Thermocouples	Construction	195	Underground	Recovered	100 (75 kg)	6P--No Concern
Thermocouples	In situ	196-198	Underground	Recovered	561 (1122 lb, 42 kg)	6Q--No Concern
THERMOCOUPLE PSYCHROMETERS						

A.2. TABLE A-II. NNWSI CONDENSED FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	PHASE	ITEM NUMBERS	WHERE USED	RECOVERY	QUANTITY (wt in kg)	BOX NO.
Thermocouple psychrometers	Construction	199	Underground	Recovered	100 (373 kg)	6M--No Concern
Thermocouple psychrometers	In situ	200,201	Underground	Recovered	20 (74 kg)	6Q--No Concern
THERMAL PROBES						
Thermal probe	In situ	202	Underground	Recovered	1 (16 g)	10Q--No Concern
TRACERS (Known Candidates)						
Fluorescein dye	In situ	203	Underground	Recovered	10 lb (3.7 kg)	7Q
Lithium bromide	Construction In situ	204 204	Surface Underground	Recovered Recovered	1500 lb (560 kg) 1500 lb (560 kg)	1M--No Concern 1N--No Concern
Lithium chloride	In situ	205	Underground	Recovered	100 lbs (37 kg)	1Q--No Concern
Perfluorinated benzoic acid	In situ	206	Underground	Recovered	1 lb (0.4 kg)	8Q
Sodium bromide	In situ	207	Surface and underground	Recovered	3000 lb (1120 kg)	1N--No Concern
Sodium chloride	In situ	208	Underground	TBD	TBD	TBD
Sulfur hexafluoride	In situ	209	Underground	TBD	50 lbs	GAS
TRANSDUCERS						
Pressure transducer	Construction In situ	210,215,216 211-214,217	Underground Underground	Recovered Recovered	215 (161 kg) 32 (24 kg)	10M--No Concern 10N--No Concern
TRANSFORMERS						
Transformer	In situ	218	Underground	Recovered	1 (19 kg)	10Q--No Concern

A.2. TABLE A-II. NNWSI CONDENSED FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	PHASE	ITEM NUMBERS	WHERE USED	RECOVERY	QUANTITY (wt in kg)	BOX NO.
ULTRASONICS						
Ultrasonics	In situ	219	Underground	Recovered	4 (15 kg)	10Q--No Concern
VALVES						
Valve	Construction	220	Underground	Recovered	TBD	10P--No Concern
WATER (With Tracers)						
Water	Construction	221-223,225,231, 232,235	Surface	Recovered	2.6×10^7 gal	3J
				Permanent	2.6×10^6 gal	3L
		224,226-230, 233,234	Underground	Recovered	1.4×10^6 gal	3J
				Permanent	1.4×10^5 gal	3L
	In situ	239,241	Surface	Recovered	4.3×10^6 gal	3K
				Permanent	4.3×10^5 gal	3L
		236-238,240,242	Underground	Recovered	1.8×10^6 gal	3K
				Permanent	1.8×10^5 gal	3L
MISC.						
Air foam/air soap	Construction	243	Underground	TBD	TBD	TBD
Aluminum pins	In situ	244,245	Underground	Recovered	at least 18	10N or 10Q: No Concern
Borehole deflectometer conduit	In situ	246	TBD	TBD	TBD	TBD
$CaCl_2$- tire ballast	Construction	247	Surface	Recovered	2000 lb (746 kg)	3M
	In situ			Recovered	2000 lb (746 kg)	3N
Fire extinguishing chemicals	Construction	248	Surface	Recovered	450 lb (168 kg)	1M--No Concern
	In situ		Underground	Recovered	450 lb (168 kg)	1N--No Concern
Chemical toilet deodorizers	Cnstrctn/In situ	249	Underground	TBD	300 lb (112 kg)	TBD
Plastic sheeting/ plastic lining	In situ	250	Underground	Recovered	100 lb (37 kg)	6Q--No Concern

A.2. TABLE A-II. NNWSI CONDENSED FLUIDS AND MATERIALS DATABASE

FLUID/MATERIAL	PHASE	ITEM NUMBERS	WHERE USED	RECOVERY	QUANTITY (wt in kg)	BOX NO.
Restraint column	In situ	251,252	Underground	Recovered	800 lb (298 kg)	10N--No Concern
Rubber from tires	TBD	253	TBD	Recovered	4000 lb (1493 kg)	6M or 6N: No Concern
				Permanent	1000 lb (373 kg)	6O--No Concern
Sand	In situ	254	Underground	Recovered	169-270 cu. ft (10 kg)	2K or 2N: No Concern
Silica flour	Construction	255	Underground	Recovered	300 lb (112 kg)	2M--No Concern
Soldering and welding fluxes	TBD	256	Surface and Underground	Recovered	10 lb (3.7 kg)	2P or 2Q: No Concern
Steel casing for vertical boreholes	In situ	257	Underground	Recovered	100 ft	10N--No Concern
Wire mesh (ground support)	In situ	258	Surface and Underground	Recovered	624,375 sq ft	10K or 10N: No Concern Ref. Francis WX-4-8898
Wooden sand-bed frame	In situ	259	Underground	Recovered	250 lb (93 kg)	6Q--No Concern
UPS w/flywheel	In situ	260	Underground	Recovered	2500 lb (933 kg)	10N--No Concern
Emergency lighting battery	In situ	261	Underground	Recovered	30 (560 kg)	3N
IDS equipment	TBD	262	TBD	TBD	TBD	TBD

A.3 Chemical Inventory from the Waste Isolation Pilot Plant

ABBREVIATIONS FOR CHEMICAL INVENTORY LIST

ME	Mine Engineering
EXP	Experimental Program
MO	Mine Operations
MT/UG	Maintenance Underground
UG/IS	Underground Instrument Shed
SNL/UG	Experimental Operations Shop

CHEMICAL INVENTORY

LOCATION	TRADENAME	CHEMICAL NAME	QUANTITY
MT/UG	5-56	PETROLEUM DISTILLATES	4 CANS
MT/UG	ACETYLENE	ACETYLENE	1 CYL
MT/UG	ANTIFREEZE	ETHYLENE CLYCOL	600 GAL
MT/UG	AUTO BODY FILLER	STYRENE MONOMER	1 CAN
MT/UG	AUTO BODY PLASTIC FILLER	STYRENE MONOMER	1 GAL
MT/UG	BATTERY CLEANER	2-BUTOXY-ETHANOL	9 CANS
MT/UG	BATTERY PROTECTOR	TOLUENE, ACETONE	5 CANS
MT/UG	CHROME ALUMINUM PAINT	XYLENE	2 CAN
MT/UG	ELECTRONIC CLEANER	1,1,1 TRICHLOROETHANE	2 CANS
MT/UG	ENGINE SPRAY PAINT	TOLUENE, METHYL ISOBUTYL KT	12 CANS
MT/UG	FIBERGLASS RESIN	STYRENE MONOMER	1 PT
MT/UG	FLEET FINISH ENAMEL		1 GAL
MT/UG	FLEETWELD 5P	WELDING RODS	5 LBS
MT/UG	FOAMING ENGINE DEGREASER	1,1,1 TRICHLORETHANE	12 OZ
MT/UG	FR HYDRAULIC FLUID	ETHYLENE GLYCOL	55 GAL
MT/UG	FREON TF DEGREASER	CHLOROFLUOROCARBON	4 12OZ
MT/UG	GEAR OIL 320	PETROLEUM HYDROCARBON	110 GAL
MT/UG	GREASE EATER	PETROLEUM DISTILLATES	1 CAN
MT/UG	HD BRAKE FLUID		4 GAL
MT/UG	HYDRAULIC OIL 134		2 GAL
MT/UG	JET WELD 3	WELDING RODS	2 BXES
MT/UG	LATEX FLOOR PAINT		1 GAL
MT/UG	MISTIC METAL MOVER	1,1,1 TRICHLORETHANE	2 LBS
MT/UG	MULTI PURPOSE CEMENT	TETRAHYDROFURAN, MEK	8 OZ
MT/UG	MYSTERY OIL	PETROLEUM DISTILLATES	1 GAL
MT/UG	NEVER-SEEZ		15 PT
MT/UG	OXYGEN	OXYGEN	1 CYL
MT/UG	PAINT THINNER	MINERAL SPIRITS	1 GAL
MT/UG	PLASTIC CLEANER	PETROLEUM DISTILLATES	5 OZ
MT/UG	RED OXIDE METAL PRIMER	IRON OXIDE	8 GAL
MT/UG	RTV SILICONE SEALER		4 TUBE
MT/UG	SAFETY SOLVENT	1,1,1 TRICHLOROETHANE	12 OZ
MT/UG	SAFETYKLEEN	MINERAL SPIRITS	5 GAL
MT/UG	SHIELD WELD 85	WELDING RODS	0
MT/UG	SOLDER	4.4 RESIN	3 BX
MT/UG	SOLDER	60/40	3 BX
MT/UG	SPRAY PAINT	TOLUENE, ACETONE	33 CANS
MT/UG	SUNFO RUST HIB PRIMER	ZINC CHROMATE	1 GAL
MT/UG	SUPREME CHAIN & BAR		1 GAL
MT/UG	UNDERCOATING		4 CANS
MT/UG	WATERLESS HAND CLEANER	PETROLEUM DISTILLATES	4 GAL
MT/UG	ZINC-IT PAINT	XYLENE, ZINC	0
MT/UG	FLEETWELD 35	WELDING RODS	2 BXES
MT/UG	ALLOY STEEL WELDING STUD	ALLOY STEEL	2 BXES
MT/UG	ALUMINUM ALLOY WLDG STUD	ALLUMINUM ALLOY GRADES	2 BXES
MT/UG	ARMORCOTE ENAMEL WHITE	ALKYD ENAMEL	6 GAL

CHEMICAL INVENTORY

LOCATION	TRADENAME	CHEMICAL NAME	QUANTITY
MT/UG	CARBON STEEL WLDG STUD	STEEL AISI CODES:1008,1010	2 BXES
MT/UG	CERAMIC STDY WLDG FERRUL	CERAMIC FERRULE	2 BXES
MT/UG	4100 METL/CRYLIC WHITE	PAINT PRODUCT	3 GAL
MT/UG	OXYGEN	OXYGEN	1 CYL
MT/UG	STAINLESS STEEL WLDG STUD	STAINLESS STEEL: AISI 304	0
MT/UG	UGL 80W-90 & 85W-140	PETROLEUM HYDROCARBON	0
MT/UG	UNICLEAN 100	C13-C14 ISOPARAFFINS	0
MT/UG	PAL-WELD	ZINC CHLORIDE, AMMONIUM CL	0
MT/UG	TAP MAGIC CUTTING FLUID	1,1,1, TRICHLOREHTANE	0
MT/UG	THERMASOLVE	PETROLEUM HYDROCARBON	0
MT/UG	D-A TORQUE FLUID	BLENDED PETROLEUM	0
MT/UG	KRYLON INT/EXT ENSMEL	ACETONE, MEK, ALCOHOL	0
MT/UG	CHROME ALUMN. PAINT	XYLENE	24 OZS
MT/UG	ANTIFREEZE	ETHYLENE GLYCOL	30 GAL
MT/UG	4102 LIGHT BASE	METL/CRYLIC	8 GALS
MT/UG	4176 WHITE PRIMER	METL/CRYLIC	9 GALS
MT/UG	5505 CLEAR BASE	VALSPAR	3 GALS
MT/UG	1285 GLOSS ENAMEL	VALSPAR	3 GALS
MT/UG	74-677 SAFETY YELLOW		2 GALS
MT/UG	CRC 5-56	CRC	108 OZS
MT/UG	AUTOMATIC TRANSMISSION FL		2 QTS
MT/UG	TEXACO DERON 2	TEXAMATIC 2	1 GAL
MT/UG	CHAIN & BAR OIL	ITASCO	1 GAL
MT/UG	PLASTIC CLEANER	PETROLEUM DISTILLATES	16 OZS
MT/UG	SAFETY SOLVENTS	MINERAL SPIRITS	3 GALS
MT/UG	SOLDER	KESTER SOLDER	2 LBS
MT/UG	ROSIN CORE 60/40	KESTER SOLDER	2 LBS
MT/UG	HYD OIL	CONOCO 68A	200 GALS
MT/UG	30 WT ENG OIL	FLEET SAE 30	110 GALS
MT/UG	90 WT GEAR OIL	CONOCO 80-90	110 GALS

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CHEMICAL INVENTORY

LOCATION	TRADENAME	CHEMICAL NAME	QUANTITY
ME	AROX EP 150 (ROCK DRILL	PETROLEUM LUBRICATING OIL	0
ME	BAKER ANALYZED REAGENT	POTASSIUM FERROCYANIDE	12 KG
ME	FLUORESCENT	PETROLEUM DISTILLATES	1 CAN
ME	HI-TECH ANTI-RUST SPRAY	TOLUOL & PETROLEUM DIST.	1 CAN
ME	ISOTHERM 902-200	PHOSPHOROUS, FORMALDEHYDE	0
ME	RAMSET	POWER CARTRIDGES	4000 RD
ME	ZINCPRIME 4Z WATR BASE		0

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CHEMICAL INVENTORY

LOCATION	TRADENAME	CHEMICAL NAME	QUANTITY
EXP	MM A-12 ADHESIVE EPOXY		1

CHEMICAL INVENTORY

LOCATION	TRADENAME	CHEMICAL NAME	QUANTITY
MO/UG	DIESEL FUEL		200 GAL
MO/UG	SPRAY PAINT	ACETONE, TOLUENE	24 CANS

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CHEMICAL INVENTORY

LOCATION	TRADENAME	CHEMICAL NAME	QUANTITY
UG/IS	ANTI FRICTION COOLANT		1 CAN
UG/IS	ANTISTATIC SPRAY		12 BTL
UG/IS	CIRCUIT BOARD CLEANER	TRICHLOROETHANE	3 CANS
UG/IS	CLEANING FLUID	TRICHLOROETHANE	2 CANS
UG/IS	EFFA DUSTER	CHLOROFLUOROCARBON	15 CYL
UG/IS	EPOXY	EPOXY-AMINE RESINS	100 CT
UG/IS	EPOXY ADHESIVE-SCOTCHWELD	EPOXY ADHESIVE	12 CANS
UG/IS	FOAM SEALANT	POLYMERIC ISOCYANATE	7 CANS
UG/IS	GLASS CLEANER		2 CANS
UG/IS	KRYLON PAINT	PETROLEUM DISTILLATES	10 CANS
UG/IS	LEAK-TEC	FORMULA 277-C	1 BTL
UG/IS	RED INSULATING VARNISH	TOLUENE	1 BTL
UG/IS	RUG CLEANER		1 CAN
UG/IS	TAPE HEAD CLEANER	TRICHLOROTRIFLUOROETHANE	2 BTL
UG/IS	TYPE H TONER		5 GAL
UG/IS	WD-40	PETROLEUM DISTILLATES	10 CANS
UG/IS	WINDSHIELD WAHSER	METHANOL	1 BTL

CHEMICAL INVENTORY

LOCATION	TRADENAME	CHEMICAL NAME	QUANTITY
SNL/UG	2 V LANTERN BATTERIES		30 CANS
SNL/UG	30 W OIL	CRUDE OIL	24 BTL
SNL/UG	483-08 SYNTHETIC ENAMEL	XYLENE, POLYISOCYANATE	3 PTS
SNL/UG	ALKYD FLAT ENAMEL	MINERAL SPIRITS	5 GAL
SNL/UG	BATTERY PROTECTOR	TOLUENE, ACETONE	10 CANS
SNL/UG	CRC LECTRA MOTIVE	1,1,1 TRICHLOROETHANE	20 CANS
SNL/UG	INSULATING VARNISH	TOLUOL, XYLOL	15 CANS
SNL/UG	M-S FREON TF SOLVENT	TRICHLOROTRIFLUOROETHANE	5 CANS
SNL/UG	MITEE	OIL, SULFUR	2 GAL
SNL/UG	NASON AUTO FINISH	TOLUENE ALCOHOL	2 GAL
SNL/UG	NASON AUTO PAINT	LEAD, TOLUENE, PET. DIST	5 GAL
SNL/UG	SPRAY ARAMA PAINT	TOLUENE, XYLENE	35 CANS
SNL/UG	TAP MAGIC	1,1,1 TRICHLOROETHANE	5 GAL
SNL/UG	TEXACO REGAL OIL		5 GAL
SNL/UG	TRANSMISSION FLUID		5 GAL
SNL/UG	URESCO ARDROX P653 PENET.	BCI GROUP	1 GAL
SNL/UG	WAGNER BRAKE FLUID	DIETHYLENE GLYCOL	5 GAL
SNL/UG	WD-40	PETROLEUM DISTILLATES	20 CANS
SNL/UG	WINDEX WINDOW CLEANER	AMMONIA D	4 QT
SNL/UG	EPOWELD 8173A, 8778	EPICHLOROHYDRIN	0
SNL/UG	POR-ROK ANCHORING CEMENT		0
SNL/UG	AMMONIUM PERSULFATE	DIAMMONIUM PEROXYDISULFATE	500 MG
SNL/UG	EFFA DUSTER(FREON 12)	DICHLORODIFLUOREMETHANE	12 CANS
SNL/UG	RED GLPT VARNISH		0
SNL/UG	FREON TF SOLVENT	HALOGENATED HYDROCARBON	6 CANS
SNL/UG	WD-40		0

A.4 Instructions for Using Table A-III: Materials Sorting

To evaluate the impact of a new material proposed for use in ESF construction, answer the following questions and proceed as directed.

1. Is the material an inorganic material, an organic material, or a metal?

2. Is the material in question a solid, a liquid, or a gas?
   If the material is a solid, proceed to "Solid."
   If the material is a liquid, proceed to "Liquid."
   If it is a gas, proceed directly to Table A-IV.

3. If the material is a solid, is it soluble in water?
   If so, proceed to "Soluble."
   If not, proceed to "Insoluble."

   If the material is a liquid, is it miscible in water?
   If so, proceed to "Miscible."
   If not, proceed to "Immiscible."

4. Does the material react with the rock?
   Reaction with the rock is defined as any process that retards or removes the substance from the transporting stream or alters the composition or character of the substance.

   If the material reacts with the rock (according to the definition above), proceed to "Reactive." Otherwise, proceed to "Nonreactive."

5. What quantity of material is used?
   The designation of size is based on total mass of the material. The designations are defined as follows:

   "Small" - total mass less than 100 kg.

   "Intermediate" - total mass between 100 and 10,000 kg.

   "Large" - total mass greater than 10,000 kg.

   Proceed to the appropriate designator.

6. When is the material used?
   Definitions for the times of usage are as follows:

   "Construction" - The material is used during any part of the construction phase of the exploratory shafts and the drifts. Before, or at the completion of the construction phase, the material is removed.

"Testing" - The material is used after the drifts are connected to ES-1. Before, or at the completion of the testing phase, the material is removed.

Note: If a material emplaced during the construction phase is not removed until during or at the end of the testing phase, apply the material to both "Construction " and "Testing." For both, make entries as appropriate in Table A-IV.

"Permanent" - The material is used in the ES (during any phase) and is either purposely left in the ground permanently or is lost to the surroundings.

Proceed to the appropriate phase of usage.

7. Read across to the appropriate column: "Inorganic", "Organic", or "Metal" (as determined in Step 1).

Each box containing a ranking ("High," "Low," or "No concern") has been assigned a unique number, from 1A to 12R. This number corresponds to the explanation/justification for why that box received its ranking. It is also documented in Table A-II, to show the category to which the material was assigned.

Go back to Table A-II and record the unique number (the category of this material) in this database, under the column heading "Box No." This allows others to go back and verify decisions.

If the ranking is "High" or "Low," proceed to Step 7(a).
If the ranking is "No concern," proceed to Step 7(b).

7(a) The ranking is "High" or "Low" so this material will be entered into one of the chemical reactivity tables (Table A-IV). The chemical reactivity tables are divided into two groups:

materials used on the surface, and
materials used underground.

Each of these groups is then divided into three subcategories:

construction,
testing,
permanent.

To determine which table the material should be added to, follow the line horizontally across Table A-III until the appropriate location (columns labeled "Chemical Reactivity Table," "Surface" or "Underground") is reached. The table designator in this box tells which table this material should be added to. The designators are as follows:

"SC":	Surface- Construction	Table A-IV-a
"ST":	Surface- Testing	Table A-IV-b
"SP":	Surface- Permanent	Table A-IV-c
"UC":	Underground- Construction	Table A-IV-d
"UT":	Underground- Testing	Table A-IV-e
"UP":	Underground- Permanent	Table A-IV-f

7(b) If the ranking is "No concern," the decision is recorded in Table A-II ("Box No.") only. The material does not have to be studied any further and so should not be entered into Table A-IV.

A.5 TABLE A-III: MATERIALS SORTING

Solid or Liquid	Solubility/ Miscibility	Reactivity with Rock	Quantity	Time of Use	Inorganic	Organic	Metal	Chemical Reactivity Table	
								(Surface)	(Underground)
Solid	Soluble	Reactive	Large	Construction	High 1A	High 5A	No concern 9A	SC	UC
				Testing	High 1B	High 5B	No concern 9B	ST	UT
				Permanent	High 1C	High 5C	Low 9C	SP	UP
			Intermediate	Construction	Low 1D	Low 5D	No concern 9D	SC	UC
				Testing	Low 1E	Low 5E	No concern 9E	ST	UT
				Permanent	Low 1F	Low 5F	Low 9F	SP	UP
			Small	Construction	No concern 1G	No concern 5G	No concern 9G	--	--
				Testing	No concern 1H	No concern 5H	No concern 9H	--	--
				Permanent	Low 1I	Low 5I	No concern 9I	SP	UP
		Nonreactive	Large	Construction	High 1J	Low 5J	No concern 9J	SC	UC
				Testing	High 1K	Low 5K	No concern 9K	ST	UT
				Permanent	High 1L	Low 5L	Low 9L	SP	UP
			Intermediate	Construction	No concern 1M	No concern 5M	No concern 9M	--	--
				Testing	No concern 1N	No concern 5N	No concern 9N	--	--
				Permanent	Low 1O	No concern 5O	Low 9O	SP	UP
			Small	Construction	No concern 1P	No concern 5P	No concern 9P	--	--
				Testing	No concern 1Q	No concern 5Q	No concern 9Q	--	--
				Permanent	No concern 1R	No concern 5R	No concern 9R	--	--
	Insoluble	Reactive	Large	Construction	High 2A	High 6A	No concern 10A	SC	UC
				Testing	High 2B	High 6B	No concern 10B	ST	UT
				Permanent	High 2C	High 6C	Low 10C	SP	UP
			Intermediate	Construction	Low 2D	Low 6D	No concern 10D	SC	UC
				Testing	Low 2E	Low 6E	No concern 10E	ST	UT
				Permanent	Low 2F	Low 6F	Low 10F	SP	UP
			Small	Construction	No concern 2G	No concern 6G	No concern 10G	--	--
				Testing	No concern 2H	No concern 6H	No concern 10H	--	--
				Permanent	Low 2I	Low 6I	Low 10I	SP	UP
		Nonreactive	Large	Construction	No concern 2J	No concern 6J	No concern 10J	--	--
				Testing	No concern 2K	No concern 6K	No concern 10K	--	--
				Permanent	No concern 2L	Low 6L	No concern 10L	SP	UP
			Intermediate	Construction	No concern 2M	No concern 6M	No concern 10M	--	--
				Testing	No concern 2N	No concern 6N	No concern 10N	--	--
				Permanent	No concern 2O	No concern 6O	No concern 10O	--	--
			Small	Construction	No concern 2P	No concern 6P	No concern 10P	--	--
				Testing	No concern 2Q	No concern 6Q	No concern 10Q	--	--
				Permanent	No concern 2R	No concern 6R	No concern 10R	--	--

TABLE A-III: MATERIALS SORTING (continued)

Solid or Liquid	Solubility/ Miscibility	Reactivity with Rock	Quantity	Time of Use	Inorganic	Organic	Metal	Chemical Reactivity Table (Surface)	(Underground)
iquid	Miscible	Reactive	Large	Construction	High 3A	High 7A	11A	SC	UC
				Testing	High 3B	High 7B	11B	ST	UT
				Permanent	High 3C	High 7C	11C	SP	UP
			Intermediate	Construction	High 3D	High 7D	11D	SC	UC
				Testing	High 3E	High 7E	11E	ST	UT
				Permanent	High 3F	High 7F	11F	SP	UP
			Small	Construction	Low 3G	Low 7G	11G	SC	UC
				Testing	Low 3H	Low 7H	11H	ST	UT
				Permanent	Low 3I	Low 7I	11I	SP	UP
		Nonreactive	Large	Construction	High 3J	High 7J	11J	SC	UC
				Testing	High 3K	High 7K	11K	ST	UT
				Permanent	High 3L	High 7L	11L	SP	UP
			Intermediate	Construction	High 3M	High 7M	11M	SC	UC
				Testing	High 3N	High 7N	11N	ST	UT
				Permanent	High 30	High 70	110	SP	UP
			Small	Construction	Low 3P	Low 7P	11P	SC	UC
				Testing	Low 3Q	Low 7Q	11Q	ST	UT
				Permanent	Low 3R	Low 7R	11R	SP	UP
	Immiscible	Reactive	Large	Construction	4A	High 8A	12A	SC	UC
				Testing	4B	High 8B	12B	ST	UT
				Permanent	4C	High 8C	12C	SP	UP
			Intermediate	Construction	4D	Low 8D	12D	SC	UC
				Testing	4E	Low 8E	12E	ST	UT
				Permanent	4F	Low 8F	12F	SP	UP
			Small	Construction	4G	Low 8G	12G	SC	UC
				Testing	4H	Low 8H	12H	ST	UT
				Permanent	4I	Low 8I	12I	SP	UP
		Nonreactive	Large	Construction	Low 4J	High 8J	12J	SC	UC
				Testing	Low 4K	High 8K	12K	ST	UT
				Permanent	Low 4L	High 8L	12L	SP	UP
			Intermediate	Construction	No concern 4M	Low 8M	High 12M	SC	UC
				Testing	No concern 4N	Low 8N	High 12N	ST	UT
				Permanent	No concern 40	Low 80	High 120	SP	UP
			Small	Construction	No concern 4P	Low 8P	High 12P	SC	UC
				Testing	No concern 4Q	Low 8Q	High 12Q	ST	UT
				Permanent	No concern 4R	Low 8R	High 12R	SP	UP

A.6 Rationale for Decisions in Table A-III: Materials Sorting

Definition of high concern: an item that is deleterious to site characterization or deleterious to repository performance.

1A,1B,1C	Large quantities of inorganic solid that can be transported by groundwater to the waste package. Reaction products have not been identified. These may also be transported by groundwater; high concern.
1D,1E,1F	Quantities are moderate in size; however, possibility of significant reaction with rock and/or groundwater transport still exists; low concern.
1G,1H	Small quantities of inorganic solid that will be used and removed. Though they are reactive with rock, the extent of reaction is likely to be small in this time frame. Groundwater transport of both the inorganic solid and/or reaction products is possible. However, such small quantities will probably exist in very dilute solutions by the time they reach the waste package; no concern.
1I	Small quantity of inorganic solid that will remain in the ground. Because of long exposure time, extent of reaction is likely to be greater than if it is removed. Transport of reactants and products will take place; low concern.
1J,1K,1L	Large quantities of inorganic solids that are soluble in water but do not react with the rock. Since there is no reaction with rock, there are no additional reaction products to be concerned about. The solid is soluble in water, so it can be transported by groundwater. Large quantities transported by groundwater could have a significant effect on the waste package; high concern.
1M,1N	These intermediate quantities of inorganic solid will be used and removed. They do not react with the rock, so there are no additional reaction products to be concerned about. Though soluble in water, only small quantities are expected to be transported by groundwater; no concern.
1O	Intermediate quantity of inorganic solid that will remain in site permanently. They do not react with the rock so there are no additional reaction products to be concerned about. Since they are permanent and soluble in water, there is an increased likelihood of transport by groundwater to the waste package; low concern.
1P,1Q,1R	Small quantities of inorganic solid. These solids do not react with rock, so there are no reaction products to be concerned about. Groundwater transport is possible. However, quantities are small enough that anything that is transported will be present only in trace amounts; no concern.

2A,2B,2C	Large quantities of inorganic solid. Solid particles are insoluble, so they will not be transported by groundwater. Concern, though, because these large quantities of particles react with the rock. Reaction products have not been identified and products could be transported by groundwater; high concern.
2D,2E,2F	Intermediate quantities of insoluble inorganic solids. Since these solids are insoluble, there is no transport by groundwater. These will react with rock. Reaction products have not been identified. Products could be transported by groundwater; low concern.
2G,2H	Small quantities of insoluble inorganic solids, which will be used and removed. Reaction with rock will be minimal for this time frame, so reaction products, if any, will exist in trace amounts; no concern.
2I	Small quantities of insoluble inorganic solid that will remain permanently. Possibility of reaction increases because of lengthy exposure time. Reaction products have not been identified. Products could be transported by groundwater; low concern.
2J-2R	Insoluble inorganic solids. Particles are insoluble, so they will not be transported by groundwater. No reaction with rock, so no reaction products to be concerned about; no concern.
3A,3B,3C	Large quantities of inorganic liquids. These liquids are miscible, so they can be easily transported by the groundwater to the waste package. They also react with the rock, so reaction products could be formed. Reaction products have not been identified; they may be transported by groundwater; high concern.
3D,3E,3F	Intermediate quantities of inorganic liquids. These liquids are of high concern for the same reasons listed above (3A,3B,3C).
3G,3H,3I	Small quantities of inorganic liquids. Though present in much smaller quantities, these liquids are still miscible and therefore could be transported by the groundwater to the waste package. Small quantities of reaction products could also be formed; low concern.
3J-3O	Large and intermediate quantities of inorganic liquids. Again, these are relatively large quantities of liquids that are miscible, so they could easily be transported by the groundwater to the waste package. They do not react with the rock, so there are no additional reaction products to be concerned with; high concern.
3P,3Q,3R	Small quantities of inorganic liquids. These inorganic liquids are miscible and they could be carried to the waste package by groundwater. Since they do not react with the rock, there are not any additional reaction products to be concerned with. Because the quantities are small, only trace amounts are expected to be transported; low concern.

4A-4I	Unable to identify any compounds in this category (immiscible inorganic liquids that react with the rock).
4J,4K,4L	Large quantities of inorganic liquids. These quantities are immiscible, so they will not be transported by groundwater. Furthermore, these liquids do not react with the rock, so there are not any reaction products to be concerned with. Based on large quantity, then, they are ranked as low concern.
4M-4R	Small to intermediate quantities of inorganic liquids. These liquids are immiscible and, therefore, they should not be transported efficiently. Since they do not react with the rock, there are not any reaction products to be concerned with. An example in this category is silicon fluid. These items are believed to have a very small impact on the site; no concern.
5A,5B,5C	Large quantities of organic solids that can be transported by groundwater to the waste package (soluble). They also react with the rock. Reaction products have not been identified. These may also be transported by groundwater; high concern.
5D,5E,5F	Intermediate quantities of soluble organic solids. Quantities are less than above, but possibility of significant reaction with rock and/or groundwater transport still exists; low concern
5G,5H	Small quantities of soluble organic solids that will be used and removed. Though they are reactive with rock, the extent of reaction is likely to be small in this time frame. Groundwater transport of both the inorganic solid and/or reaction products is possible. However, such small quantities will probably exist in very dilute solutions by the time they reach the waste package; no concern.
5I	Small quantity of soluble organic solid that will remain in the ground. Because of long exposure time, the extent of reaction is likely to be greater than if the solid is used and removed. Transport of reactants and products will take place; low concern.
5J-5L	Large quantities of organic solid that are soluble in water but do not react with the rock. Since there is no reaction with rock, there are no additional reaction products to be concerned about. The solid is soluble in water, so it can be transported by groundwater. Large quantities transported by groundwater could have a minor impact on the waste package; low concern.
5M-5R	These intermediate and small quantities of soluble organic solids will be used and removed. They do not react with the rock, so there are no additional reaction products to be concerned about. Though soluble in water, only small quantities are expected to be transported by groundwater; no concern.

6A,6B,6C	Large quantities of insoluble organic solids. Solid particles are insoluble, so they will not be transported by groundwater. Concern, though, because these large quantities of particles react with the rock. Reaction products have not been identified and products could be transported by groundwater; high concern.
6D,6E,6F	Intermediate quantities of insoluble organic solids. Since these solids are insoluble, there is no transport by groundwater. These will react with rock, though, and reaction products have not been identified. Products could be transported by groundwater; low concern.
6G,6H	Small quantities of insoluble organic solids, which will be used and removed. Reaction with rock will be minimal for this time frame, so reaction products, if any, will exist in trace amounts; no concern.
6I	Small quantities of insoluble organic solids that will remain permanently. Possibility of reaction increases because of lengthy exposure time. Reaction products have not been identified. Products could be transported by groundwater; low concern.
6J-6K	Large quantities of insoluble organic solids that will be used and removed. Particles are insoluble, so they will not be transported by groundwater. Since there is no reaction with rock, there are no reaction products to be concerned about; no concern.
6L	Small quantities of insoluble organic solid that will remain permanently. Solids are insoluble, so they are not likely to be transported by groundwater. Since there is no reaction with rock, there are no reaction products to be concerned with. Because of the lengthy exposure time, the solids are ranked as low concern.
6M-6R	Small to intermediate quantities of insoluble organic solids. Particles are insoluble, so they will not be transported by groundwater. Since there is no reaction with the rock, there are no reaction products to be concerned with. No concern.
7A,7B,7C	Large quantities of miscible organic liquids. These liquids are miscible, so they could be transported by the groundwater to the waste package. They also react with the rock, so reaction products could be formed. Reaction products have not been identified; they may be transported by groundwater; high concern.
7D,7E,7F	Intermediate quantities of miscible organic liquids. These liquids are of high concern for the same reasons listed above (7A,7B,7C).
7G,7H,7I	Small quantities of miscible organic liquids. Though present in much smaller quantities, these liquids are still miscible and therefore could be transported by the groundwater to the waste package. Small quantities of reaction products could also be formed; low concern.

7J-7O	Large and intermediate quantities of miscible organic liquids. Again, these are relatively large quantities of liquids that are miscible, so they could easily be transported by the groundwater to the waste package. They do not react with the rock, so there are no additional reaction products to be concerned with; high concern.
7P,7Q,7R	Small quantities of organic liquids. These organic liquids are miscible and could be carried to the waste package by groundwater. Since they do not react with the rock, there are not any additional reaction products to be concerned with. Because the quantities are small, only trace amounts are expected to be transported; low concern.
8A,8B,8C	Large quantities of immiscible organic liquids. These liquids are not likely to be transported by groundwater. They also react with the rock, so reaction products could be formed. Reaction products have not been identified, and they may be transported by groundwater; high concern.
8D-8I	Small to intermediate quantities of immiscible organic liquids. Since these liquids are immiscible, they are not likely to be transported by groundwater. They react with the rock, so reaction products could be formed. Reaction products have not been identified. The smaller quantities imply that smaller quantities of reaction products could be formed; low concern.
8J,8K,8L	Large quantities of immiscible organic liquids. These quantities are immiscible, so they will not be transported by groundwater. Furthermore, these liquids do not react with the rock, so there are not any reaction products to be concerned with. Based on large quantity, then, they are ranked as high concern.
8M-8R	Small to intermediate quantities of organic liquids. These liquids are immiscible and, therefore, they should not be transported efficiently. Since they do not react with the rock, there are not any reaction products to be concerned with. These items are believed to have a very small impact on the site; low concern.
9A,9B	Large quantities of soluble metals that can be transported by groundwater to the waste package. Reaction products have not been identified. These may also be transported by groundwater. However, the extent of reaction during this time frame will be minimal, so reaction products, if any, will exist in trace amounts; no concern.
9C	Large quantities of soluble metals that can be transported by groundwater to the waste package. These metals will be left permanently. They also react with the rock. Extent of reaction is likely to be greater than if they are used and removed (because of long exposure time). Transport of small amounts of reactants and products will take place; low concern.

9D,9E	Intermediate quantities of soluble metals, which will be used and removed. Though they are reactive with rock, the extent of reaction is likely to be small in this time frame. Groundwater transport of both the metal and/or reaction products is possible. However, they will probably exist in very dilute solutions; no concern.
9F	Intermediate quantities of soluble metals that will remain in the ground. Because of long exposure time, extent of reaction is likely to be greater than if they are removed. Transport of reactants and products will take place; low concern.
9G,9H,9I	Small quantities of soluble metals that react with the rock. Groundwater transport of both the metal and/or reaction products is possible. In small quantities though, only trace amounts will be transported; no concern.
9J,9K	Large quantities of metals that are soluble in water but do not react with the rock. Since there is no reaction with rock, there are no additional reaction products to be concerned about. The solid is soluble in water, so it can be transported by groundwater. Probably only trace amounts will be transported; no concern.
9L	Large quantities of soluble metal that will remain in the site permanently. They do not react with the rock, so there are no additional reaction products to be concerned with. Since they are permanent and soluble in water, there is an increased likelihood of small quantities being transported by groundwater to the waste package; no concern.
9M,9N	These intermediate quantities of soluble metals will be used and removed. They do not react with the rock, so there are no additional reaction products to be concerned about. Though soluble in water, only small quantities are expected to be transported by groundwater; no concern.
9O	Intermediate quantity of soluble metal that will remain in the site permanently. They do not react with the rock, so there are no additional reaction products to be concerned about. Since they are permanent and soluble in water, there is an increased likelihood of transport by groundwater to the waste package; low concern.
9P,9Q,9R	Small quantities of soluble metals. These solids do not react with rock, so there are no reaction products to be concerned about. Groundwater transport is possible. However, quantities are small enough that anything that is transported will be present only in trace amounts; no concern.
10A,10B	Large quantities of insoluble metals. Solid particles are insoluble, so they will not be transported by groundwater. These large quantities of particles can react with the rock. The extent of reaction during this time frame should be small, so reaction products, if any, will be present in trace amounts; no concern.

10C	Large quantities of insoluble metals that will remain in the ground permanently. Metals are insoluble, so they will not be transported by groundwater. These metals will react with the rock. Extent of reaction is likely to be greater than if they were removed after use (because of long exposure time). Transport of small amounts of products may occur; low concern.
10D,10E	Intermediate quantities of insoluble metals, which will be used and removed. Reaction with rock will be minimal for this time frame, so reaction products, if any, will exist in trace amounts; no concern.
10F	Intermediate quantities of insoluble metals that will remain permanently. Possibility of reaction increases because of lengthy exposure time. Reaction products have not been identified. Products could be transported by groundwater; low concern.
10G,10H	Small quantities of insoluble metals that will be used and removed. Reaction with rock will be minimal for this time frame, especially with small initial quantities. Reaction products, if any, will exist in trace amounts; no concern.
10I	Small quantities of insoluble metals that will remain permanently. Possibility of reaction increases because of lengthy exposure time. Reaction products have not been identified and could be transported by groundwater; low concern.
10J-10R	Insoluble metals. Particles are insoluble, so they will not be transported by groundwater. Since there is no reaction with the rock, there are no reaction products to be concerened about; no concern.
11A-11R	Miscible liquid metals. Unable to identify any miscible liquid metals that are planned for use in the ESF.
12A-12I	Immiscible liquid metals. Unable to identify any immiscible liquid metals that react with the rock and are planned for use in the ESF.
12J-12L	Large quantities of immiscible liquid metals that do not react with the rock. Unable to identify any liquid metals in this category that are planned for use in large quantities in the ESF.
12M-12R	Small to intermediate quantities of immiscible liquid metals. An example of a metal in this category is mercury amalgamate with gold. A metal like this may interfere with data taking and is also a health hazard; high concern.

A.7 Instructions for Using Table A-IV: Chemical Reactivity

Having determined in Table A-III which materials should be assigned to Table A-IV (High and Low only), and where they should be assigned, proceed as follows.

1. On the appropriate existing Table A-IV (a-f), add the name of the material to both the first blank column and the first blank row.

2. For future reference, note the type of material in the column and row marked "Type." The designators are as follows:

   "I" - Inorganic
   "O" - Organic
   "M" - Metal

   This information will be useful when looking at reactions with other materials.

3. For future reference, note the quantity of material in the column and row marked "Quantity." The designators are as follows:

   "S" - Small
   "I" - Intermediate
   "L" - Large

   The quantity is determined in Step 5 of the "Instructions for Using Table A-III: Materials Sorting." Again, this information will be useful when looking at reactions with other materials.

4. Determine if a pair of materials will react.

   (a) Pair the item in Row 1 of the far left-hand column with the material in question.

   (b) Decide if these two materials will react.

   (c) If there could potentially be a significant reaction between these two materials, then

      (1) Mark the box in that row and that column with a bullet.

      (2) On a separate sheet, document the reaction of concern.

   (d) If the potential for a significant reaction between the two materials does not exist, then

      (1) Mark the box with an asterisk.

      (2) This pair of materials does not need to be studied any further.

   (e) Repeat process until each ROW has been considered.

A.8 Table A-IV (a to f): Chemical Reactivity

Table A-IV-a: Surface - Construction

	Type	Qnty	Ethylene Glycol	Brake Fluid	Hydraulic Fluid	Torque Converter Fluid	Diesel Fuel	Gasoline	Kerosene	Gear Lubricant	Grease, Multipurpose	Rope Dressing	Wheel Bearing Lubricant	Engine Oil 20W40	Hydraulic Oil	Hydraulic Transmission Oil	Lubricating Oil	Road Oil	Rock Drill Oil	Cleaning Solvent	Spray Paint	Machine Parts Cleaning Solvents	$CaCl_2$ Tire Ballast	Water	Halon	Acetylene	Carbon Dioxide	Carbon Monoxide	Oxygen	Nitrogen	Nitrogen Dioxide
Type			O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	I O	I	I	Gas	G	G	G	G	G	G
Quantity			I	I	I	I	L	L	I	I	L	S	S	I	I	S	I	L	I	S	S	S	I	L	S	S	L	S	L	L	S
Ethylene Glycol	O	I		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	●	*	*	*	*	*	*	*
Brake Fluid	O	I			*	*	●	●	●	*	*	*	*	*	*	*	*	*	*	●	*	●	*	*	*	*	*	*	*	*	*
Hydraulic Fluid						*	●	●	●	*	*	*	*	*	*	*	*	*	*	●	*	●	*	*	*	*	*	*	*	*	*
Torque Converter Fluid	O	I					●	●	●	*	*	*	*	*	*	*	*	*	*	●	*	●	*	*	*	*	*	*	*	*	*
Diesel Fuel	O	L						●	●	●	●	*	●	●	●	●	●	*	*	●	*	●	*	*	*	*	*	*	*	*	*
Gasoline	O	L							●	●	●	*	●	●	●	●	●	*	*	●	*	●	*	*	*	*	*	*	*	*	*
Kerosene	O	I								●	●	*	●	●	●	●	●	*	*	●	*	●	*	*	*	*	*	*	*	*	*
Gear Lubricant	O	I									*	*	*	*	*	*	*	*	*	●	*	●	*	*	*	*	*	*	*	*	*
Grease, Multi-purpose	O	L										*	*	*	*	*	*	*	*	●	*	●	*	*	*	*	*	*	*	*	*
Rope Dressing	O	S											*	*	*	*	*	*	*	●	*	●	*	*	*	*	*	*	*	*	*
Wheel Bearing Lubricant	O	S												*	*	*	*	*	*	●	*	●	*	*	*	*	*	*	*	*	*

KEY

* No significant reaction

● Potentially significant reaction between hydrocarbon and solvent

Table A-IV-a: Surface - Construction (continued)

	Type	Qnty	Ethylene Glycol	Brake Fluid	Hydraulic Fluid	Torque Converter Fluid	Diesel Fuel	Gasoline	Kerosene	Gear Lubricant	Grease, Multipurpose	Rope Dressing	Wheel Bearing Lubricant	Engine O 20W40	Hydraulic Oil	Hydraulic Transmission Oil	Lubricating Oil	Road Oil	Rock Drill Oil	Cleaning Solvent	Spray Paint	Machine Parts Cleaning Solvents	CaCl Tire Ballast	Water	Halon	Acetylene	Carbon Dioxide	Carbon Monoxide	Oxygen	Nitrogen	Nitrogen Dioxide
Type			O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	I O	I	I	Gas	G	G	G	G	G	G
Quantity			I	I	I	I	L	L	I	I	L	S	S	I	I	S	I	L	I	S	S	S	I	L	S	S	L	S	L	L	S
Engine Oil, 20W40	O	I													*	*	*	*	*	●	*	●	*	*	*	*	*	*	*	*	*
Hydraulic Oil	O	I														*	*	*	*	●	*	●	*	*	*	*	*	*	*	*	*
Hydraulic Transmission Oil	O	S															*	*	*	●	*	●	*	*	*	*	*	*	*	*	*
Lubricating Oil	O	I																*	*	●	*	●	*	*	*	*	*	*	*	*	*
Road Oil	O	L																	*	*	*	*	*	*	*	*	*	*	*	*	*
Rock Drill Oil	O	I																		●	*	●	*	*	*	*	*	*	*	*	*
Cleaning Solvents	O	S																			*	*	*	*	*	*	*	*	*	*	*
Spray Paint	O	S																				●	*	*	*	*	*	*	*	*	*
Machine Parts Cleaning Solvent	I O	S																					*	*	*	*	*	*	*	*	*
$CaCl_2$ Tire Ballast	I	I																						*	*	*	*	*	*	*	*
Water	I	L																							*	*	*	*	*	*	*

Table A-IV-b: Surface - Testing

	Type	Qnty	Ethylene Glycol	Gasoline	Gear Lubricant	Grease, Multi-purpose	Rope Dressing	Engine Oil 20W40	Hydraulic Oil	Hydraulic Trans-mission Oil	Lubricating Oil	Road Oil	Cleaning Solvents	Spray Paint	Machine Parts Cleaning Solvent	Fluor-rescein Dye	$CaCl_2$ Tire Ballast	Water	Carbon Dioxide	Oxygen	Nitrogen
Type			O	O	O	O	O	O	O	O	O	O	O	O	I O	O	I	I	G	G	G
Quantity			I	L	I	I	S	I	I	S	I	L	S	S	S	S	I	L	L	L	L
Ethylene Glycol	O	I		*	*	*	*	*	*	*	*	*	*	*	*	*	*	●	*	*	*
Gasoline	O	I			●	●	*	●	●	●	●	*	*	*	*	*	*	*	*	*	*
Gear Lubricant	O	I				*	*	*	*	*	*	*	●	*	●	*	*	*	*	*	*
Grease, Multi-purpose	O	I					*	*	*	*	*	*	●	*	●	*	*	*	*	*	*
Rope Dressing	O	S						*	*	*	*	*	*	*	*	*	*	*	*	*	*
Engine Oil, 20W40	O	I							*	*	*	*	●	*	●	*	*	*	*	*	*
Hydraulic Oil	O	I								*	*	*	●	*	●	*	*	*	*	*	*
Hydraulic Trans-mission Oil	O	S									*	*	●	*	●	*	*	*	*	*	*
Lubricating Oil	O	I										*	●	*	●	*	*	*	*	*	*
Road Oil	O	L											*	*	*	*	*	*	*	*	*

KEY

* No significant reaction

● Potentially significant reaction between hydrocarbons and solvent

Table A-IV-b: Surface - Testing (continued)

	Type	Qnty	Ethylene Glycol	Gasoline	Gear Lubricant	Grease, Multi-purpose	Rope Dress-ing	Engine Oil 20W40	Hydraulic Oil	Hydraulic Trans-mission Oil	Lubri-cating Oil	Road Oil	Cleaning Solvents	Spray Paint	Machine Parts Cleaning Solvent	Fluor-rescein Dye	CaCl Tire Ballast	Water	Carbon Dioxide	Oxygen	Nitrogen
Type			O	O	O	O	O	O	O	O	O	O	O	O	I O	O	I	I	G	G	G
Quantity			I	L	I	I	S	I	S	S	I	L	S	S	S	S	I	L	L	L	L
Cleaning Solvents	O	S												*	*	*	*	*	*	*	*
Spray Paint	O	S													*	*	*	*	*	*	*
Machine Parts Cleaning Solvent	I O	S														*	*	*	*	*	*
Fluorescein Dye	O	S															*	*	*	*	*
$CaCl_2$ Tire Ballast	I	I																*	*	*	*
Water	I	L																	*	*	*

Table A-IV-c: Surface - Permanent

	Type	Qnty	Brake Fluid	Hydraulic Fluid	Torque Converter Fluid	Transmission Fluid	Gear Lubricant SAE90	Engine Oil, 20W40	Hydraulic Transmission Oil	Lubricating Oil	Cleaning Solvents	Carbon Dioxide	Oxygen	Nitrogen
Type			0	0	0	0	0	0	0	0	0	G	G	G
Quantity			I	I	S	I	S	S	S	I	S	L	L	L
Brake Fluid	0	I		*	*	*	*	*	*	*	●	*	*	*
Hydraulic Fluid	0	I			*	*	*	*	*	*	●	*	*	*
Torque Converter Fluid	0	S				*	*	*	*	*	●	*	*	*
Transmission Fluid	0	I					*	*	*	*	●	*	*	*
Gear Lubricant	0	S						*	*	*	●	*	*	*
Engine Oil, 20W40	0	S							*	*	●	*	*	*
Hydraulic Transmission Oil	0	S								*	●	*	*	*
Lubricating Oil	0	I									●	*	*	*
Cleaning Solvents	0	S										*	*	*

KEY

* No significant reaction

● Potentially significant reaction between hydrocarbon and solvent

Table A-IV-d: Underground - Construction

	Type	Qnty	Torque Converter Fluid	Grease, Multi-Purpose	Rope Dressing	Hydraulic Oil	Lubricating Oil	Rock Drill Oil	Spray Paint	Machine Parts Cleaning Solvents	Water	Halon	Acetylene	Carbon Dioxide	Carbon Mon-oxide	Oxygen	Nitrogen	Nitrogen Dioxide
Type			O	O	O	O	O	O	O	I O	I	G	G	G	G	G	G	G
Quantity			S	I	S	I	I	I	S	S	L	S	S	L	I	L	L	S
Torque Converter Fluid	O	S		*	*	*	*	*	*	●	*	*	*	*	*	*	*	*
Grease, Multipurpose	O	I			*	*	*	*	*	●	*	*	*	*	*	*	*	*
Rope Dressing	O	S				*	*	*	*	●	*	*	*	*	*	*	*	*
Hydraulic Oil	O	I					*	*	*	●	*	*	*	*	*	*	*	*
Lubricating Oil	O	I						*	*	●	*	*	*	*	*	*	*	*
Rock Drill Oil	O	I							*	*	*	*	*	*	*	*	*	*
Spray Paint	O	S								*	*	*	*	*	*	*	*	*
Machine Parts Cleaning Solvent	I O	S									*	*	*	*	*	*	*	*
Water	I	L										*	*	*	*	*	*	*

KEY

* No significant reaction

● Potentially significant reaction between hydrocarbons and solvent

Table A-IV-e: Underground - Testing

	Type	Qnty	Brake Fluid	Hydraulic Fluid	Transmission Fluid	Diesel Fuel	Gear Lubricant	Grease, Multi-Purpose	Water Pump Grease	Rope Dressing	Water Soluble Oil Mixture	Spray Paint	Machine Parts Cleaning Solvent	Fluorescein Dye	Perfluorinated Benzioc Acid	H_2SO_4	Water	Carbon Dioxide	Oxygen	Nitrogen
Type			O	O	O	O	O	O	O	O	O	O	I O	O	O	I	I	G	G	G
Quantity			I	I	I	I	I	I	S	S	S	S	S	S	S	I	L	L	L	L
Brake Fluid	O	I		*	*	●	*	*	*	*	*	*	●	*	*	*	*	*	*	*
Hydraulic Fluid	O	I			*	●	*	*	*	*	*	*	●	*	*	*	*	*	*	*
Transmission Fluid	O	I				●	*	*	*	*	*	*	●	*	*	*	*	*	*	*
Diesel Fuel	O	L					●	●	●	*	*	*	*	*	*	*	*	*	*	*
Gear Lubricant	O	I						*	*	*	*	*	●	*	*	*	*	*	*	*
Grease, Multipurpose	O	I							*	*	*	*	●	*	*	*	*	*	*	*
Water Pump Grease	O	S								*	*	*	●	*	*	*	*	*	*	*
Rope Dressing	O	S									*	*	*	*	*	*	*	*	*	*
Water Soluble Oil Mixture	O	S										*	*	*	*	*	*	*	*	*
Spray Paint	O	S											*	*	*	*	*	*	*	*

KEY

* No significant reaction

● Potentially significant reactio between hydrocarbon and solvent

Table A-IV-e: Underground - Testing (continued)

	Type	Qnty	Brake Fluid	Hydraulic Fluid	Trans-mission Fluid	Diesel Fuel	Gear Lubricant	Grease, Multi-Purpose	Water Pump Grease	Rope Dress-ing	Water Soluble Oil Mixture	Spray Paint	Machine Parts Cleaning Solvent	Fluorescein Dye	Per-fluorinated Benzoic Acid	H_2SO_4	Water	Carbon Dioxide	Oxygen	Nitrogen
Type			0	0	0	0	0	0	0	0	0	0	I 0	0	0	I	I	G	G	G
Quantity			I	I	I	I	I	I	S	S	S	S	S	S	S	I	L	L	L	L
Machine Parts Cleaning Solvent	I 0	S												*	*	*	*	*	*	*
Fluorescein Dye	0	S													*	*	*	*	*	*
Per-fluorinated Benzoic Acid	0	S														*	*	*	*	*
H_2SO_4	I	I															*	*	*	*
Water	I	L																*	*	*

Table A-IV-f: Underground - Permanent

	Type	Qnty	Brake Fluid	Hydraulic Fluid	Torque Converter Fluid	Transmission Fluid	Gear Lubricant	Carbon Dioxide	Oxygen	Nitrogen
Type			O	O	O	O	O	G	G	G
Quantity			S	S	S	S	S	L	L	L
Brake Fluid	O	S		*	*	*	*	*	*	*
Hydraulic Fluid	O	S			*	*	*	*	*	*
Torque Converter Fluid	O	S			*	*	*	*	*	*
Transmission Fluid	O	S					*	*	*	*
Gear Lubricant	O	S								

KEY

* No significant reaction

B.2 Rock Properties

The potential for water flow through fractured welded tuff is governed by properties of the rock mass and by the degree of saturation. Unfortunately, many of these properties, such as fracture aperture and fracture frequency, will not be known until actual underground studies take place. Rock property data used in this study are based on the NNWSI Project standards, which represent, to the best of our knowledge, the expected properties of the site.

Predominant strata at Yucca Mountain are Tiva Canyon, Paintbrush, Topopah Spring, and Calico Hills. The types of information needed for the materials transport calculations were the type of rock, layering, porosity, and fracture parameters. Where possible, rock property data were taken from the Reference Information Base and from data presented in the Site Characterization Plan. For data consistency, however, the grain densities and matrix porosities were taken from the SNL report SAND84-1471.[34]

Because water flow through unsaturated rock is a principal mechanism for transporting soluble radionuclides and other contaminants from a repository to the surrounding environment, determining the hydraulic properties of the system is an essential part of the analysis of radionuclide transport. Two methods commonly used for determining hydraulic parameters are mercury intrusion and thermocouple psychrometry. A detailed analysis of these methods is presented by Klavetter and Peters;[22] a summary of the advantages and disadvantages of each method is shown here in Table B-I.

Klavetter and Peters conclude that, although there is favorable comparison between the calculated and experimental values for saturated hydraulic conductivity, there is poor correlation between the saturation curves determined from thermocouple psychrometry and the curves calculated from pore-size distributions derived from mercury-intrusion data.[22] Their results suggest that the saturation curves derived from thermocouple psychrometry more accurately indicate the true hydrologic characteristics of the tuff samples. Therefore, they recommend that the Project use psychrometer data to determine the saturation curves. LANL supports this position.

TABLE B-1

COMPARISON OF METHODS FOR DETERMINING HYDRAULIC PROPERTIES

Method	Advantages	Disadvantages
Mercury intrusion	1. Data required for estimating the entire saturation curve may be obtained in a relatively short time. 2. The range of pressures observed may be considerably higher than with other methods. 3. Samples may be retested.	1. Needs a porous media in which the character of the interstitial spaces is unrelated to the physiochemical properties of the saturating fluid. 2. No irreducible minimum wetting-phase saturation or residual saturation can be obtained. 3. The pore system at the surface of the sample is not representative of the infinite pore system away from the surface. 4. The model, a bundle of parallel tubes, is so oversimplified that calculated and measured relative permeabilities often do not agree. 5. Errors in pore-sized distributions from data can occur if the pores are distributed in a random arrangement instead of by the orderly arrangement assumed by the capillary-bundle theory.
Thermocouple psychrometry	1. Time required to obtain data is one to several days, depending on the time estimated to achieve equilibrium and the number of saturation and humidity measurements selected to represent the curve. 2. Repeatable and consistent results.	1. Sensitive to environmental conditions. The temperature must be fairly well controlled. 2. Relatively more expensive and time consuming than mercury intrusion. 3. Sensitivity of only about -10 m of water pressure head. Not accurate above approximately -20 m to -30 m of pressure head. (This may be a significant disadvantage for some Yucca Mountain tuffs.)
Permeametry	1. Simple, accurate, and relatively inexpensive. 2. Relatively flexible. 3. Accuracy is limited primarily by the accuracy of the measurements of the liquid flow rate and the pressure drop across the sample.	1. For low conductivity samples, the test can be time consuming. 2. Disadvantages are relatively minor.

B.3 Water Composition and Content at Yucca Mountain

Water chemistry plays a critical role in determining the performance of the waste package components. Chemical differences between water samples reflect mineralogical characteristics unique to the zone from which they were derived.[35,36] Samples of vadose water from the repository horizon have not yet been obtained, but samples have been taken from various wells in the Yucca Mountain area. Table B-II, taken from Ogard and Kerrisk,[36] shows the chemical compositions of these water samples. Because of the similarity between the water chemistry of Well J-13 water and the water chemistry of water found below the exploratory block, Well J-13 was selected as the reference water chemistry. This water provides the most likely composition for repository horizon water and therefore will be used as the "mean" value until actual samples of the repository horizon are available.

The flux of groundwater through the host rock will influence the transport of fluids and materials from the ESF to the candidate repository location. Case and Kelsall report that, because of the combined effects of low average rainfall and permeability and capillary barriers between stratigraphic units, the flux through most of the Topopah Spring welded tuff is probably restricted to a value equal to or less than the *in situ* matrix conductivity, that is, about 0.04 in./yr (1 mm/yr).[37]

Information about water chemistry was needed in the calculational models for materials transport and in the groundwater chemistry interactions.

TABLE B-II

CHEMICAL COMPOSITION OF WATER SAMPLES TAKEN FROM WELLS IN THE YUCCA MOUNTAIN AREA[a]

Site Designation	On Site pH (units)	Labortory pH (units)	Water Temperature (°C)	Ca	Dissolved Constituents (mg/L)										
					Mg	Na	K	HCO_3 Field	HCO_3 Laboratory	Cl	SO_4	SiO_2	Li	Sr	F
UE-25b#1	7.1	6.8	36.0	19	0.73	53	3.7	173	158	13	24	53	950	44	1.5
UE-25b#1	7.5	7.5	36.0	17	.59	46	3.5	139	139	8.5	22	52	220	38	1.6
UE-25b#1	7.1	7.7	37.2	18	.72	46	2.8	133	138	7.5	21	51	120	47	1.6
UE-29a#2	7.2	7.6	25.1	10	.2	44	1.1	107	112	11	22	44	100	39	1.0
UE-29a#2	7.0	7.4	22.7	10	.3	44	1.3	107	110	8.8	21	44	110	33	.9
USW H-1	7.7	7.8	33.0	4.5	<.1	51	2.4	--	115	5.7	18	47	40	5	1.2
USW G-4	7.7	7.5	35.6	13	.2	57	2.1	139	143	5.9	19	45	67	17	2.5
USW H-1	7.5	8.0	34.7	6.2	<.1	51	2.6	--	122	5.8	19	40	40	20	1.0
USW H-4	7.4	7.9	34.8	17	.29	73	1.6	173	171	6.9	26	46	130	27	4.8
USW H-5	7.8	7.8	36.5	1.9	.01	60	2.1	126	124	6.1	16	48	62	9	1.4
USW H-5	7.9	8.0	35.3	2.0	<.01	60	2.1	127	124	6.1	16	48	71	4	1.4
USW H-6	8.1	8.3	37.8	4.1	.09	86	1.3	182	188	7.6	29	48	82	8	4.7
USW VH-1	7.9	8.0	35.2	11	1.6	79	1.9	167	158	11	44	50	90	70	2.7
USW VH-1	7.5	7.9	35.5	10	1.5	80	1.9	165	158	10	45	50	90	70	2.7
USW VH-1	7.5	8.0	35.5	9.9	1.5	78	1.8	162	158	10	44	49	90	60	2.7
J-12	7.1	-	27.0	14	2.1	38	5.1	--	119	7.3	22	54	40	10	2.1
J-13	7.2	-	31.0	12	2.1	42	5.0	--	124	7.1	17	57	40	20	2.4

[a] Table taken from Ogard and Kerrisk, Ref. 36.

B.4 Groundwater Chemistry

As mentioned previously, changes in the chemical composition of the groundwater that exceed the limits established by the Waste Package Canister Study could cause the containers to deteriorate more rapidly than expected, based on current groundwater chemistry assumptions. Therefore, groundwater chemistry changes caused by added materials must be within acceptable limits.

LLNL has expressed concern about the potential deleterious effects of ESF materials on the postclosure waste package environment (Ref. 2, Chapter 8.3.5.9, and Refs. 38-42). Their main concern is that water whose composition has been significantly altered will eventually come in contact with a waste package. LLNL has established water quality performance goals for groundwater contacting the waste package container, as shown in Table B-III (Ref. 2, Chapter 8.3.5.9). What this means for materials used in the ESF is that nothing should be used that will change the water chemistry in the waste package environment beyond the specified limits.[41] LLNL defines the waste package environment as the waste package and rock that extend several meters into the host rock. Because materials used at the ESF may affect water that subsequently enters the waste package environment, they must not effect changes in the water chemistry that exceed the specified limits.

LLNL offered the following comments after reviewing the NNWSI Fluids and Materials Database.[40]

1. Concrete materials: These have the potential to alter groundwater chemistry drastically, with severe effects on waste form performance; specifically pH, calcium, and silicon may be affected.
2. Tracers: The number of tracers should be limited to one or two. All tracers listed are halogen bearing or are known chelating agents. Fluorine is of particular concern as it is known to accelerate the corrosion of Zircaloy and the glass waste form. Other halogens also have the potential to increase the corrosion of other metal components in the waste package.
3. Water: All water to be used should come from Well J-13 or from a well with similar water chemistry.
4. Paint and solvents: Avoid unnecessary use.
5. Fuels: When possible, refuel on the surface.
6. Lubricants and oils: Minimize spillage.
7. Automotive fluids: Restrict handling to the surface in an area removed from the repository site.

TABLE B-III

WATER QUALITY PERFORMANCE GOALS

Performance Parameter	Tentative Goal
pH	5.5 to 9
Cl^-	<20 ppm
F^-	<6 ppm
NO_3^-	<15 ppm
SO_4^{2-}	<50 ppm
CO_3^{2-}, HCO_3^-	<200 ppm
Total anions	<220 ppm
Organics	TBD
Colloids	TBD
O_2	0.1 to 8 ppm
NH_3	<1 ppm
Si^{4+}	>20 ppm
Na^+	<100 ppm
K^+	<50 ppm
Na/Ca	>1
Total heavy metals	<2 ppm
Total other cations	<50 ppm

B.5 Blasting Agents

Because the blasting agents and their decomposition products can penetrate the rock, it is important to evaluate their effects on the site. This was done by first determining the components of both explosives and their products and then evaluating the effects of blasting on the surroundings and on other materials.

B.5.1 Quantity and Composition

The amount of blasting agents used is directly dependent on the volume of rock excavated.[43] At the ESF, approximately 135,100 yd^3 (103,300 m^3) of rock will be excavated.[44] The locations and volumes of excavations are as follows:

Location	Volume Excavated (yd^3)	(m^3)
ES-1 shaft excavation	8,434	6,450
ES-2 shaft excavation	5,812	4,444
Main Test level	108,889	83,257
Calico Hills	10,889	8,326
Upper Demonstration Breakout Room	1,089	833

Quantities of blasting agents are measured in terms of the powder factor (lb/yd^3),[43] which represents the amount of explosive (lb) used to break a volume of rock (yd^3). Typical values range from 1.5 to 12 lb/yd^3. Fenix and Scisson, Inc., (F&S) recommends that a value of 6.1 lb/yd^3 be used for the construction of the ESF. Therefore, the total quantity of explosives used is approximately 824,270 lb (135,113 yd^3 * 6.1 lb/yd^3).

Explosives are made up of fuels and oxidizers,[43] composed primarily of the elements oxygen, nitrogen, hydrogen, and carbon. Table B-IV shows the components of common explosives. When the explosives are detonated in Yucca Mountain, reaction of the explosives with the rock is expected to be negligible. After the blast, small amounts of unreacted explosive are expected to remain. The chemical interaction of these unreacted amounts with other materials was included in the decision tree analysis process described in Section 2.2.

Similarly, Table B-V shows the products that are formed as a result of the use of explosives.[43] Gaseous products are likely to be ventilated to the surface, but small amounts will penetrate the rock. Because the gas that penetrates the rock and the solid product alumina could potentially react with the rock, they were also considered in the decision tree analysis process described in Section 2.2.

TABLE B-IV

COMPONENTS OF EXPLOSIVES

Common Fuels

1. Fuel oil
2. Carbon
3. Aluminum
4. Trinitrotoluene (TNT)
5. Smokeless powder
6. Monomethylamine
7. Nitrate
8. Monethanol amine nitrate

Common Sensitizers

1. Nitroglycerin
2. Nitrostarch
3. Aluminum
4. TNT
5. Smokeless powder
6. Monomethylamine nitrate
7. Monoethylamine nitrate

Common Oxidizers

1. Ammonium nitrate (the most common)
2. Sodium nitrate
3. Calcium nitrate

Other Ingredients

1. Water gums
2. Thickeners
3. Cross-linking agents; used in
    a. slurries
    b. gelatinizers
    c. densifiers
    d. antacids
    e. stabilizers
    f. absorbents
    g. flame retardants

TABLE B-V

PRODUCTS FORMED FROM EXPLOSIVES

Gaseous Products

1. Water
2. Carbon dioxide
3. Nitrogen
4. Nitric oxide
5. Carbon monoxide
6. NH_2
7. Methane

Solid Products

Alumina (Al_2O_3)

The distance that the blasting agent will penetrate the rock is also of concern. It appears that the deepest penetration for gaseous products will be about 3 to 5 ft (0.9 to 1.5 m).[43] If the rock is particularly permeable, this distance might be greater.

B.5.2 Effect of Blasting

Almost everyone agrees that to some degree blasting will damage the rock directly surrounding the blasting area, either by creating new cracks or by extending and widening existing cracks. The extent to which this damage occurs can have a significant impact on the ability of the site to isolate radioactive waste by creating a preferential pathway for water to the repository. Case and Kelsall have investigated the modification of permeability in the fractured welded tuff of the Topopah Spring unit as a result of blasting in the host rock.[37] Their analysis found that the combination of lower bound rock mass strength and upper bound *in situ* stress results in inelastic behavior adjacent to the shaft walls, which in turn results in predicted changes in rock mass permeability at the shaft wall as high as 2 orders of magnitude.

They also point out that actual blasting results may be influenced by blasting methods and by how well the blasting is executed.[37] Case histories suggest that the width of blast damage may vary from approximately 1 ft (0.3 m) for cases in which controlled blasting methods such as smooth blasting are used to approximately 6.6 ft (2.0 m) for cases in which conventional blasting methods are used. Cracking is influenced both by the blasting method and by the charge weight of the explosives. Perimeter blasting uses controlled methods to limit the number and extent of new cracks in the completed excavation. Two techniques are available for controlled perimeter blasting:

1. presplitting, and
2. smooth blasting.

Because relatively low-charge weights can be used in perimeter holes, the damage to the rock beyond the perimeter can be limited.

Van Eeckhout investigated these same two controlled blasting techniques and found that smooth-wall blasting is preferred for the construction of the exploratory shafts.[45] Van Eeckhout believes that the slightly smaller amount of damage obtained by presplitting does not compensate for the additional time and coordination required. By using controlled blasting techniques, Van Eeckhout concluded that rock damage could be limited to less than 3 ft (1 m).

As Case and Kelsall note,[37] Hocking and St. John (1979) summarized the US Bureau of Mines (USBM) work and concluded that the diameter of blast-damage zones for the high-energy explosive in hard rock, such as granite, should range from 15 to 20 charge diameters. For a low-energy explosive, used as a decoupled explosive in smooth blasting, the damaged zone should be only 5 to 10 charge diameters. Case and Kelsall[37] also point out that, although care might be taken to limit damage caused from blasting by selecting an alternate excavation method, the effects of stress reduction will occur regardless of the excavation method used.

Calculations of the amount of blasting agents used (see previous page) assumed smooth blasting techniques. The blast-damaged zone (or MPZ) used in the materials transport calculations extended to 24 ft (7 m).[30]

B.6 Cements and Concretes

There is concern that calcium and chloride from concrete used in the shaft liner and other grouting applications will be transported to the repository and will change the groundwater composition by amounts greater than the limits specified by the Waste Package Canister Study.

Because of the potential increase in the calcium content of the groundwater, the following areas were investigated:[44,46,47]

1. the composition of cements,
2. amount of concrete used underground,
3. leach rates of calcium and chlorides,
4. transport from the source.

B.6.1 Chemical Composition

Like any concrete, the concrete for the shaft liner will be a mixture of cement, sand/aggregate, and water. Harig gives the following mixture for a typical concrete mix for a shaft liner (given in weight percentages):[47]

42% coarse aggregate (crushed rock),
34% fine aggregate (sand),
16% cement,
8% water.

This mixture has a cement-to-water ratio of 2:1. By comparison, the cement-to-water ratio of a cement-based grout is typically 1:5 to 1:10.[47]

The compositions of each of these components are needed for the chemical interaction analysis. A typical ordinary Portland cement is composed of the following:[46]

1. calcium-silicate hydrate,
2. tricalcium aluminum hydrate,
3. tetracalcium aluminoferrite hydrate,
4. unreacted Portlandite, $Ca(OH)_2$ (minor amounts),
5. sodium and potassium alkalis (minor amounts),
6. dissolvable alkalis (between 0.05% and 0.15%).

Sand and aggregate are composed of quartzite, SiO_2, and small amounts of limestone, $CaCO_3$.[46]

B.6.2 Amount and Location of Concrete Use

Concrete will primarily be used in the construction of the shaft liners, collars, and pads. Approximate amounts are listed below.[46]

1.	ES-1: Shaft collar and pad	222 yd^3 (170 m^3)
	Shaft liner	2683 yd^3 (2050 m^3)

2.	ES-2: Shaft collar and pad	222 yd^3 (170 m^3)
	Shaft liner	1850 yd^3 (1415 m^3)

This information was also needed for the decision tree analysis process (Section 2.2).

Harig states that the concrete mix for the shaft liner will have an approximate unit weight of 145 lb/ft^3 (2324 kg/m^3), so a column of concrete would exert a pressure of approximately 1 psi/vertical-ft (0.223 atm/vertical-m).[47] The shaft lining will be poured in approximately 20-ft (6.1-m) lifts. Hence, a 20-psi (1.4-atm) fluid pressure could exist at the bottom of the column. This pressure will exist for 1 to 2 h, until the concrete sets.

B.6.3 Leaching of Calcium

Because calcium leached from concrete can change the groundwater chemistry, it is important to know how much calcium can be expected to leach from the shaft liner. A literature search was conducted for any articles relating to calcium leaching from concrete. Unfortunately, very little information about this exists as the bulk of the studies deals with the leaching of radionuclides from containment vessels.

Personal communications with Clarence Duffy (LANL principal investigator for the concrete water chemistry contract with Pennsylvania State University) indicated that scoping-type calculations would be nothing more than guesses because of variabilities in

1. set time,
2. concentration of carbon dioxide in the system,
3. groundwater composition, and
4. amount of groundwater contacting concrete.

The problem is further complicated by the fact that the thermodynamic parameters are not easily predicted. Intuitively, Duffy believes that the amount of calcium that leaches will be small, but there is no simple calculation to prove it.

Sandia report SAND85-0598 by Fernandez *et al.*,[30] currently in preparation, addresses the question of leaching from the liner. In this report, Fernandez *et al.* note that leaching of minerals from concrete is governed by diffusion of ionic species in the pore spaces of the cement and by diffusion and dispersion of those same chemical species in the rock backfill and the MPZ. Precipitation is expected to occur as a consequence of leached ionic species interacting with groundwater and the rocks. In the report, Fernandez *et al.* attempt to estimate the nature and quantity of precipitates formed from the interaction of groundwater with the concrete liner. In the case of calcite, precipitation is found to occur at nucleation sites on existent solid surfaces and, for the anticipated water passage case, the deposition of solids is expected to be a localized phenomenon. More details about their study will not be known until the report is released.

Until this issue can be studied in more detail, we conclude that calcium will probably precipitate as a result of a change in pH caused by the buffering capacity of the rock. It is assumed that once out of solution, because it is no longer soluble, calcium will not be transported by groundwater and the quantity source term will become unimportant.

B.6.4 Transport from the Source

Harig also addresses concerns regarding the potential of the concrete from the liner to penetrate the rock formation and decrease its permeability.[47] He concludes that this is "extremely unlikely" that the concrete used for the shaft lining will penetrate more than a few centimeters into the rock surrounding the shaft. Arguments supporting this conclusion are as follows:[47]

1. The rock matrix of the formation is of relatively low permeability, even to water.

2. Expected fracture apertures are too small for cement particles, and, since the mix is approximately 76% coarse and fine aggregate, bridging would occur over fractures and prevent cement penetration.

3. Concrete sets in several hours, limiting the time available for penetration.

4. Pressures available are below those required for effective grouting, even with a grout capable of penetrating the fractures.

Furthermore, Harig states that concretes typically shrink on the order of 0.1% while curing.[47] This, he says, will frequently cause a crack behind the lining after it is cured, which will tend to pull the concrete out of the fractures that it may have penetrated slightly. If necessary, the lining could be removed by overexcavation, which would remove any minor zones of penetration and again present a fresh rock surface. To offset the possibility of hydrostatic pressure developing on the lining, Harig suggests the use of "weep holes" (holes drilled in the lining to enhance drainage).

B.7 Drilling Fluids

Reynolds Electrical and Engineering Co., Inc., (REECo) estimates that the total amount of drilling fluid used for ES construction and drifting will be approximately 33 million gallons (1.25×10^8 L) (see Table A-I). Of this total, some portion will be lost to the surroundings. This unrecovered drilling fluid could affect both the results of the *in situ* tests and the transport of radionuclides from the repository, so it is important to know how much will be lost. To establish a limit on the amount of drilling fluid that is lost, experts in the field of mining were asked to evaluate how much drilling fluid could reasonably be removed and the probable distribution of the unrecovered portion.

Fenix & Scisson (F&S) estimated that, under normal shaft sinking conditions, each blasting bench would use an average of about 971 gal (3675 L) of water, or 243 gal per foot of advance (3018 L per meter of advance).[48] They said that it is normal to collect 90-95% of this water by means of evaporation to the ventilation system, by absorption by broken rock that is hoisted to the surface, and by pumping and lifting the water to the surface. F&S noted, though, that the G-4 borehole logs suggested that an average figure of less than 30% might be more correct. For safety reasons, F&S believed that dry drilling such a small shaft would be virtually impossible.

For the drifts, F&S estimated that under normal drifting conditions with a drill jumbo, each heading would use an average of about 2968 gal per 12 ft round or 247 gal per foot of advance.[48] Recovery, they said, would depend on the grade of the drift and the permeability of the host rock. Equipping the drill jumbos with ventilated operator cabs might allow dry drilling (with approval from the Mine Safety and Health Administration). This would reduce water consumption to about 64 gal per foot of drift advance (795 L per meter of drift advance).

Detail remarks offered by F&S are as follows:[48]

1. Purposely plan the design for a maximum of downgrade development; this will allow 70 to 80% recovery of drill water.
2. Water recovery in the drift to Drillhole Wash may be on the order of 85% because it is being driven downgrade.
3. The drift to the Imbricate structure will be developed downgrade (-8%), so recovery should be high, about 90%.
4. The drift to Ghost Dance is driven upgrade at 4.27%. Recovery could be less than 50%, and there will be a lot of evaporation. Special sumps and methods of collection will be required in this drift.

In October 1983, Coppage of F&S provided estimates of shaft sinking water losses to formation rock.[49] In that study, Coppage estimated that as much as 50 to 60 gal (190 to 227 L) of water would be left in the rock mass after each blast round was mucked out. He also pointed out that, although losses from drill water to the rock are unavoidable, they are certainly controllable. Coppage recommended the following measures to help reduce the losses to the formation:

1. Use faster penetrating drills.
2. Use less water and more air, instead of using a drill-water flow rate of 3 gal/min (11.4 L/min).
3. Have sufficient diaphragm pumps on the shaft bottom during shot hole drilling to keep the water from collecting in low areas.
4. Use the minimum possible number of drill holes to fragment the rock.
5. Avoid drilling into fractures.
6. Use collar pipes on the drill holes.
7. Avoid water spillage and unnecessary usage.

Roger Zimmerman from SNL used the following approach to determine the amount of drilling fluid lost to the surroundings:[50]

1. Use G-tunnel permeability measurements to determine rock acceptability of water from drilling.
2. Use rough estimates of drill performance to estimate the drill water flow potential into the rock.
3. Compare No. (1) with No. (2) and make a recommendation.

Assumptions used by Zimmerman are as follows:[50]

1. A jack leg drill is used.
2. The potential energy at the base of the drill is 16.5 ft (503 cm or 7 psi).
3. An effective pressure of 11.6 ft (352 cm or 5 psi) is acting on the rock over a 2-ft (0.6-m) interval behind the drill bit. (He notes that this quantity could be high because of other assumptions.)
4. Approximately 243 gal (920 L) of water could be used in the drilling process for one round.
5. As much as 17 gal (64 L) of drilling fluid could be lost into the fracture system in one round. (This is based on a rock mass acceptance of 7% and the hypothesis that no water went into the rock matrix.)
6. Water does not remain in a disk because of gravity considerations.
7. Water is accepted by the fracture, passes through the excavated region, and is not removed in the muck. (The nominal saturation of the matrix is

at least 60%, and the matrix effects should be small because of low-matrix permeability.)

Because his estimate showed that a measurable amount of water could go into the rock mass in drilling with a jack leg, Zimmerman concluded that because of all the uncertainties, a conservative figure of 7% should be used as the estimated amount of drilling water lost to the welded tuff during the mining process.[50] Furthermore, Zimmerman noted that if a twin jumbo were used, as much as four times the quantity of water could go into the hole, during the drilling, at a pressure that would probably be much higher. Thus, a larger quantity of water could go into the rock mass in a typical round and not be removed by the rock.

Using a hypothetical TOSPAC problem by Peters, Hunter concluded that the exposure of the surface to large quantities of water would not significantly affect the ability of the site to contain and isolate radionuclides.[11] He went on to say that calculations indicated that any large quantity of water contacting welded tuff rock would not move very far into the matrix in a period of weeks to months. Therefore, he believed that water from drilling or mining operations in the Topopah Spring unit would probably drain through the fractures. However, these analyses indicated that water would remain in the matrix, move quickly into the unsaturated tuff matrix, and equilibrate to increase the overall matrix saturation slightly. Therefore, he also concluded that even 1.5 million gallons (5.7×10^6 L) of water distributed through the underground would not significantly affect the long-term performance capabilities of the repository.

Dan Koss of REECo was also asked to estimate the amount of drilling fluid lost during ES construction and drifting. Koss stated that if none is lost to the rock formation, all the water used in face drilling, bolting, and mucking operations would eventually be removed.[51] He felt that the actual numerical prediction of how much water is lost to the rock formation should be made by someone with a more thorough geotechnical understanding of Yucca Mountain. Koss did, however, offer the following guidelines:

1. Shaft sinking will probably be performed by the bench method. Refuge water will mostly be removed with the muck. If there is excess water, it will be pumped into the sinking bucket and hoisted out with the muck.

2. For drifting done in an uphill heading, refuge water will run downhill on the drift floor and be captured in a sump. For drifting done in a downhill heading, refuge water will be captured at the face and pumped out to a sump by means of a dewatering line.

3. Water will be used to retard dust during face drilling, bolting, and mucking operations. At the ESF, there will probably be a limit on the rate at which this water can be applied.

Based on the technical arguments provided by these experts, a value of 10% was selected for the amount of drilling fluid that would be lost to the surroundings as a result of ESF shaft construction and drifting. Of the 33 million gallons (1.25×10^8 L) of drilling fluid expected to be used during ESF construction, approximately 29,861,600 gal (1.13×10^8 L) will be used on the surface. The remaining 3,159,950 gal (1.20×10^7 L) will be used underground. Therefore, the loss of drilling fluid underground is expected to amount to 315,995 gal (1.2×10^6 L). This value was used to evaluate the transport of drilling fluid in the materials transport portion of this evaluation.

B.8 Effect of Ventilation System

While drilling fluids are being added to the host rock, the ventilation system will be removing water from the rock. To determine the extent of this drying effect, ventilation reports, including those from the Climax Mine, were studied.

Hopkins *et al.* have performed a computational investigation to determine whether cyclic ventilation would cause a reduction in the saturation of the drift walls and adjacent host rock.[52] Both one-dimensional and two-dimensional cases were studied. The one-dimensional studies provided insight into the effects of ventilation cycling ratios and cycle periods on the removal of moisture from the drift wall. The saturation time histories resulting from the one-dimensional calculations showed that within 1 yr saturation was not affected beyond approximately 2 m from the drift wall. Moreover, the results of the one-dimensional calculations indicated that drift ventilation appreciably reduced drift-wall saturation. It also showed that cyclic ventilation increased the efficiency of moisture removal; cycling yielded more moisture removal per unit power of input to the ventilation equipment. Finally, the one-dimensional calculations indicated that for reasonable cycling conditions the cumulative flux approached that of constant ventilation as time progressed.

The two-dimensional case analyzed water velocities in the vicinity of the waste canister, providing a means of approximating the long-term effect of ventilation on the advection of potentially hazardous solutes away from the repository region.[52] Constant ventilation for 50 yr after drift excavation resulted in a fluid velocity field that indicated that advective contaminant transport away from emplacement holes could be prevented for a period of 275-420 yr. Thus, drift ventilation may be used to postpone the onset of advective transport of solutes away from the repository region. The period and extent of enhanced containment are a function of the infiltration rate and the relative humidity of the ventilation air.

The Spent Fuel Test at Climax (SFT-C) that was conducted in stock granite at 420 m below the surface at the NTS provided an opportunity to collect actual field data.[53,54] The ventilation system employed in the SFT-C test array was an open circuit through which inlet air was drawn down the personnel access shaft, pulled through the test area, and exhausted up the canister access hole by surface-mounted exhaust fans. The principal mechanism for removal of energy is heat transfer to the ventilation air stream. Energy removed by ventilation was of two types:

1. sensible heat: energy associated with increasing the temperature of air at a constant water content;

2. latent heat of vaporization: energy associated with vaporizing water and adding it to the air stream.

Total energy removal from the SFT-C was about 148 MW.h during the spent-fuel storage phase of the test.[54] Of this, 76.6% was removed as sensible heat and 23.3% was removed as latent heat of vaporization. Interpretation of the latent heat plot (shown in Fig. B-1) indicates that "drying out" by evaporation of the

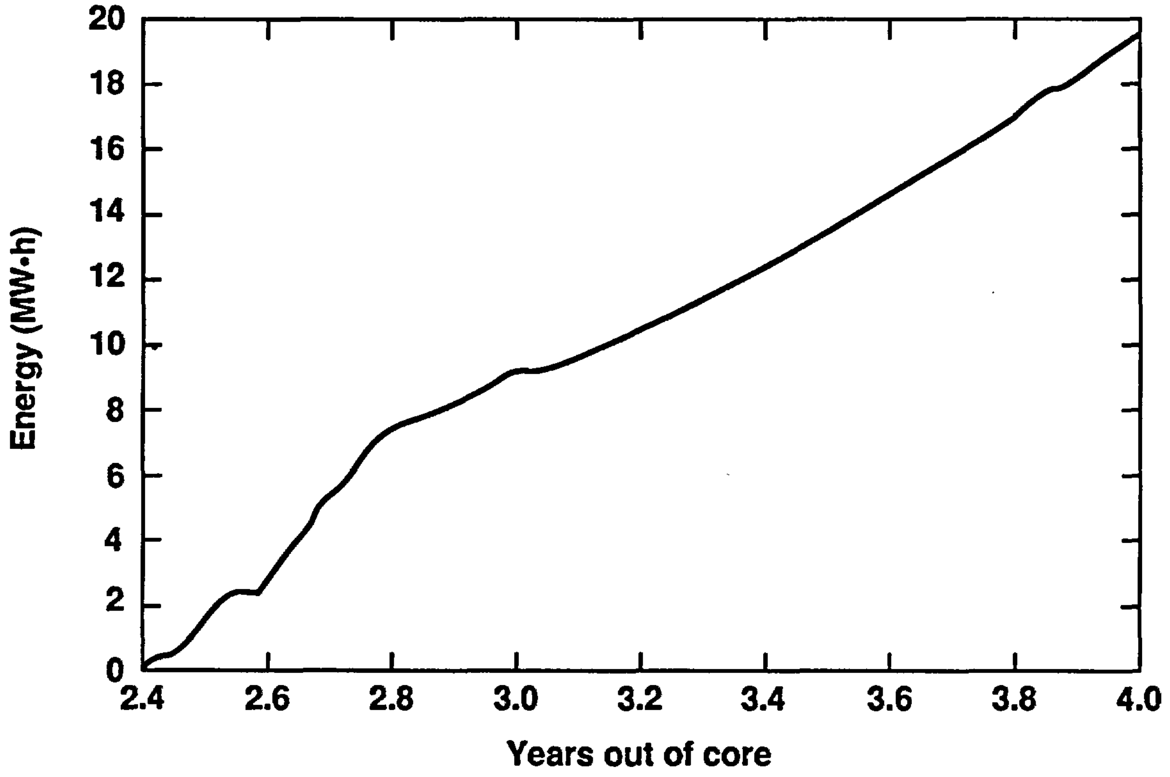

Fig. B-1. History of cumulative thermal energy removed by vaporization of water (redrawn from Patrick *et al.*, Ref. 53).

construction water was occurring during the first 0.4 yr of the test. This represents approximately 3170 gal (12,000 L) or an evaporation rate of 0.87 gal/h (3.3 L/h).[55] Following that evaporation, the curve shows that a phase of nearly constant slope occurred. This phase is interpreted as steady evaporation of seepage and pore water and constitutes approximately 5020 gal (19,000 L) or an evaporation rate of 0.5 gal/h (1.8 L/h). Also of interest is the observation that the rate of water removal was reduced during the winter months. In all, approximately 40,000 lb (20 tons) of water are removed from the facility each year in the ventilation air stream.[54]

Eaton and Peterson analyzed the influence of the ventilation system on the movement of residual construction water and *in situ* pore water in the drifts.[55] These calculations were done using NORIA, for periods of 1 week to 100 yr. The results, shown in Fig. B-2, illustrate that after only 4 weeks much of the residual construction water had been removed. Eaton and Peterson observed enhanced drying in the MPZ and, by 1 yr, they found that the effect of drying had penetrated approximately 2 m into the undisturbed rock. They concluded that the ventilation system was effective in changing the saturation because it removed residual water from the drift walls before the capillary forces could transport it away from the drift walls into the undisturbed rock.

These studies indicate that the ventilation system will have a significant drying effect between 1 month and 2 yr. To be conservative, LANL concludes that drying by ventilation cannot be expected to counteract the effects of wet mining the bulk permeability and infiltration rooms. However, in the long term (over 3 to 4 yr), the ventilation system can be expected to remove more water than was added during construction.

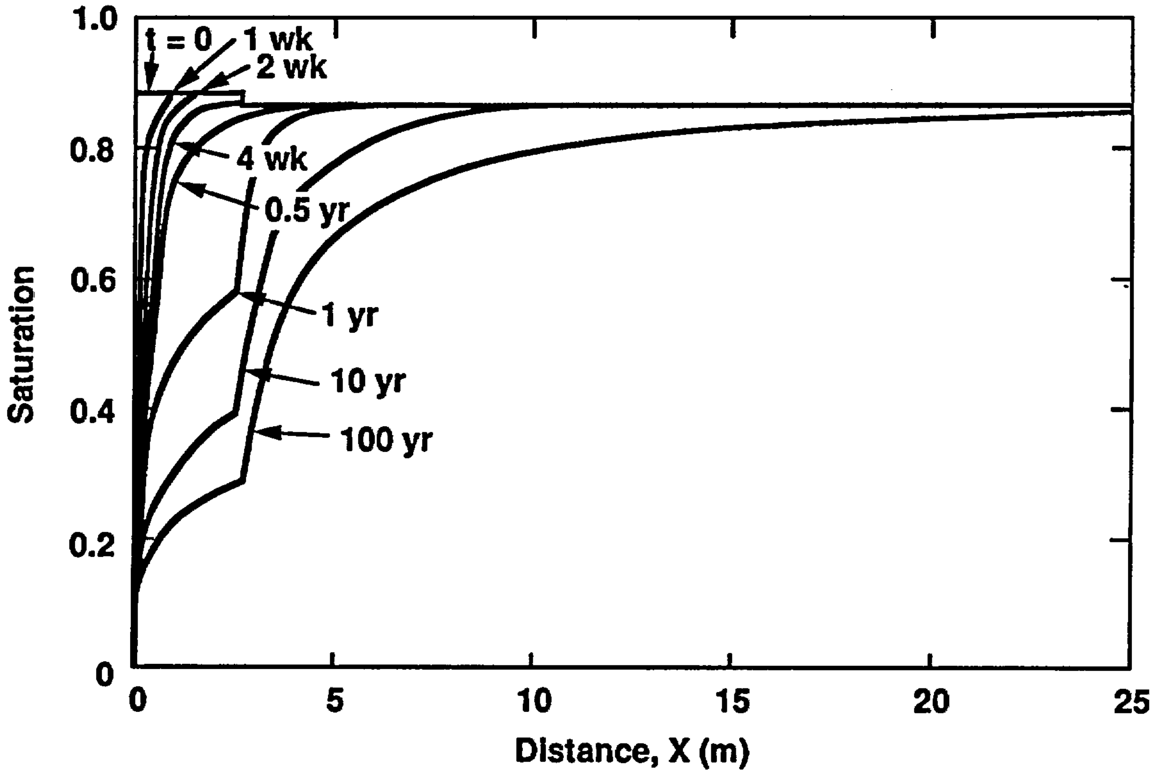

Fig. B-2. Effect of drift ventilation on saturation profiles for Topopah Spring, for up to 100 yr (redrawn from Eaton and Peterson, Ref. 55).

B.9 Other Site Characterization Data Issues

One principal investigator, A. E. Norris (LANL), had the following specific comments about the use of tracers.[56]

1. The chlorine-36 Water Movement Tracer Test is sensitive to the introduction of chlorine-36 and chlorine into the samples that will be collected as the ES is mined.
2. A correction for Well J-13 water in the chlorine-36 samples can be applied to the data if this water is traced with bromide ions.
3. A corollary requirement is that no tracers containing chlorine be used in Well J-13 waters while the ES is being mined.
4. Water used either to drill or to overcore holes should not be traced with bromide if bromide is used as a tracer for the Diffusion Test. Lithium chloride or sodium chloride could serve.
5. The packers used in the Diffusion Test may be pressurized with nitrogen. Should a gas leak occur, the contents of a tank of nitrogen might be lost to the underground environment. Most, if not all, of this nitrogen would be exhausted to the ventilation system.

Norris' main concern stems not from a need to restrict materials usage (except tracer chemistry), but from a need to identify what is being used so that he can make the appropriate corrections in his results. Therefore, Norris' concern is more of an administrative record-keeping problem than a usage problem.

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