Site Technical Position

Repository Design Issues

For The

Nevada Nuclear Waste Storage Investigations

Draft

January 1984

Division of Waste Management

U. S. Nuclear Regulatory Commission

8402150572 840130
PDR WASTE
WM-11 PDR

United States Nuclear Regulatory Commission
Engineering Branch

Site Technical Position - Repository Design Issues For
The Nevada Nuclear Waste Storage Investigation Site

Background

In review of an application for Construction Authorization for a high-level waste geologic repository, the NRC staff is required to make a determination if the site and design meet the technical criteria of 10 CFR Part 60. The NRC staff determination will be based on the answers to, and supporting analyses of, technical questions concerning groundwater flow, geochemical retardation, waste form and waste package, geologic stability, and facility design. During the process of Site Characterization, the Department of Energy (DOE) performs the laboratory and field investigations that develop the information needed to address these basic technical questions.

Investigations needed to characterize a geologic repository are complex and involve long lead times. The Nuclear Waste Policy Act of 1982 (the Act) has established a schedule for site characterization and selection. Specifically, the Act requires publication of Site Characterization Plans (SCPs) by DOE at an early stage of the process. Subsequent to the receipt of an SCP the NRC must prepare a formal Site Characterization Analysis (SCA) for each site. Documented site reviews, technical meetings, and single-issue site technical position papers will precede and supplement the SCA's.

Because of the complexity and long lead times for site characterization investigations, it is essential that activities be organized to make possible an NRC determination of site acceptability. Proper organization necessitates early identification of technical questions relevant to the specific site. Therefore, this document establishes the NRC position as to the essential technical questions (specific issues) relevant to design at the Nevada Nuclear Waste Storage Investigation (NNWSI) site. Future Site Technical Positions relevant to design will address both NRC staff concerns regarding selected specific issues and acceptable technical approaches for addressing those specific issues.

Terminology used by NRC staff to describe issues is as follows:

Site issues are defined as questions about a specific site that must be answered or resolved to complete licensing assessments of the site and design suitability in terms of 10 CFR Part 60. Site issues are not necessarily controversial questions. Site issues can be divided into performance issues and specific issues.

Performance Issues are broad questions concerning both the operational and long-term performance of the various elements of the overall geologic repository system (e.g., waste form, container, geologic setting). Performance issues are derived directly from performance objectives in 10 CFR Part 60 (including environmental objectives of 10 CFR Part 51). Development of performance issues for a geologic repository is explained in detail in Appendix C of NUREG-0960, "Draft Site Characterization Analysis of the Site Characterization Report for the Basalt Waste Isolation Project," March 1983.

Specific Issues generally are questions about conditions and processes (information needs) that must be considered in assessing the performance issues. Performance issues include the integration of numerous specific issues. Performance issues establish the relationship between specific issues discussed in this Site Technical Position and the performance objectives of 10 CFR Part 60.

Performance issues for a geologic repository are:

1. How does the repository design account for the basic NRC health and safety criteria for the operational period of the repository?

2. How do the design criteria and conceptual design accomodate the retrievability option?

3. When and how does water contact the engineered barrier?

4. When and how does water contact the waste package?

5. When and how does water contact the waste form?

6. When, how, and at what rate are radionuclides released from the waste form?

7. When, how, and at what rate are radionuclides released from the waste package?

8. When, how, and at what rate are radionuclides released from the engineered barrier?

9. When, how, and at what rate are radionuclides released from the disturbed zone?

10. When, how and at what rate are radionuclides released from the farfield to the accessible environment?

11. What is the pre-waste emplacement groundwater travel time along the fastest path of radionuclide travel from the disturbed zone to the accessible environment?

12. Have the NEPA Environmental/Institutional/Siting requirements for nuclear facilities been met?

Because design is an integral part of every aspect in repository development, information on design for the NNWSI site will be an important part of the total repository system information needs of the NRC staff. Specific issues identified in the following section delineate information concerning design at the NNWSI site needed by the NRC staff to assess adequately the performance issues. The sequential order in which issues are identified should not be interpreted as the order of relative importance.

Technical Position

This is not consistent with our standard format for UTP's. Needs to be revised in next draft.

It is the position of the NRC staff that, based on the current level of the NNWSI Project, assessment of the Technical Criteria in 10 CFR Part 60 requires that, at a minimum, the following specific issues concerning design should be addressed:

4.0 REPOSITORY DESIGN

4.1 How does the repository design account for the basic NRC health and safety criteria for the operational period of the repository?

10 CFR Part 60 contains technical requirements for the repository design to facilitate compliance with the NRC health and safety criteria for the operational period of the repository. These include criteria for both

the restricted and unrestricted areas of the geologic repository operations area. DOE should identify those structures, systems and components which are important to safety. The natural and induced geologic conditions and their effects on proper operation of the geologic repository operations area should be considered. The design of different components and the interfaces between these components, as well as the interface between design and performance confirmation testing are all issues which need to be addressed to assure compliance with 10 CFR Part 60.

4.1.1 What are the restricted and unrestricted areas of the geologic repository operations area?

In order to apply the criteria of 10 CFR Part 60 to the restricted and unrestricted areas, it is necessary to determine what the boundaries are for these areas. These areas should be determined based on the design for the geologic repository operations area.

4.1.1.1 What provisions are taken in the repository design to assure that radiation levels and releases of radioactive materials to unrestricted areas do not exceed limits specified in 10 CFR Part 20?

There are two means by which releases of radioactive materials and radiation from restricted areas within the geologic repository operations area would reach unrestricted areas:

- diffusion through rock and soil
- transport by fluids

Development areas could be designated as either restricted or unrestricted. The distance between restricted and unrestricted areas could be as small as the thickness of a ventilation door. Since diffusion occurs only over very limited distances in solid media, it is not a credible mechanism for the release of radionuclides to unrestricted areas.

Hence, release of radiation and radionuclides would occur due to fluid transport, the transport media being air and water. In the case of water transport, there are two possible alternatives.

- transport by surface watercourses
- transport by groundwater

In the underground facility or near-field, there will be some seepage of water into the storage rooms. This seepage occurs because construction of the openings creates a pressure drop and water will tend to flow to a point where the pressure is less. Because the repository is located in the unsaturated zone, this seepage is likely to be sporadic. The DOE should analyze the potential of water as a medium of radionuclide transport from the restricted to unrestricted areas. If the development areas are unrestricted, water movement from the emplacement rooms to development areas should be monitored for radionuclides. If contaminated water is detected (in excess of 10 CFR Part 20 limits) in restricted areas, provision should be made for handling and treating the water before release to unrestricted areas.

The other possible transport medium from the underground facility is the exhaust air from the underground ventilation system. Section 60.133(g)(3) requires that separate ventilation systems be provided for the excavation and waste emplacement areas. Hence, radionuclide releases would normally be expected in the waste emplacement ventilation system. However, there will be locations where the two ventilation systems occupy adjacent airways and leakage between systems could occur.

The releases of radioactive material are accompanied by releases of ionizing radiation. To satisfy the performance objectives, it must also be assured that the doses and levels of radiation meet the limits in 10 CFR Part 20. As with releases of radionuclides, the standards for radiation doses and levels for the general public (unrestricted areas) are set well below those in restricted areas. However, as the attenuation of radiation levels follows an inverse square law (Glasstone and Sesonske, 1981), it can be shown that radiation doses and levels which meet 10 CFR Part 20 limits in restricted areas will result in satisfactory levels in unrestricted areas.

4.1.1.2 What provisions are taken in the repository design to assure that radiation levels and releases of radioactive material into the air in the restricted areas do not exceed limits specified in 10 CFR Part 20?

The concentrations of radioactive materials in the airways within restricted areas of the underground facility must be within the limits given in 10 CFR Part 20. Emplacement areas will probably be restricted areas while development (or excavation) areas could be either restricted or unrestricted. The dilution times required to satisfy these requirements depends on the airflow rates and the initial concentrations of contaminants in the airstreams. The initial concentration in a storage room will depend on the condition of the room into which the release occurred:

- open and ventilated
- bulkheaded and backfilled
- bulkheaded and unbackfilled

In the open and ventilated case, the airflow into which the release occurs would be the cross-sectional area of the aperture through which the release occurs multipled by the air velocity. The concentration of the contaminant could be quite high initially. However, since the contaminated airflow is small compared to the total airflow in the storage room, the concentration will diminish as mixing occurs with exhaust air from other rooms. Depending on the velocity of the airflow and the location of the room in which the release occurred, dilution to the allowable concentration could occur before the contaminated air reaches the exhaust shaft. Where rooms are bulkheaded and backfilled, the release could be primarily contained within the backfill. In the case of bulkheaded but unbackfilled rooms, the airborne radionuclides could diffuse throughout the room and some of the release could be carried into the exhaust airways through leakage. Dilution to within the limits in 10 CFR Part 20 would be required if it were necessary to breach the bulkheads and enter the room.

4.1.2 What structures, systems, and components of the repository are important to safety?

As part of the conceptual design, all structures, systems, and components important to safety should be identified as well as the methodology used to determine important to safety. Section 60.131(b) of 10 CFR Part 60 outlines the design criteria for structures, systems and components important to safety. The criteria cover the following areas of concern:

- protection against natural phenomena and environmental conditions
- protection against dynamic effects of equipment failure and similiar events
- protection against fires and explosions
- emergency capability
- utility services

- inspection, testing, and maintenance
- criticality control
- instrumentation and control systems
- compliance with mining regulations
- shaft conveyances used in radioactive waste handling

In order to determine compliance with 10 CFR Part 60, it is essential to determine how these concerns are addressed in the repository design.

4.1.2.1 What provisions are taken in the repository design to assure that structures, systems, and components important to safety will meet the 10 CFR 60.131 criteria?

Once the structures, systems, and components important to safety have been identified, the design criteria of 10 CFR Part 60 should be applied as appropriate. As an example, the following information should be supplied so that it can be verified that the radiation doses and releases of radioactive materials will satisfy 10 CFR 20:

1. The layout of the repository including the number and dimensions of entries, storage rooms, returns, and shafts;

2. The design of the development and waste emplacement (confinement) ventilation systems in the underground facility including the airflows supplied to the various openings;

3. The condition of the storage rooms after completion of waste placement, that is:

    - open and ventilated
    - bulkheaded and backfilled
    - bulkheaded and unbackfilled

If rooms are bulkheaded, it is important to monitor the concentrations of any radionuclides contained within them;

4. The design and location of filtration units for the removal of airborne radionuclides from the underground ventilation system exhausts. To limit the releases to the atmosphere, filtration systems are required should any radionuclides be detected in the exhaust air;

5. The design of monitoring systems and detection of radionuclides in the airways and effluents;

6. Design of underground handling systems for contaminated water. Contaminated water should be handled in an enclosed system (not open ditches) in order to limit exposure to individuals;

7. Design of surface handling systems for contaminated water from the underground facility;

8. The radiation levels at the waste package and in the operator's cabins on the equipment (both underground and surface);

9. The design of the ventilation system for surface facilities and airflows supplied, including monitoring systems for radiation levels and concentrations of airborne radionuclides;

10. The design aspects of structures, systems, and components which facilitate maintenance and repair in order to limit the time required to work in the vicinity of radioactive materials;

Stop

11. The design of a radiation alarm system to warn of significant levels of radiation or radioactive mateirals in the air or in effluents;

12. The design of utility systems to ensure that structures, systems, and components important to safety will function under both normal and accident conditions;

13. The design of systems for processing, transporting, handling, storage, retrieval, and emplacement to ensure that a nuclear criticality accident does not occur; and

14. The design of the shaft conveyance systems including the cage location systems, the interlock systems, and systems to indicate when waste packages are ready for transfer.

4.1.3 What provisions are taken in the repository design for surface facilities to assure safe handling and storage of wastes prior to emplacement?

Surface facilities should be designed to ensure safe handling and storage of wastes, to ensure the ventilation system protects against radiation exposures and offsite releases, the monitoring and control of contaminated effluents, the treatment of radioactive facility wastes, and be designed to facilitate decommissioning.

4.1.4 What provisions are taken in the repository design for the underground facilities to assure that disruptive events such as flooding, fires, and explosions will not spread through the facility?

In the unsaturated zone above the water table sustained flow of groundwater is generally unlikely. However, perched water zones and water-bearing faults can exist within the unsaturated zone, and may result in sustained groundwater flows into the underground facility if they are intersected by the repository or are connected hydraulically to the repository. The mechanisms of flow of groundwater in the unsaturated zone are poorly understood (National Research Council, 1983). Hence the scenarios for water inflow into the repository need to be analyzed in detail.

Construction of the openings results in a disturbed zone surrounding them. The rock in the disturbed zone will be more fractured than the rest of the rock mass and thus have a greater permeability, other things being equal. The sources and impacts of inflows on waste emplacement should be assessed. Inflows which limit the ability to safely emplace the waste should be quantified for hole and room scales. Potential intrusion of water can range from small to major and may be gradual or sudden. Sources of intrusion could include unidentified boreholes, gas pockets, fracture zones, and surface runoff. Potential water intrusions and their impact on repository operations should be addressed.

The presence of rock bolts, shotcrete and/or steel sets may alter the hydrologic conditions in the vicinity of the shaft and repository rooms. Whether these systems create preferential pathways for flow or impede flow in the case of shotcrete needs to be assessed.

Waste empalcement will result in a non-uniform increase in the temperature of the rock surrounding the openings. This temperature increase will result in an increase in the vapor pressure of the water due to vaporization of liquid (Bear, 1979). Due to the phase change, groundwater movements will be altered. It is important to know whether these changes will result in a reduction in the isolation capability of the repository.

4.1.5 What provisions are taken in the repository design of the operations area to allow implementation of a performance confirmation program?

A program to monitor repository conditions and responses should be outlined as a part of repository design. The program will require a clear logic to define the amounts and types of information needed. The repository design should include a system for assessing how closely the actual performance is to the performance predicted during design. The design should allow the instrumentation system to monitor repository performance without interference from repository operations. The performance confirmation program should gather information on the response and interactions between the geologic media and waste form for comparison to baseline data and expected responses.

Subpart F of 10 CFR Part 60 contains the requirements for a Performance Confirmation Program, which shall include in situ monitoring, laboratory and field testing, and in situ experiments as appropriate. As a minimum, measurements shall be made of:

- rock deformation and displacement
- changes in rock stress and strain
- rate and location of water inflows

- changes in groundwater conditions
- rock pore water pressure
- thermal and thermomechanical response of the rock mass
- radionuclide and radioactivity in the repository

The purpose of these measurements is to determine the actual behavior of the rock mass and compare it to the design assumptions. Significant differences between actual and predicted behavior may necessitate modifications to repository design or to contruction methods.

4.1.6 What provisions are taken to implement a quality assurance program for structures, systems, and components important to safety?

Subpart G of 10 CFR Part 60 require that there be a quality assurance program to provide adequate confidence that the geologic repository and its subsystems and components perform satisfactorily in service. This program applies to all systems, structures and components important to safety, to design and characterization of barriers important to waste isolation, and to activities related thereto including: site characterization, facility and equipment construction, facility operation, performance confirmation, permanent closure, and decontamination and dismantling of surface facilities.

4.1.7 What provisions are taken to implement a program for certifying personnel operating systems and components important to safety?

Subpart H of 10 CFR Part 60 requires that operations of systems and components that are important to safety be performed only by trained and certified personnel. In addition it requires that the physical condition and general health of certified personnel be such as to minimize risk of health-caused operational errors that could endanger public health and safety.

4.2 How do the repository performance criteria and the conceptual design accommodate the retrieval requirements of 10 CFR Part 60.111?

Section 60.111(b) of 10 CFR Part 60 requires that the geologic repository operations are be designed so that any or all of the emplaced waste can be retrieved at any time up to 50 years after waste emplacement operations are initiated, unless a different time period is approved or specified by NRC. While this requirement for retrievability is not intended to dictate design decisions such as whether or not to backfill storage rooms, adequate provisions for retrieval must be incorporated into the design. Included in the design criteria may be thermal loads, deformation limits, backfill functions, and allowable working temperatures. The conceptual design will interpret the design criteria into a functional repository with retrieval as a designed option.

4.2.1 What provisions are taken in the repository design of the underground facility to preserve the option of waste retrieval as required by 10 CFR Part 60?

As a minimum, the following information must be obtained and considered in determining how the design criteria and conceptual design accommodate the retrievability option:

1. Whether the storage rooms will be open and ventilated, bulkheaded, or immediately backfilled;

2. Whether canisters will be stored in vertical or horizontal drilled holes or in the excavated area of storage rooms;

3. Whether drilled storage holes will be lined;

4. The number of canisters stored per hole;

5. The type of equipment for overcoring of drilled holes or remining of backfill, if found necessary;

6. The manner in which repository operations will accommodate retrieval from a local area concurrent with development and storage;

7. The manner in which repository operations will accommodate retrieval of all canisters within the repository;

8. Surface handling and disposal systems for retrieved canisters;

9. How will thermal loading in the storage rooms be controlled during retrieval?;

10. The effect of thermal loading and cycles of cooling and heating on stability of openings;

11. Detection and retrieval methods for single or multiple breached canisters from the borehole, especially in the case of breached canister(s) located near the middle of the lined borehole; and

12. Information on materials handling systems to deal with breached canister(s) and contaminated rock and backfill (if utilized).

The storage room options (open and ventilated, bulkheaded, or immediately backfilled) can affect storage room environment after full canister emplacement. All three options have different impacts on retrievability, open rooms having the least impact, and backfilled rooms having the greatest. Canister emplacement configuration in vertical or horizontal drillholes or in the excavated area of storage rooms strongly affects equipment design for retrieval. Borehole instability after canister emplacement may cause breaching of canister(s).

A plan for handling breached canisters during retrieval must be integrated with any chosen storage concept. A breached canister could interfere with the retrieval of other canisters, thereby slowing the retrieval rate.

If the rooms have been backfilled, the backfill must be removed before the canister(s) can be retrieved. Because of the elevated temperature and the likelihood of any radionuclides which may have escaped from breached canisters being contained within the backfill, remining backfill will be done in a hostile environment. Protection of personnel from radionuclide release must be assured, while maintaining the required retrieval schedule.

Retrieval of some or all of the canisters within the repository may be required. Because local retrieval may be concurrent with storage operations, it is necessary to allow coordination of these activities in the repository design.

Except with open storage rooms, ventilation during retrieval must provide for the thermal impact of stored canisters on host rock and ambient air temperatures. Handling host backfill material must be properly planned. Weakened ground and thermal spalling may require rehabilitating rooms for safe entry. Thermal impacts on stability of openings must be identified in order to develop schemes and schedules for retrieval in a timely manner.

In backfilled rooms, breach of a canister may result in contamination of the backfill. In such cases, special systems for handling the contaminated material and for decontaminating it (and equipment which has come in contact with it) will be required.

4.2.2 What provisions are taken in the repository design of the surface facilities to assure safe handling and storage of waste during implementation of the retrieval option?

The surface facility handling and storage systems, ventilation systems, effluent monitoring and control systems, and facility waste treatment systems should have adequate capacity and capability to handle all requirements if the retrieval option was initiated.

4.3 When and how does water contact the engineered barriers?

When, how, and at what rate are radionuclides released from the disturbed zone?

Design related aspects of concern include the rock mass disturbed zones around the underground facility, the shafts, and boreholes, and the excavated area of the shafts and boreholes. In order to design stable repository openings, an extensive geotechnical data base is required. This involves detailed field and laboratory investigations with respect to geology, hydrogeology, and geomechanics. From these investigations, the baseline information on subsurface stratigraphy and associated geologic structure, groundwater regime, and mechanical and thermomenchanical properties can be determined for use in repository design.

In addition, the following questions should be addressed:

- How is repository performance expected to be affected by exploratory shafts?

- How is repository performance expected to be affected by repository shafts?

- How is repository performance expected to be affected by exploratory boreholes?

Shaft sealing is more complex than borehole sealing, and so the emphasis is on shafts (both exploratory and repository). Special concerns related to borehole sealing are discussed in another section.

The proposed repository horizon is in the Topopah Springs member of the Paintbrush tuff which is about 400 feet above the static water table. Before meaningful performance assessments can be made and seal design criteria developed, the physical processes governing the flow of water through fractured (jointed) tuff in the unsaturated zone should be determined (National Research Council, 1983). In addition, the movement of gaseous contaminants emanating from the repository or its surroundings through air-filled pore space and possibly reaching the accessible environment should be determined (Evans, 1983). The potential for water inflow from below the repository horizon to the repository through faults should be considered in establishing the seal design criteria.

4.3.1 What are the natural geologic features and processes which will cause water to contact the engineered barriers and to be carried away from the engineered barriers?

The geologic and hydrologic setting of the repository will undergo a screening process designed to enhance the potential for safe waste emplacement. Certain adverse but not disqualifying conditions may survive the screening process. The effects of natural conditions on construction may include sophisticated water handling systems, overexcavation to allow for closures prior to placement, increased extraction ratio for gassy conditions and increased ventilation capacity to allow for worker and equipment efficiency. Other effects may be identified during repository development which will require design changes to accomodate safe waste emplacement. The range of probable effects resulting from natural conditions need to be identified.

Geologic anamolies in the form of anamolous zones, shear zones, water pockets, gas pockets, and other variations from the expected geology may preclude safe waste emplacement. Large repository areas may be affected by anamolous zones in the rock mass. These zones may constitute preferential seepage pathways both in and out of the repository. Gas and water pockets may represent unstable roof or floor conditions precluding safe emplacement of the waste. The potential effects of the geologic anamolies on stability, containment, and isolation of the waste should be defined.

Siting criteria are designed to limit the detrimental effects of future events. However, over the isolation/containment period some geologic events or works of men may result in water reaching the engineered barriers. The events which could possibly lead to water inflows into the repository need to be identified, the inflow quantities estimated, and the consequences defined. The effect on the engineered barriers need to be identified in terms of reduced performance and loss in isolation capability.

Changes to the tectonic regime may result in faulting in the vicinity of the repository. The resulting change in the hydrologic regime may result in inflows to the engineered barriers. The range of possible faulting in terms of location with regard to the repository, the existing hydrologic conditions, the magnitude of the displacement, and the stratigraphy will need to be assessed to estimate inflows and their impacts on engineered barriers.

Dynamic vibrations resulting from seismic events such as earthquakes may cause damage to the containment and isolation capability of the underground facility. Also, localized damage may be expected if a tunnel is crossed by a fault which was displaced as a result of the seismic event. Thus, anticipated seismic loadings should be considered in the repository design.

4.3.2 What are the repository-induced changes which will cause water to contact the engineered barriers and to be carried away from the engineered barriers?

The primary function of the underground facility is the isolation of the wastes from the accessible environment. This requires, among other factors, ensuring that the time for groundwater to travel to the accessible environment is in conformance with 10 CFR Part 60 requirements. The redistribution of stresses resulting from excavation, and the increased rock temperatures resulting from the heat radiating from the waste package, both affect rock mass permeability and hence, groundwater flow. As temperature increases, the hydraulic conductivity also increases, other things being equal. An increase in temperature will also tend to cause the rock to dilate, thus resulting in a tendency for joints to open. However, the increase in the stress level due to stress redistribution and thermal stresses will tend to close the joints. While these tendencies are in opposition, the effects will not necessarily cancel each other out so that the coefficient of permeability and hence the groundwater flow will change. Closure of storage holes due to movements along fracture planes could result in damage to waste packages and contribute to releases of radioactivity. Groundwater flows into the storage holes would transport the released radioactivity.

Section 60.133(e) of 10 CFR Part 60 requires that openings be designed so that operations can be carried out safely, and the potential for deleterious rock movement or fracturing of overlying or surrounding rock is reduced. This means that the openings must be stable, i.e., the strength of the rock surrounding an opening must exceed the stresses acting on it. In a repository for high-level nuclear waste, the stresses are contributed by three sources:

- in situ (virgin) stresses, which occur everywhere in the rock and which are due to the depth of overlying strata and the tectonic history
- excavation-induced stresses, which are a manifestation of the redistribution of stress as a result of excavation of the opening
- thermal stresses, which are induced by the thermal gradient in the rock resulting from the radiation of heat from the waste packages and the conduction of the heat through the rock mass.

It is important to define the design methodology and the models that were used to determine the mechanical and thermal stress conditions in the storage rooms of the repository. Since models are idealizations of the in situ situation and since the results of modeling will depend to some extent on the nature of the simplifying assumptions which were made, it is important to establish the validity of the models and the input parameters used in modeling.

Rock mass strength is the level of stress concentration (resulting from in situ stresses and excavation, thermal, hydrological, and earthquake loadings) at which rock will fail. Therefore, the determination of rock mass strength properties and their variation with time and temperature is very important to the design of stable openings. Rock mass strength depends on the strength of the intact rock, joints/discontinuities, and interstitial fillings.

Review of DOE's currently available documents (SAND 81-0212, 1981; SAND 82-1723, 1982) clearly indicates that additional tests are necessary on different-sized samples to determine the joint shear strength. The data base for intact rock shear strength seems sufficient but can be improved by conducting more tests on specimens under expected repository conditions. The effect of lithophysae and the degree of welding on the compresive, tensile, and shear sterngth of the Yucca Mountain tuff should be established through laboratory and in situ tests. The geological setting in the G-tunnel differs from that at Yucca Mountain in the extent and distributin of welded tuff. Since there are apparent differences in rock mass properties between welded and non-welded tuff, a rationale should be established for application of the G-tunnel data to the Yucca Mountain site for any conceptual design.

At the Yucca Mountain site, the Topopah Spring Member and the overlying stratigraphic units may be divided into two groups:

- relatively low-density rock which exhibits high porosity and sparse fracturing (nonwelded tuff)

- relatively high-density rock which exhibits low porosity and dense fracturing (welded tuff)

The differences in the degree of welding and porosity appear to govern the strength variability of tuff, and this needs to be specially addressed during site investigation. The test findings to date indicate that the compressive strength is inversely proportional to porosity (SAND 80-1453). For the Topopah Spring Member, which has been categorized as moderately to densely welded, the porosity ranges from 10 to 25%. Therefore, its strength could have a wide range of values, and should be investigated during site characterization.

Moreover, strength variability is further complicated by the presence of fractures in tuff. In general, the degree of fracturing in tuff is directly related to the degree of welding. Typically, densely welded zones are heavily fractured while intervening non-welded zones have few or no fractures. According to Scott et al (1983), the Topopah Spring Member is especially marked by dense fracturing. This certainly has an impact on the rock mass strength and needs to be further examined. A reliable estimate of rock mass strength of tuff in the repository horizon needs to be established. There are several empirical approaches available for preliminary assessment of the rock mass strength. These approaches have their own inherent deficiencies, and require the determination of joint spacings, nature of interstitial fillings and their spatial variability, persistence of fractures, and groundwater conditions.

The rock mass deformation characteristics and their variation with time and temperature need to be analyzed. Investigations into the stress-deformation characteristics for the intact rock and rock mass should concentrate on large-scale, in situ testing supplemented by small-scale, laboratory tests. Non-linearity, time dependence, and spatial and directional variability of the stress-deformation characteristics need to be better defined so that a representative set of input parameters can be used for numerical modeling to optimize repository design. Constitutive models need to be developed for predicting rock mass deformation. A failure criterion should be developed to incorporate rock mass discontinuities.

With respect to rock mass deformation, it is generally recognized that a meaningful analysis of the sbability of underground openings can be made only after establishing what constitutes instability or failure. Deformation analyses based on laboratory and field experimental data and analytical models thus become a very important tool in designing the repository and assessing its performance through time. Most laboratory studies performed so far have involved intact rock specimens of very small sizes. However, the actual stress-deformation behavior is mainly controlled by the geologic imperfections which cannot generally be represented in small-scale test specimens. Hence, representative large-scale in situ tests should be performed to determine the rock mass stress-deformation behavior.

The design logic and analytical approaches should be clearly defined to determine the manner in which the improving data base from the site characterization program is utilized in the design of openings.

4.3.2.1 What provisions are taken in the repository design of the seals for shafts and boreholes to reduce the potential for creating either a preferential pathway for groundwater or promoting the migration of radioactive waste through existing pathways.

Shafts and boreholes are the most direct potential pathway to the accessible environment. Thus it is necessary that their construction cause a minimum of disturbance to the surrounding rock. In order to minimize the potential for migration of air or water borne radionuclides, the shafts and boreholes must be sealed. The seals must be capable of meeting the performance objectives stated in 10 CFR Part 60.

The two primary purposes of the short-term seal (STS) (which incorporates the shaft lining) are to maintain stability and dry working conditions during the operating life of the shaft. Neither of these tasks is directly related to the requirement for radionuclide isolation. However, the STS will be present during permanent closure of the repository, and will have to be either removed or incorporated into the long-term seal (LTS).

Construction technique can influence the effectiveness of the STS. Most of the shaft lining techniques (e.g., conventional slip-forming or pre-cast segments) leave numerous joints in the liner which may later require grouting. If the shaft is drilled and a steel casing is used, another interface is created between the casing and the cement.

The properties of the materials that will be used in the STS will be important to long term sealing, especially if the STS is not removed at permanent closure.

Information necessary to evaluate shaft and borehole sealing plans include:

1. A description of the pre-existing hydrologic system, including but not limited to:

    a) Formation permeabilities.

b) The character of vertical hydraulic connections between aquifers at depth, perched water tables, and other permeable zones.

c) Flow rates and travel times along pre-existing flowpaths from the repository to the accessible environment.

d) The hydraulic heads measured in each water bearing zone to determine the maximum pressure and pressure gradient across or through the seal.

e) Anticipated effects of groundwater on shaft construction.

f) Hydrologic monitoring and modeling of the groundwater system before, during and after shaft construction.

2. A description of rock mass characteristics of the units to be encountered, including:

a) The rock mass strength, and the predicted variation in the rock mass strength down the stratigraphic column with time, temperature, and location.

b) Fracture characteristics in each rock unit, including spacing, orientation, frequency, and condition.

c) Rock mass deformation characteristics, and their variation with time, temperature, and location.

d) The in situ stress state, and its variation with time and location.

3. An approach to characterization of the Disturbed Rock Zone (DRZ) that will be formed around the shafts, to include:

   a) A theoretical prediction of the permeability increase in the DRZ, based on site-specific information.

   b) A description of tests planned during and after shaft construction to fully characterize the DRZ and other changes in the hydrologic system.

4. A discussion of the proposed shaft construction technique, including blasting patterns, pre-grouting plans, temporary support, and materials and construction specifications.

5. A discussion of the proposed Short Term Seal (STS) design, including:

   a) The relationship between the STS and the conceptual design for the Long Term Seal (LTS).

   b) Construction plans for the STS, including lining or casing technique, plans for grouting the liner or casing to the wall rock, and chemical seals, if necessary.

   c) The materials that will be used in the STS, and their long term (more than 50 years) characteristics and compatibility with the host rock environment.

   d) Incorporation of testing of LTS materials in the STS program. Consideration should be given to using several different potential LTS materials in the STS and observing their effectiveness during the operating phase of the shaft.

e) Plans for remedial sealing.

f) Testing to determine continuity of grouted zones.

4.3.2.2 What provisions are taken in the repository design of the shafts, boreholes, and seals to assure that releases of radioactive materials conform to the requirements of 10 CFR Part 60.112.

wrong

10 CFR Part 60 require that shafts and boreholes should not become preferential pathways for groundwater movement. A knowledge of the pre-existing hydrologic system is necessary to determine shaft construction details, and to assess the changes resulting from shaft construction. The exploratory shaft is to be constructed using the drill-and-blast method, and permeable water-bearing zones could cause water to flow into the shaft, slowing construction. Pre-grouting might be required in certain zones, and this could later affect hydrologic tetsing and rock mass sealing.

A major mechanism of permeability enhancement in the DRZ is stress relief which may open pre-existing fractures. Rock response to the shaft will also be affected by the rock mass strength and the in situ stress state.

Construction specifications must be reviewed to determine that the construction technique does not interfere with site characterization and shaft sealing operations.

A complete LTS design would be premature at present, because much needed information on the site and on sealing materials is not available. A conceptual design of the LTS is, however, essential to guide research on sealing materials and site characterization activities. This design should be based on performance assessment modeling using field and laboratory data.

Sealing of boreholes is less of a concern than shaft sealing. Boreholes are much smaller in size, and the DRZ around boreholes is not substantial owing to the small size of boreholes relative to the fracture spacing. In addition, advanced borehole sealing techniques have been developed by the oil industry (Coons et al., 1982). Nevertheless, boreholes do represent potential preferential groundwater pathways. The total number of boreholes penetrating the repository horizon should be kept to a minimum, and so the purpose of each borehole should be carefully defined.

The information required to assess the borehole sealing program includes:

- the total number of boreholes

- the purpose of each borehole, and the tests to be performed

- the location, depth, and size of each borehole

- casing and sealing plans, and the materials to be used in casing and sealing.

Construction of the shafts results in the creation of a zone of disturbed rock which is more permeable than the surrounding rock. This disturbed rock zone (DRZ) might become a preferential pathway for water-borne radionuclides. Moreover, it could provide a hydraulic connection between the repository and any zones of perched water or between the repository and aquifers below the repository.

It is not known at this time whether the exploratory shaft and associated underground openings will be incorporated into the repository. If these facilities do become incorporated into the repository, then they must be sealed in the same manner as the repository shafts.

It is understood that, during site characterization, long horizontal boreholes will be drilled from the exploratory headings in order to obtain information about the continuity of the candidate formation. These holes may intersect future repository workings and therefore must be sealed.

As a minimum, discussion of long term shaft sealing aspects should include:

1. A conceptual design of the LTS, based on performance assessment modeling.

2. Site characteirzation plans that relate to long term sealing.

3. Information about the sealing materials that will be required for a complete LTS design, and a discussion of the research that is currently being performed to meet those requirements.

As in the case of shafts, exploratory boreholes are a potential pathway for transfer of radionuclides to the environment. Thus, it is necessary that exploratory boreholes be sealed.

The possibility of individuals of future generations penetrating the repository horizon with exploratory boreholes need to be evaluated.

4.4 <u>When and how does water contact the waste package from the engineered barrier?</u>

<u>When, how and at what rate are radionuclides released from the engineered barriers?</u>

Limitation of the radionuclide release rate is a fundamental requirement for a geologic repository. The performance criteria for the engineered barriers are given in Section 60.113 of 10 CFR Part 60. Before a license can be granted, there must be reasonable assurance that these criteria - that is, that releases of radioactive material and radiation dosages fall within the limits specified in 10 CFR Part 60.113 - will be met.

4.4.1 What provisions are taken in the repository design of the of the engineered barriers to assure compliance with the containment and isolation requirements of 10 CFR Part 60.113.

The repository should be designed to preserve the isolation capabilities of the host media. By limiting changes to the natural conditions, the geologic media becomes an integral part of the containment system. The engineered system, including barriers and seals, should be designed to enhance the natural capabilities of the medium and to aide in restoring the disturbed portion of the media to sufficient level of containment and isolation capability. The repository design should take into account the benefits gained from the engineered systems design.

The engineered barriers can be positively influenced by the repository design. Room dimensions and roof and floor conditions should be chosen to facilitate construction of the engineered barriers adjacent the host rock. The configuration of entries and rooms can be designed to promote longer travel time for air and water between engineered barriers. Areas where the repository design contributes to engineered barrier performance should be identified and expanded as possible.

The release rate from the engineered barrier system is the design release rate for the underground facility. There are two potential pathways to the accessible environment for radioactive materials released by the engineered barriers:

- Repository shafts (if they are not adequately sealed).
- Fractures and pore spaces in the rock.

The transport mechanism through the fractures and pore spaces would be primarily in the vapor phase, with some movement by groundwater. Given unsaturated conditions, groundwater movement may be sporadic or nonexistent (if water in the pore spaces is discontinuous). However, it is necessary to have reasonable assurance that the engineered barriers in conjunction with the host rock will limit releases to the accessible environment specified in 10 CFR Part 60.

The waste packages radiate heat, the quantity of which decreases with time. This heat will be conducted away from the waste packages by the rock. As a result the temperature of the rock at the perimeter of the storage rooms will increase to a maximum and then gradually decrease. An increase in temperature from the virgin rock temperature results in thermal stresses and subsequent changes in temperature result in changes in the thermal stress levels. These temperature and stress changes will both affect groundwater flow (liquid and vapor phases).

4.4.2 What provisions are taken in the repository design of the backfill immediately surrounding the waste canister to assure compliance with the containment and isolation requirements of 10 CFR Part 60.113.

The repository design should contribute to the waste package performance by limiting adverse impacts on the waste package and using the beneficial properties of the host rock to enhance waste package performance.

The design of stable emplacement holes will assist in meeting the containment requirements.

The type of waste, overpack and shielding material determine the release rate from the waste package.

The integrity of the waste package is first component in the limiting releases to the accessible environment. To establish the waste package performance, the environment around the package and the components of the package require monitoring to ensure expected performance. The program should compare the expected environments and response to the design environment and response.

4.4.3 What provisions are taken in the repository design to assure that the orientation, goemetry, layout, and depth of the underground facility contribute to the containment and isolation requirements of 10 CFR Part 60.113.

The long-term stability of repository openings is a major factor in meeting the containment and isolation requirements. This includes the repository rooms and the emplacement holes.