

SITE TECHNICAL POSITION
Waste Package Issues
For
The Basalt Waste Isolation Project

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United States Nuclear Regulatory Commission
Waste Management Division
Engineering Branch

Site Technical Position - Waste Package
Issues For Nuclear Waste Storage in Basalt

1. 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 (NWPAA) has established a schedule for site characterization and selection. Specifically, NWPAA 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 basalt sites. Future Site Technical Positions relevant to ^{the} waste package will address both NRC staff concerns regarding selected specific issues and acceptable technical approaches and verification required for addressing those specific issues.

2. 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.

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.

3. 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, waste package, 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 Appendix C of NUREG-0960 are:

1. How do the design criteria and conceptual design address releases of radioactive materials to unrestricted areas within the limits specified in 10 CFR 60?
2. How do the design criteria and conceptual design accommodate the retrievability option?
3. When and how does water contact the backfill?
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 backfill and from the engineered barrier system?
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 the waste form and package constitute the principal engineered barrier to the release of radionuclides to the host rock, information on waste package development for basalt sites will be an integral part of the total repository system information needs of the NRC staff.

Specific Issues generally are questions about conditions and processes (information needed) 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 60.

Specific issues identified in the following section delineate information concerning the waste form and package at basalt sites 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.

4. TECHNICAL POSITION

It is the position of the NRC staff that, based on our current level of knowledge of the Basalt Waste Isolation Project, 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, as a minimum, the following issues concerning waste package performance be addressed.

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

When and how does water contact the waste form?

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

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

D. What are the conditions which affect criticality?

To address these issues, a series of specific issues has been developed in Appendix C of NUREG-0960, as follows:

1. What are the possible mechanisms by which water will penetrate packing materials around containers?

2. To what extent over time will groundwater flow, temperature, or other effects change the ability of packing materials to control flow through those materials? What chemical and physical changes are possible? What are the chemical and physical properties?
3. What are the hydrothermal conditions with time at the surfaces of the waste form and containers and within packing materials which influence property changes and radionuclide release?
4. What are the possible mechanical failure modes for the container?
5. What are the chemical and physical property changes in container materials and what are the resultant properties?
6. What are the mechanical loads on containers vs. time? How do the packing materials affect the loading?
7. What are the possible corrosion failure modes for the containers?
8. What is the effect of packing materials on the corrosion mechanisms for the container?
9. How do Eh, pH, and PO_2 change with time in the vicinity of the container in the packaging?
10. What is the radiolytic generation of hydrogen, oxygen, and other species due to gamma radiation in the vicinity of the container?

11. What is the dependence of the oxygen removal rate from packing materials upon temperature, pressure, radiolysis, packing materials, physical characteristics, groundwater flow rates, and composition and time?
12. How do microbes effect conditions affecting corrosion modes? What effect do microbes have on the conditions affecting transport?
13. What is the solubility of radionuclides vs. time in the vicinity of the waste form and packing materials? How are radionuclides released from the waste form?
14. 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?
15. What is the effect of water residence time on release of radionuclides from the waste form?
16. What are the ranges of residence times of a unit volume of water in contact with a unit area waste form and when do the residence times occur? For spent fuel how do hulls change the effective residence time?
17. How do the packing (spent fuel hulls if applicable), canister, and container materials and/or their alteration products interact with the waste form to cause its alteration and/or effect release radionuclides?
18. How does the Eh, pH, and PO_2 change with time in the vicinity of the surface of the waste form? (relates to 9)

19. What is the production of particles and colloids (by or near the waste form) which can hold or transport radionuclides or effect waste form degradation?
20. For spent fuel what are the failure mechanisms for hulls and what is their failure rate?
21. What are the transport and retardation processes and how do they effect the flux of radionuclides with time in packing materials?
22. How do the species which incorporate radionuclides change with time in the waste package? (This includes particles, colloids and solubles.)
23. Can actinides be concentrated to increase heating in the packing materials or create a potential for criticality?
24. How do radionuclides migrate through failed containers and how does this change with time? (relates to 5)
25. What are the convective flows in the waste package vs. time? (relates to 1)
26. Does alpha radiation in the waste package materials affect chemistry and hence transport and species identification?
27. What are the conditions which affect criticality?

5. DISCUSSION

The rationale for each performance issue along with the related specific issues is contained in the following discussion. Many of the issues specifically call for knowledge of various parameters as functions of time (e.g., issues 2, 3, 6, 9, 11, 13, 14, 18, 21, 22, 24, and 25). This does not preclude the use of bounding or sensitivity analyses as a basis for licensing. In fact, as more data and better understanding are acquired on the processes and parameters related to the issues, DOE may justify that detailed knowledge of some of these parameters as functions of time are not necessary and that complete resolution of some of these issues are not required if the waste package and the environment contain features which can be used to address these issues and contribute to a satisfactory containment of the radionuclides and/or prolong the waste package life. 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.

5.1 When and how does water contact the waste package (and 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. 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 this performance objective.

The design criteria for the waste package and its components (60.135(a)(1)) further require that the packages 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 compromise the function of the waste packages or performance of the underground facility or the geologic setting. Consideration of waste package design shall include (60.135(a)(2)) factors of solubility, oxidation/reduction reactions, corrosion, hydriding, gas generation, thermal effects, mechanical strength, mechanical stress, radiolysis, radiation damage, radionuclide retardation, leaching, fire and explosion hazards, thermal loads and synergistic interactions.

These design criteria apply to all waste package components including those which the licensees do not claim credits for satisfaction of performance requirements. Therefore in addressing specific issues for each waste package components: packing, container and waste form factors stated in 60.135(a)(1) and 60.135(a)(2) must be considered.

5.1.1 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 adverse effects on its performance.

5.1.1.1. What are the possible mechanisms by which water will penetrate packing materials around containers? (Specific Issue 1) 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.

- 5.1.1.2 How do Eh, pH, and PO_2 change with time in the vicinity of the container and in the packaging? (Specific Issue 9)

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

- 5.1.1.3 To what extent over time will groundwater flow, temperature, or other effects change the ability of packing materials to control flow through those materials? What chemical and physical changes are possible? What are the chemical and physical properties? (Specific Issue 2)

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.

- 5.1.1.4 What is the dependence of the oxygen removal rate from packing materials upon temperature, pressure, radiolysis, packing materials, physical characteristics, groundwater flow rates, and composition and time? (Specific Issue 11)

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.

5.1.2 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.

Evaluation of release rate will consider factors stated in 60.135 as discussed in 2.1.

5.1.2.1 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.

5.1.2.2 What are the mechanical loads on containers vs. time? How do the packing materials affect the loading? (Specific Issue 6)

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.

5.1.2.3 What are the possible mechanical failure modes for the container? (Specific Issue 4)

This issue is discussed under ⁵2.1.2.2 above.

5.1.2.4 What are the chemical and physical property changes in container materials and what are the resultant properties? (Specific Issue 5)

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.

5.1.2.5 What are the possible corrosion failure modes for the container? (Specific Issue 7)

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.

5.1.2.6 What is the effect of packing materials on the corrosion mechanisms for the container? (Specific Issue 8)

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

5.1.2.7 What is the radiolytic generation of hydrogen, oxygen, and other species due to gamma radiation in the vicinity of the container? (Specific Issue 10)

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.

5.1.2.8 How do microbes effect conditions affecting corrosion modes? (Specific Issue 12, the effect of microbes on transport is addressed in 2.3.7)

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.

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

As discussed above, one of the performance objectives in 10 CFR Part 60 (60.113(a)(1)(ii)(B) and 60.135(a)(2)) addresses the rate at which radionuclides will be released from the engineered barrier system and some of the factors 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.

The design criteria for the waste package and its components (60.135.a.2) further require that the factors considered in the design shall include but not be limited to solubility, oxidation/reduction reactions, corrosion, hydriding, gas generation, thermal effects, mechanical strength, mechanical stress, radiolysis, radiation damage, radionuclide retardation, leaching, fire and explosion hazards, thermal loads and synergistic interactions. These factors should thus be all considered.

5.2.1 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? (Specific Issue 14)

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.

5.2.2 How does the Eh, pH, and PO_2 change with time in the vicinity of the surface of the waste form? (Specific Issue 18)

This information is necessary to define the time-dependent redox 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.

5.2.3 What is the solubility of radionuclides vs. time in the vicinity of the waste form and packing materials? How are radionuclides released from the waste form? (Specific Issue 13) 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.

5.2.4 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.

5.2.5 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? (Specific Issue 19)

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 mechanisms. 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.

5.2.6 What are the ranges of residence times of a unit volume of water in contact with a unit area waste form and when do the residence times occur? For spent fuel how does cladding change the effective residence time? (Specific Issue 16)

As discussed in the rationale for issue ⁵2.1.2.1, 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.

5.2.7 For spent fuel, what are the failure mechanisms for hulls and what is their failure rate? (Specific Issue 20)

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.

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

As discussed above, one of the performance objectives in 10 CFR Part 60 (60.113(a)(1)(ii)(B) and 60.135(a)(2)) addresses the rate at which radionuclides will be released from the engineered barrier system and some of the factors 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.

Evaluation of radionuclides release rate from the waste package will consider factors stated in 60.135.a.2 as discussed in 2.1.

5.3.1 How do radionuclides migrate through failed containers and how does this change with time? (Specific Issue 24)

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.

5.3.2 What are the convective flows in the waste package vs. time?
(Specific Issue 25)

The concerns underlying this issue have been expressed in 5.1.1.1, 5.1.2.1, and 5.2.6 above.

5.3.3 What are the transport and retardation processes and how do they affect the flux of radionuclides with time in packing materials?
(Specific Issue 21)

As mentioned in 5.3 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.

5.3.4 How do the radionuclide species change with time in the waste package? (This includes particles, colloids and solubles.
Specific Issue 22)

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.

5.3.5 What is the solubility of radionuclides vs. time in the vicinity of the waste form and packing materials? How are radionuclides released from the waste form? (Specific Issue 13)

The rationale for this issue appears under Issues ⁵2.3.4 and ⁵2.2.3 above.

5.3.6 Does alpha radiation in the waste packing materials affect chemistry and hence transport and species identification? (Specific Issue 26)

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, perhaps through bounding analyses.

5.3.7 Do microbes affect transport in packing materials? If so, how? (Specific Issue 12. The effects of microbes are addressed in 5.1.2.8).

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.

5.4 What are the conditions which affect criticality?

This general issue is also listed as Specific Issue 27. 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.

5.4.1 Can actinides be concentrated to increase heating in the packing materials or create a potential for criticality?
(Specific Issue 23)

To reach the finding required by 60.131(b)(7) mentioned in ⁵2.4 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.