TECHNICAL POSITION ON BOREHOLE AND SHAFT SEALING

Purpose: This position paper is intended to supplement the USNRC Regulatory Guide, "Standard Format and Content Guide" for High-Level Waste Repositories, in defining the information needs during site characterization for borehole and shaft sealing.

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1.0 BACKGROUND

DOE is presently planning to dispose of high-level waste in a deep geologic repository. Characterization of the site and access to the underground facility will be accomplished by manmade underground openings such as shafts and boreholes. These manmade openings will be sealed prior to decommissioning of the nuclear waste facility based on the requirements of 10 CFR 60. This technical position on borehole and shaft sealing will give guidance on information needs required to make findings in the license reviews to insure that the requirements and provisions of 10 CFR 60 have been met. It will also specify minimum design measures that the staff considers would constitute a reasonable demonstration that 10 CFR 60 requirements and provisions are met.

2.0 REGULATORY FRAMKEWORK

The unique requirements of a high-level waste repository causes the criteria governing the design of shaft and borehole seals to be more stringent than existing criteria (i.e. state and local requirements) for routine plugging of boreholes. Boreholes in most states are routinely sealed, as required, when they are no longer in use. Sealing technology to meet these state requirements exists in the petroleum industry. However, there are several distinct differences between the current petroleum industry sealing technology and technology required for the sealing of openings in a geologic repository. This is based on the longevity requirement and the isolation and containment requirements for the geologic repository. Although the state criteria (Appendix A) will have to be addressed by the DOE, more stringent criteria for borehole and shaft sealing has been promulgated by the NRC. The technical rule 10 CFR 60 requires the DOE to design the seals to meet the following requirements:

(a) General design requirements: Seals for shafts and boreholes shall be designed so that following permanent closure they do

not become pathways that will compromise the geologic repository's ability to meet the performance objectives.

(b) Selection of materials and Placement methods: Materials and placement methods for seals shall be selected to reduce, to the

extent practicable, (i) the potential for creating a preferential pathway for groundwater; or (ii) radioactive waste migration through existing pathways.

The DOE design is also required to be verified by in-situ testing. The technical rule 10 CFR 60 requires the DOE to perform the following in order to test the design:

(a) During the early or developmental stages of construction, a program for in situ testing of such features as borehole and shaft seals, backfill, and the thermal interaction effects of the waste packages, backfill, rock and groundwater shall be conducted.

(b) The testing shall be initiated as early as is practicable.

(c) Test sections shall be established to test the effectiveness of borehole and shaft seals before full-scale operation proceeds to seal boreholes and shafts.

The design requirements and design testing, along with the individual state requirements, establish the licensing requirements for borehole and shaft seals for a high-level waste repository.

The Standard Format and Content Regulatory Guide for high-level waste repositories recommends that the DOE include in their Site Characterization Reports the following data on sealing shafts, boreholes, and underground openings:

Sealing of Shafts, Boreholes, and Underground Openings

Describe the proposed treatment of the disturbed section of rock around openings and excavated surfaces. Describe proposed design measures to control groundwater movement into the facility. Provide laboratory and field data when available and inferred site conditions on which the selection of the treatment measures was based. Describe the proposed design for the sealing of boreholes and shafts. Provide laboratory and field data and inferred site conditions on which the design was based. Provide the mechanical, chemical, and hydrologic properties of proposed sealing materials.

This data will be the basis from which the DOE will develop the information required to make findings in the license reviews that the requirements and provisions of 10 CFR 60 have been met. By the time the DOE submits the Safety Analysis Report as their License Application, the DOE should have developed, as required by the Procedural Rule, 10 CFR 60,..." a description and analysis of the design and performance requirements for structures, systems, and components of the geologic repository which are important to safety. The analysis and evaluation shall consider...(iii) The effectiveness of engineered and natural barriers, including barriers that may not be themselves a part of the geologic repository operations area against the release of radioactive material to the environment." This would include the effectiveness of the seals by themselves and as part of the overall performance of the repository. From this information, a licensing decision should be possible if the DOE has supplied the necessary information as described in this technical position.

DOE will also adhere to technical criteria concerning the siting and use of manmade openings as follows:

As a minimum, the location of exploratory boreholes and shafts shall be selected so as to limit the total number of subsurface penetrations above and around the underground facility consistent with the information needed for site characterization.

To the extent practical, exploratory boreholes and shafts in the geologic repository operations area shall be located where shafts are planned for underground facility construction and operation or where large unexcavated pillars are planned.

Subsurface exploratory drilling, excavation, and in situ testing before and during construction shall be planned and coordinated with geologic repository operations area design and construction.

3.0 DISCUSSION OF SEALING ISSUES

The following are issues involving the sealing of repository openings that are currently viewed by the NRC as the most critical sealing issues related to repository performance.

These issues are based on what the licensing criteria is for sealing and where the available information or technology is insufficient to have adequate confidence that the licensing criteria has been met.

3.1 Long-Term Stability of Seals

The performance of the seal system over the life span of the repository will continue to be an area of much controversy. Tests and analyses must be performed to show the scientific community and the public that the seal system will perform for very long periods of time under adverse conditions. Methods of obtaining this information could involve the following:

- Analytical models that analyze the system's performance over long time periods. Analyses using the models must include valid field and laboratory data.

- o Analog studies of proposed sealing materials and their longevity in simulated environments, taking into account past experience with such materials.

- o Long-term and/or accelerated laboratory testing of sealing materials in simulated repository environments

- o Long-term in situ field testing of sealing materials

- o Geochemical stability analysis of materials in repository environment

3.2 Design of Shafts with Considerations for Long-Term Sealing

Knowledge of the extent of damage to the host rock from shaft and tunnel excavation suffers from a limited data base. The amount and degree of damage done by excavation could be an influencing factor in the effectiveness of shaft seals. If the host rock becomes extensively fractured, the flow of groundwater and transport of radionuclides would occur through the fractured area and around the emplaced seal. Areas of consideration in this issue are:

- o Selection of excavation techniques that inflict minimal damage (fracturing) to the host rock

- o Quality control of excavation procedures so as to assure minimal damage to the host rock

- o Selection of shaft liners with long-life capabilities

- o Selection and control of grouting of liner to host rock with long-term sealing considerations

- o Protective excavation and reinforcement measures to minimize rock relaxation

- o Installation of grout curtains and cut-off collars

3.3 Installation Procedures for Sealing

The placement techniques used in sealing shafts and boreholes could be a controlling factor in seal performance. Reliability must be obtained in the methods and equipment used for the installation of the seal materials. The repeatability of results using these

methods and equipment must also be proven. Areas of consideration in this issue are:

- o Development of technically feasible procedures for placement of seal materials
- o Adequate quality control to assure proper placement of seals
- o Field testing of installation procedures

3.4 Impact of Thermal Loading on Seals

The thermal loading caused by the emplaced waste on the borehole and shaft seals may damage the seal system. There must be confidence that the seal system will perform adequately under the adverse conditions that result from high temperatures that will occur. Consideration should be given to:

- o Chemical stability of seal materials at elevated temperatures
- o Changes in the stress field of sealed area caused by changes in temperature

3.5 Compatibility of Seals to Host Rock

The compatibility of the physical and chemical characteristics of the seal material and the host rock is an important consideration. The site specific data of the host rock should be used to develop the seal design for each repository. Important parameters to consider are:

- o physical/mechanical characteristics - compressive strength, creep, stress field, hydrologic data (pressures and flow rates), lithology, rock fractures

- o chemical characteristics - mineralogy, phase changes, pH, Eh, groundwater geochemistry, rock-groundwater interaction, seal-groundwater interaction

3.6 Achieving Low Permeabilities in the Sealed Area

The borehole and shaft seals are emplaced to reduce, to the extent practicable, the potential for creating a preferential pathway for groundwater or radioactive waste. This will mean designing and emplacing a seal that produces a low permeability in the seal zone

which at least approaches the permeability of the undisturbed host rock. The zone under consideration would include the disturbed zone, the interface between the host rock and the seal, and the seal itself. Areas of consideration in this issue are:

- o characterizing and sealing the disturbed zone surrounding the opening

- o developing seal materials and a seal system with low permeability and high sorptivity

4.0 INFORMATION NEEDED TO ASSESS THE ISSUES

The requirements set forth in 10 CFR 60 for borehole and shaft sealing were written to assure that the disrupted zones of the repository would be sealed in such a way as to compliment the isolation and containment capabilities of the host rock. The following is a compilation of the information on borehole and shaft sealing the staff deems necessary to make findings in the license reviews. It also specifies mimimum design measures that would constitute reasonable demonstration that the requirements and provisions of 10 CFR 60 have been met. This complilation is a

partial generic listing of information needs presently considerd applicable.

4.1 Rock Characteristics

The following is the host rock data needs necessary to adequately design the sealing system for compatibility with the host rock and long-term stability of the sealing system:

- o Pre-mining stress field and stress concentration factors
- o Extent of fracturing around openings that must be sealed, (both natural, and excavation induced fracturing)
- o Geological data, including lithology, rock fractures, and competence of strata (or a stratum)
- o Rock mechanical properties, including compressive strengths, modulus of elasticity, creep characteristics
- o Hydrological data, to identify zones of high porosity and/or permeability

- Location of zones where flow of gas may be encountered, with estimates of pressure and flow rate

4.2 Seal Material Characteristics

The materials used for borehole and shaft sealing should have characteristics that will enhance compatibility with the host rock as well as contribute to the isolation and containment of radionuclides. Considerations for seal material selection should include:

- Chemical properties
  - longevity
  - sorptivity
  - alteration and/or stability of material in host rock environment
- Hydraulic properties
  - permeability of seal

- permeability of seal-host rock interface

o Mechanical properties

- elasticity of the seal and seal zone
- tensile and compressive strengths of the seal
- tensile and shear strengths of the bond

o Thermal properties

- differential thermal expansion
- differential thermal conductivity
- differential thermal diffusivity

4.3 Sealing of Rock Fractures

The amount of effort that has to be spent in sealing the fractures surrounding the openings will be dependent on the original state of the host rock and the amount of damage incurred by the host rock during excavation and consequent stress relaxation. The affected zone will be characterized and assessed to determine the amount of rehabilitation necessary to make the fractured zone perform in an acceptable fashion. Information necessary to make findings are:

- o Methods used to determine damaged zone in host rock
- o Characteristics of host rock
- o Type and suitability of sealing material to be used, and expected in-situ properties (strength, shrinkage, set-up time, etc.)
- o Methods of placement of sealing material, expected operating pressures and depths of penetration

4.4 Design, Excavation, and Construction of Shafts

It is important in the designing of the repository shafts to consider long-term sealing capabilities. Proper control of the design, excavation, and construction of the shafts must be maintained in order to assure its licensability. The design, excavation, and construction of the shaft will, of course, be site specific (i.e. use and extent of shaft linings, grouting techniques). However, the information needed to adequately assess the shafts' impact on repository performance is basically generic. The following should be addressed:

- o provisions for minimizing extent of fracturing due to excavation and stress relaxation
- o provisions to seal strata at specific locations to control inflow of water and gas, and stabilize zones of weak rock
- o provisions to account for the effects of stress orientations
- o provisions for the use of liners, including liner design, installation procedures, and long-term stability
- o method and emplacement techniques for sealing between the liner and the host rock
- o provisions in shaft design to cope with ground movements, including bending, compression, buckling, and shear
- o provisions made for later installation of shaft seals

4.5 Borehole and Shaft Seals

The design and installation methods for borehole and shaft seals must be developed using reproducible data and approved test methods. The seals should attain the following as minimum design measures:

- o achieve seal area permeabilities approaching that of the host rock, or as low as can be reasonably achieved and still not compromise the repository performance

- o achieve chemical and physical compatibility and stability with the host rock, or, if alterations occur to the original seal characteristics, these alterations will not compromise the seal system

- o achieve, with reasonable assurance, 10,000 year life expectancy of the seal system

- o achieve a retardation of radionuclides which at least approaches that of the host rock

The information on placement of borehole and shaft seals required to make findings in the license reviews is as follows:

- o location and description of all abandoned openings

- procedures for cleaning and preparing openings for sealing

- complete records of drilling operation, including identification of areas with poor core recovery, fractured areas

- geological data, including lithology, strata competency, rock physical properties, hydrological characteristics, location of gas flows, chemical and thermal environment for sealing

- seal design and construction procedures, including methods of emplacement of seals

- maximum water pressure and pressure gradient across the seal for which the seal should be designed

- quality assurance for the sealing program

- procedures for determining adequacy of the rock formation seal at the proposed seal locations

- procedures for testing whether the seal will perform effectively

- procedures for field testing the proposed seal, with appropriate performance monitoring

- procedures for determining the in-situ quality of the seal, including its strength and permeability

- procedures for installation of a monitoring system to evaluate seal performance

5.0 IN-SITU TESTING AND VERIFICATION PROGRAM

The in-situ testing and verification program will be conducted by the DOE to confirm the adequacy of the design in meeting the minimum design measures set forth in this position paper. The verification program will consist of design analyses, and testing of the procedures used for placement of the seals. This program should consist of laboratory tests, field tests, and in-situ tests. It is understood that during this testing period, it is possible that the field tests may give results that are below the minimum design

measures and that the design assumptions may have to be verified. This may be due to the lack of established procedures in this area and the use of state-of-the-art techniques. However, prior to license application, the DOE should have the capability of verifying, through in-situ tests, that the mimimum design measures set forth in this position paper will be met.

6.0 SUMMARY

The DOE is required by 10 CFR 60 to seal boreholes and shafts at decommissioning of a nuclear waste repository. This technical position on borehole and shaft sealing establishes; 1) borehole and shaft seal issues, 2) what information is needed to resolve these issues, 3) what information should be submitted in the license application, 4) mimimum design measures, and 5) in-situ testing and verification needs for licensing. The guidance given by this document establishes what information will be required to make findings in the license review that the sealing requirements and provisions of 10 CFR 60 have been met.