SITE TECHNICAL POSITION

Waste Form and Package Issues
For
The Nevada Nuclear Waste Storage Investigations

Tuff STP-2.0

DRAFT

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Division of Waste Management
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United States Nuclear Regulatory Commission
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Engineering Branch

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Background

In the review of an application for Construction Authorization for a high-level waste geologic repository, the NRC staff is required to determine whether 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 package performance, 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 (NWPA) has established a schedule for site characterization and selection. Specifically, NWPA 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 waste form and package performance at tuff sites. Future Site Technical Positions relevent to waste form and package will address both NRC staff concerns regarding selected specific issues and acceptable technical approaches for addressing those specific issues.

Terminology

Many of the issues identified by NRC are related to various elements of a geologic repository system. These elements and other terms important to repository performance are defined below. Other terms are defined in Explanation of Frequently Used Terms and Chapter 9 of NUREG-0960, "Draft Site Characterization Analysis of the Site Characterization Report for the Basalt Waste Isolation Project," March 1983.

Accessible environment is (1) the atmosphere, (2) land surface, (3) surface water, (4) oceans, and (5) the portion of the lithosphere that is outside the controlled area.

Backfill is material that might be emplaced in the underground openings of the underground facility other than the emplacement holes, shafts, and boreholes.

Controlled area is a surface location, to be marked by suitable monuments extending horizontally no more than 10 kilometers in any direction from the underground facility, and the underlying subsurface, which area has been committed to use as a geologic repository and from which incompatible activities would be restricted following permanent closure.

Disturbed zone is that portion of the controlled area whose physical or chemical properties have changed as a result of underground facility construction or from heat generated by the emplaced radioactive wastes such that the resultant change of properties may have a significant effect on the performance of the geologic repository.

Emplacement hole is an opening in the rock directly surrounding the waste package.

Engineered barrier system is the waste package and the underground facility.

Far field is the portion of the geologic setting that lies between the outer edge of the disturbed zone and the accessible environment.

Geologic setting includes the geologic, hydrologic, and geochemical systems of the region in which a geologic repository operations area is or may be located.

Near field is that portion of the repository system where waste-caused processes can have a significant impact on waste isolation.

Packing is that part of the waste package that is emplaced between the outer container and the rock wall of the emplacement hole.

Underground facility is the underground structure, including openings, and backfill materials, but excluding shafts, boreholes, and their seals.

Waste form is the radioactive waste materials and any encapsulating or stabilizing matrix.

Waste package is the waste form and any containers, shielding, packing, and other components surrounding the waste form.

Technical Issues

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 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 60 (including environmental objectives of 10 CFR 51). Development of performance issues for a geologic repository is explained in detail in

Appendix C of NUREG-0960. Performance issues for a geologic repository, as developed in NUREG-0960 and adapted for a tuff site are as follows:

1. How do the design criteria and conceptual design address releases of radioactive materials to unrestricted areas within the limits specified in 10 CFR 20?

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

3. When, how and at what rate will water contact the backfill?

4. When, how and at what rate will water contact the waste package?

5. When, how and at what rate will water contact the waste form?

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

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

8. When, how and at what rate will radionuclides be released from the backfill?

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

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

11. What will be 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 the waste package constitute the principal engineered barrier to the release of radionuclides to the host rock, information on waste package development for salt sites will be an integral part of the total repository system information needs of the NRC staff. Specific issues identified in the following section delineate information concerning the waste form and package at salt sites needed by the NRC staff to assess adequately the performance issues. The sequential order in which specific issues are identified should not be interpreted as the order of relative importance.

Technical Position

It is the position of the NRC staff that, based on our current level of knowledge of the Nevada Nuclear Waste Storage Investigations, and the potential waste forms and packages that may be used at that location, assessment of the Technical Criteria in 10 CFR Part 60 requires that, at a minimum, the following specific issues concerning waste package performance be addressed.

2.0 <u>Waste Package</u>

2.1 When, how and at what rate does water contact the waste form?

2.1.1 When, how and at what rate does water penetrate the packing?

2.1.1.1 What are the possible mechanisms by which water will penetrate packing materials around containers? What are the predicted flow rates?

2.1.1.2 What is the predicted temperature, pressure, flow rate and chemical composition, including Eh and pH, of the water reaching the container as a function of time?

2.1.1.3 To what extent, as a function of time, will groundwater flow, temperature, radiation, or other effects change the ability of packing materials to control the flow and chemical composition of groundwater passing through those materials?

2.1.1.4 How does oxygen activity change with time in the vicinity of the container and in the packaging? Further, how does this change depend on groundwater flow and chemistry, temperature, pressure, radiolysis, and the packing materials themselves?

2.1.2 When, how and at what rate does water penetrate the container?

2.1.2.1 What are the anticipated physical dimensions of container breach as a function of time?

2.1.2.2 What are the mechanical loads on containers vs. time? How do the packing materials affect the loading?

2.1.2.3 What are the possible mechanical failure modes for the container?

2.1.2.4 How do the chemical and physical properties of container materials change as a result of groundwater flow, and temperature, radiation, and other effects, and what are the resultant properties?

2.1.2.5 What are the possible corrosion failure modes for the container, and what are the effects of radiation on these failure modes?

2.1.2.6 What is the effect of packing materials on the corrosion mechanisms for the container?

2.1.2.7 What is the radiolytic generation of hydrogen, oxygen, and other species due to gamma radiation in the vicinity of the container?

2.1.2.8 Do microbes affect corrosion, and if so, how?

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

2.2.1 What properties of the waste form change with time and alter the ability of the waste form to contribute to the overall performance of the repository system or impact the performance of other barrier materials and properties of the site?

2.2.2 What will be the temperature, pressure, flow rate,and chemical composition, including Eh and pH, of the water reaching the waste form as a function of time?

2.2.3 What is the solubility of the waste form under anticipated repository conditions? What are the possible dissolution mechanisms of the waste form under these conditions? Which dissolution mechanism or mechanisms is most likely, and what is the anticipated dissolution rate? What significant non-radioactive dissolution products are likely to be produced?

2.2.4 What are the solubilities of the significant radionuclides under anticipated repository conditions? What are the possible leaching mechanisms of these radionuclides under these conditions? Which leaching mechanism or mechanisms is most likely, and what is the anticipated dissolution rate of the radionuclides? What chemical species are likely to be produced?

2.2.5 What is the production of particles and colloids (by or near the waste form) which can hold or transport radionuclides or affect waste form degradation?

2.2.6 What are the ranges of residence times of a unit volume of water in contact with a unit area waste form as a function of time? For spent fuel how does cladding change the effective residence time?

2.2.7 For spent fuel, what are the failure mechanisms for cladding and what are their failure rates?

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

2.3.1 How do radionuclides migrate through failed containers and how does this change with time?

2.3.2 What are the convective flows in the waste package vs. time?

2.3.3 What are the transport and retardation processes important to the time-dependent flux of radionuclides in packing materials?

2.3.4 How do the radionuclide species change with time in the waste package? (This includes particles, colloids and solubles.)

2.3.5 What is the solubility of these species as a function of time in the vicinity of the packing materials?

2.3.6 Does alpha radiation in the waste packing materials affect chemistry and hence transport and species identification?

2.3.7 Do microbes affect transport in packing materials? If so, how?

2.4 What are the conditions which affect criticality?

2.4.1 Can actinides be concentrated to increase heating in the packing materials or create a potential for criticality?

Discussion

The rationale for each issue is contained in the following discussion. The issues are intended to provide guidance to DOE with respect to what the NRC staff considers important to determining compliance with the provisions of 10 CFR Part 60.113 that address waste package performance and those parts of 60.135 which merit further elaboration.

2.0 Waste Package

2.1 When, how and at what rate does water contact the waste form?

The performance objective of 10 CFR Part 60 addressing containment (60.113(a)(1)(ii)(A)) requires that containment of HLW within the waste packages be substantially complete for a period of not less than 300 to 1,000 years (period to be determined by the Commission) after permanent closure of the repository. The performance objectives addressing the design criteria for the waste package from 10 CFR Part 60 (60.135 (a) (1)) requires that packages for HLW shall be designed so that the in-situ chemical physical and nuclear properties of the waste package and its interactions with the emplacement environment do not comprise the function of the waste packages or the performance of the underground facility or the geologic setting. The criteria continues (60.135 (a) (2)) by stating that the design shall include but not be limited to consideration of the following factors: solubility, oxidation/reduction reactions, corrosion, hydriding, gas generation, radiolysis, radiation damage, radionuclide retardation, leaching, fire and explosion hazards, thermal loads and synergistic interactions. Under reasonably foreseeable conditions, release of HLW will be through dissolution of or leaching from the waste form by groundwater. Therefore an understanding of the time, rate, and nature of water contacting the waste form is essential to being able to demonstrate compliance with these performance objectives.

2.1.1 When, how and at what rate does water penetrate the packing?

Before water contacts the waste form it must penetrate the packing and then any containers separating the packing from the waste form. The packing will affect the time and rate at which water reaches the container, and may be designed to delay or reduce such contact. Further, the packing is likely to alter the water's chemical composition and thereby affect the processes by which water will degrade the container. Whether or not DOE wishes to take advantage of these processes to enhance waste package performance, it will be necessary for the NRC to determine whether they have any <u>adverse</u> effects on its performance.

2.1.1.1 What are the possible mechanisms by which water will penetrate packing materials around containers? What are the flow rates resulting from these mechanisms?

In order to assess the effects of packing on the rate and chemical composition of water reaching the containers, it will be necessary to determine how the water penetrates the packing. Possible mechanisms might include porous flow through a packing unchanged by time, very slow flow inhibited by swelling of the packing due to saturation, or flow through cracks in the packing resulting from thermal degradation of the packing materials.

2.1.1.2 What will be the temperature, pressure, flow rate and chemical composition, including Eh and pH, of the water reaching the container as a function of time?

This information is necessary to define the time-dependent environment of the containers to be able to model the chemical, and part of the physical processes involved in container degradation.

2.1.1.3 To what extent, as a function of time, will groundwater flow, temperature, radiation, or other effects change the ability of packing materials to control the flow and chemical composition of groundwater passing through those materials?

This issue recognizes that the packing materials may not be presumed to be stable in the environment which they will be placed over the interval of interest for assessing repository performance. Some demonstration, perhaps through the use of bounding analyses, will be needed to demonstrate that the packing does not change in ways that unacceptably degrade the performance of the waste package as a whole.

2.1.1.4 How does oxygen activity change with time in the vicinity of the container and in the packaging? Further, how does this change depend on groundwater flow and chemistry, temperature, pressure, radiolysis, and the packing materials themselves?

These questions are also covered under the more general statements in items 2.1.1.2 and 2.1.1.3 above. They are raised here to highlight the NRC staff's concern that the rate, speciation, and behavior of the HLW radionuclides released from the waste form are expected to be strongly dependent on the oxygen activity present. The staff further considers that assessment of oxygen activity and the reliability of that assessment are major technical questions which must be addressed early.

2.1.2 When, how and at what rate does water penetrate the container?

As discussed under 2.1 and 2.1.1 above, one of the performance objectives in 10 CFR Part 60 addresses the interval during which the containment of HLW is substantially complete (60.113 (a)(1)(ii)(A)). A second performance objective (60.113(a)(1)(ii)(B)) addresses the rate at which radionuclides will be released from the engineered barrier system. This release rate will depend, in part, on the rate and nature of the radionuclides released from the waste form, which in turn will depend on the way in which water penetrates the container. Finally, the NRC staff recognizes that although the boundary which has been established for HLW containment lies at the outer edge of the packing associated with the waste package, the interval during which the container remains intact will be of major significance in assessing the interval over which containment of HLW will be substantially complete.

2.1.2.1 What are the anticipated physical dimensions of container breach as a function of time?

This question addresses, in part, the extent to which groundwater contacting the waste form will be static or free-flowing. If groundwater surrounding the waste form is largely static, the concentration of leaching and dissolution products will build up and solubility and perhaps auto-catalytic effects may become important.

2.1.2.2 What are the mechanical loads on containers vs. time? How do the packing materials affect the loading?

Container breach may occur through a variety of mechanisms, including crushing due to lithostatic stresses, perhaps altered by hydrostatic effects, or by stress corrosion. To assess the importance of these failure modes, an understanding of the mechanical stresses on the container will be necessary.

2.1.2.3 What are the possible mechanical failure modes for the container?

This issue is discussed under 2.1.2.2 above.

2.1.2.4 How do the chemical and physical properties of container materials change as a result of groundwater flow, temperature, radiation, and other effects, and what are the resultant properties?

This issue recognizes that container properties may not be presumed to be constant in the environment in which it will be placed over the interval of interest for assessing repository performance. Some demonstration, perhaps through the use of bounding analyses, will be needed to demonstrate that the container does not change in ways that unacceptably degrade the performance of the waste package as a whole. In particular, the effects of radiation on the strength and corrosion resistance of the container will be subject to scrutiny.

2.1.2.5 What are the possible corrosion failure modes for the container, and what are the effects of radiation on these failure modes?

In order to determine the time and nature of likely container breach, it will be necessary to demonstrate that the failure mode associated with that breach will be the most rapid of those failure modes which may be postulated to occur. It is therefore necessary to identify the full set of failure modes, including corrosion failure modes, and to determine which are the most significant, particularly in the radiation environment to which they will be exposed.

2.1.2.6 What is the effect of packing materials on the corrosion mechanisms for the container?

This issue is intended to identify the information concerning packing material performance needed to assess container corrosion, and to re-examine the responses to issues 2.1.1.2 through 2.2.1.4 from that perspective to ensure completeness.

2.1.2.7 What is the radiolytic generation of hydrogen, oxygen, and other species due to gamma radiation in the vicinity of the container?

This issue explicitly addresses radiation-induced phenomena so that the immediate effects of these phenomena may be assessed independently of their secondary effects on conditions or processes such as container strength or corrosion rates.

2.1.2.8 Do microbes affect corrosion, and if so, how?

It has been suggested that bacterial effects can result in enhanced corrosion of the container. The extent to which bacteria can survive in the underground facility during the interval of interest and the effects which such bacteria may have on container degradation must be assessed.

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

As discussed above, two of the performance objectives in 10 CFR Part 60 (60.113(a)(1)(ii)(B) and 60.135(a)(2)) address the rate at which radionuclides will be released from the engineered barrier system and some of the factor to be included in characterizing the release of radionuclides, respectively. This release rate will depend in part, perhaps most significantly, on the rate at which radionuclides will be released from the waste form. Further, the mechanism and extent of radionuclide retardation in both the packing material and in the geologic setting will depend on the amount and species of the radionuclides released.

2.2.1 What properties of the waste form change with time and alter the ability of the waste form to contribute to the overall performance of the repository system or impact the performance of other barrier materials and properties of the site?

This issue addresses concerns such as devitrification of glass waste forms, or degradation of any waste forms due to radioactive decay prior to and during contact with groundwater. Effects of radioactive decay include degradation due both to radiation effects and to transmutation of radionuclides into elements which tend to destabilize the waste form.

2.2.2 What will be the temperature, pressure, flow rate,and chemical composition, including Eh and pH, of the water reaching the waste form as a function of time?

This information is necessary to define the time-dependent environment of the waste form to be able to model the chemical, and part of the physical processes involved in waste form degradation and dissolution, and in radionuclide leaching.

2.2.3 What is the solubility of the waste form under anticipated repository conditions? What are the possible dissolution mechanisms of the waste form under these conditions? Which dissolution mechanism or mechanisms is most likely, and what is the anticipated dissolution rate? What significant non-radioactive dissolution products are likely to be produced?

The above information will be necessary to assess whether radionuclide releases from the waste form will be controlled by the dissolution of the waste form itself, and if so, what the resulting radionuclide release rates will be. It will also be necessary to determine the amount and nature of non-radioactive dissolution products to determine their effects on the ability of the packing materials and the geology to inhibit radionuclide migration.

2.2.4 What are the solubilities of the significant radionuclides under anticipated repository conditions? What are the possible leaching mechanisms of these radionuclides under these conditions? Which leaching mechanism or mechanisms is most likely, and what is the anticipated dissolution rate of the radionuclides? What chemical species are likely to be produced?

The rationale for needing this information is comparable to the discussion in 2.2.3 above.

2.2.5 What is the production of particles and colloids (by or near the waste form) which can hold or transport radionuclides or affect waste form degradation?

In order to predict radionuclide migration, it is necessary to recognize that radionuclide-bearing particulates or colloids may be formed whose size or nature causes them to behave in ways not predicted by conventional radionuclide retardation mechnanisms. It is therefore necessary to determine whether such species are likely to be formed, and if so, to assess what their behavior is likely to be.

2.2.6 What are the ranges of residence times of a unit volume of water in contact with a unit area waste form as a function of time? For spent fuel how does cladding change the effective residence time?

As discussed in the rationale for issue 2.1.2.1, this question addresses, in part, the extent to which groundwater contacting the waste form will be static or free-flowing. If groundwater surrounding the waste form is largely static, the concentration of leaching and dissolution products will build up and solubility and perhaps auto-catalytic effects may become important.

2.2.7 For spent fuel, what are the failure mechanisms for cladding, what are their failure rates, and what are the significant effects of the failure products?

This issue deals with the extent to which spent fuel cladding may enhance or degrade the performance of the waste package. Whether or not DOE wishes to take advantage of the cladding to enhance waste package performance, it will be necessary for the NRC to determine whether the cladding has any adverse effects on waste package performance.

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

As discussed above, two of the performance objectives in 10 CFR Part 60 (60.113(a)(1)(ii)(B) and 60.135(a)(2)) address the rate at which radionuclides will be released from the engineered barrier system and some of the factor to be included in characterizing the release of radionuclides, respectively. This release rate will depend strongly on the rate at which radionuclides will be released from the waste package. Further, the packing surrounding the container may be capable of considerable influence on the nature and rate of release of certain radionuclides, in particular, trapping or delaying radionuclides whose retardation by the adjacent geology may be uncertain. Finally, the mechanism and extent of radionuclide retardation in the geologic setting will depend in part on the amount and species of the radionuclides released.

2.3.1 How do radionuclides migrate through failed containers and how does this change with time?

This issue recognizes that radionuclide release from containers may vary anywhere between general release from a uniformly failed container to a highly concentrated release from a small breach in what is effectively a point source. The extent to which packing can be expected to mitigate releases will depend in part on whether those releases will occur in patterns, rates, or concentrations which will potentially overload it.

2.3.2 What are the convective flows in the waste package vs. time?

The concerns underlying this issue have been expressed in 2.1.1.1, 2.1.2.1, and 2.2.6 above.

2.3.3 What are the transport and retardation processes important to the time-dependent flux of radionuclides in packing materials?

As mentioned in 2.3 above, the packing surrounding the container may be capable of considerable influence on the nature and rate of release of certain radionuclides, in particular, trapping or delaying radionuclides whose retardation by the adjacent geology may be uncertain. These effects are likely to be a function of both the equilibrium conditions which would result in the adsorption or precipitation of the radionuclides and the kinetics of those processes. These phenomena, coupled with the groundwater flowrates through the packing, constitute the transport and retardation processes.

2.3.4 How do the radionuclide species change with time in the waste package? (This includes particles, colloids and solubles.)

This issue recognizes that substantial changes in such parameters as temperature, oxygen activity, and radiation field are likely to occur during the 10,000 year interval of interest, and that these changes are likely to affect the radionuclide species released from the waste packages.

2.3.5 What is the solubility of these species as a function of time in the vicinity of the packing materials?

The rationale for this issue appears under Issue 2.3.4 above.

2.3.6 Does alpha radiation in the waste packing materials affect chemistry and hence transport and species identification?

The NRC staff considers that radionuclide bearing species may not necessarily behave as though they were stable isotopes. If DOE wishes to make such an assumption, it will be necessary to demonstrate its validity, perhps through bounding analyses.

2.3.7 Do microbes affect transport in packing materials? If so, how?

It has been suggested that bacterial effects can result in enhanced radionuclide transport. The extent to which bacteria can survive in the packing during the interval of interest and the effects which such bacteria may have on radionuclide speciation or on transport in the packing must be assessed.

2.4 What are the conditions which affect criticality?

In 10 CFR Part 60, 60.131(b)(7) requires all systems be designed so that criticality will be impossible unless two unlikely, independent, and concurrent or sequential changes have occurred.

2.4.1 Can actinides be concentrated to increase heating in the packing materials or create a potential for criticality?

To reach the finding required by 60.131(b)(7) mentioned in 2.4 above, the staff will require an analysis showing that no transport or other processes can be reasonably expected to result in reconcentration of actinides in the packing materials in such a way as to significantly increase heating or affect criticality.

A sound design philosophy, for an opening requiring long-term stability in rock, follows a pattern in which greater accuracy and detail are obtained as additional information becomes available. The design is complete when it fully addresses all geological conditions that may impact the stability of the opening under the conditions and nature of its use.

Current methodology for a comprehensive design approach with preliminary or generalized geologic data incorporates empirical rock classification systems. A comprehensive design approach based on more detailed geologic data may incorporate analytical or numerical modeling techniques.

The excavation-induced stresses can be obtained using analytical approaches and a 2-D numerical modeling method. Thermally-induced stresses can be computed using thermomechanical analyses. Stresses around the openings can be compared to the rock mass strength estimates to determine the stability of the openings.

The conceptual design obtained by the above mentioned techniques should have sufficent flexibility to accommodate the improvements that can be incorporated by using in situ data from the exploratory shaft testing. The estimates that were used for the design input parameters can be verified and/or refined as in situ data on rock mass strength, modulus of deformation, rock mass thermal properties, in situ stresses, and groundwater is obtained from the underground testing program. The spatial variability of the in situ data in the repository horizon can be estimated, and sensitivity analyses carried out using a range of expected design input parameters. These analyses will determine the effect of geologic variability on repository design.