SITE TECHNICAL POSITION

Waste Package Issues

Nuclear Waste Storage Investigations in Basalt

Basalt STP-2.0

DRAFT

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Division of Waste Management
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Site Technical Position - Waste Package Issues for
Nuclear Waste Storage Investigations in Basalt

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 60. The NRC staff determination will be used on the answers to, and supporting analyses of, technical questions concerning groundwater flow, geochemical retardation, 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 (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 SCAs.

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 package performance at basalt sites. Future Site Technical Positions relevant to waste package design will address both NRC staff concerns regarding selected specific issues and acceptable technical approaches for addressing those specific issues.

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 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 basalt 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 accomodate the retrievability options?

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

4. When, how, and at what rate will groundwater contact the waste package container and packing materials?

5. When, how, and at what rate will groundwater 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 far-field 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 Environment/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 form and package development for basalt sites will be an integral part of the total repository system information needs of the NRC staff. Specific issues identified in the following sections 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 specific issues are identified should not be interpreted as the order of relative importance.

Specific Issues generally are questions about conditions and processes (information needs) that must be considered in assessing the performance issues and requirements of 10 CFR 60. The integration of numerous specific issues is included in the makeup of a performance issue. The relationship between specific issues listed below and the performance objectives of 10 CFR 60 is established, in part, by the performance issues provided above.

It is the position of the NRC staff that, based on our current level of knowledge of the basalt sites and the potential waste forms and packages that may be used in them, assessment of the Technical Criteria in 10 CFR 60 requries that, at a minimum, the following specific issues concerning waste package performance be addressed. The paragraph numbering system followed below is consistent with that used in Appendix C of NUREG-0960 and is retained here as a means of relating the specific issues in this Site Technical Position for waste package to Site Technical Positions for groundwater, geochemistry, etc., and to those performance issues listed above that are related to waste package design and performance.

2.0 WASTE PACKAGE

The waste package specific issues presented below are intended to elicit information concerning waste package design and performance prediction that will enable an assessment to be made of the ability of each waste package component to meet its functional requirements.

2.1

When, how, and at what rate will groundwater penetrate the packing around the waste package and contact the container?

2.1.1

What are the possible mechanisms and associated flow rates by which groundwater will penetrate the packing materials around waste package containers?

2.1.2
What will be the physical characteristics (e. g., temperature, pressure, and flow rates) of the groundwater reaching the waste package container as a function of time?

2.1.3
What will be the chemical characteristics (e. g., Eh, pH, and chemical composition) of the groundwater reaching the waste package container as a function of time?

2.1.3.1
How will the chemical characteristics of the groundwater reaching the waste package container be affected by radiolysis?

2.1.3.2
How will the chemical characteristics of the groundwater contacting the waste package container be affected by chemical reaction with the packing and container materials?

2.1.4
To what extent, as a function of time, will groundwater migration, temperature, radiation, or other effects change the ability of waste package packing materials to control the flow and chemical composition of groundwater passing through those materials?

2.1.5
How will the partial pressure of oxygen vary with time in the vicinity of the waste package packing and container?

2.1.5.1
How will the time dependence of oxygen removal from the waste package packing materials vary as a function of groundwater migration and composition, temperature, pressure, radiolysis and other parameters?

2.1.5.2
How will the time dependence of oxygen removal from the waste package packing materials vary as a function of the composition and physical structure (e.g., density, cracks and pore distribution) of the packing?

2.1.6
How will the design features of the packing accomodate all potential natural and waste package - induced conditions?

2.2
When, how, and at what rate will groundwater penetrate the waste package container?

2.2.1
What will the physical properties of the waste package container materials be as affected by temperature, radiation, interaction with the packing materials, groundwater migration, and other effects?

2.2.2
What will the chemical properties of the waste package container materials be as affected by temperature, radiation, interaction with the packing materials, groundwater migration, and other effects?

2.2.3
What are the possible mechanical failure modes for the waste package container?

2.2.3.1
What will be the mechanical loads on the waste package container as a function of time?

2.2.3.1.1
What will be the magnitude of the lithostatic/hydrostatic loads on the waste package container and the resultant stress developed within the container as a function of time?

2.2.3.1.2
What will be the magnitude of the thermal stresses developed within the waste package container as a function of time?

2.2.3.2
How will the packing materials around the waste package container affect the loading?

2.2.4
What are the potential corrosion failure modes for the waste package container?

2.2.4.1
What are the rates of corrosion as a function of time for the various corrosion modes of the waste package container?

2.2.4.2
What are the effects of radiation on the corrosion failure modes and associated corrosion rates for the waste package container?

2.2.4.2.1
What is the predicted rate of radiolytic generation of hydrogen, oxygen, and other species due to gamma radiation in the vicinity of the waste package container?

2.2.4.2.2
How will the generation of hydrogen, oxygen, and other species affect the corrosion modes and rates of the waste package container?

2.2.4.3
What effects will the packing materials around the waste package container have on the corrosion mechanisms and rates for the container?

2.2.4.4
Will microbes affect corrosion of the waste package container, and if so, how?

2.2.5
What are the anticipated physical dimensions of waste package container breach as a function of time?

2.2.6
What will be the physical characteristics (e.g., temperature, pressure, and flow rate) of the groundwater penetrating the waste package container and reaching the waste form as a function of time?

2.2.7
What will be the chemical characteristics (e.g., Eh, pH, and chemical constituents of the groundwater penetrating the waste package container and reaching the waste form as a function of time?

2.2.8
How will the design of the waste package container accomodate all potential natural and waste package induced conditions?

2.3
When, how, and at what rate will radionuclides be released from the waste form?

2.3.1
What are the physical, chemical, and mechanical properties of the waste form, how do those properties of the waste form change with time, and how will such changes 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?

2.3.2
What is the solubility of the waste form under the range of potential repository conditions?

2.3.2.1
What are the possible dissolution mechanisms of the waste form under the range of potential repository conditions?

2.3.2.1.1
Which waste form dissolution mechanism or mechanisms are most likely?

2.3.2.1.2
What are the rates of dissolution associated with the potential waste form dissolution mechanisms?

2.3.2.2
What non-radioactive dissolution products are likely to be produced from the waste form?

2.3.2.3
What are the solubilities of the radionuclides released from the waste form?

2.3.2.4
What will be the chemical species of the radionuclides released from the waste form?

2.3.3
What colloids or other suspended particles will be produced from the waste form?

2.3.3.1
How may the formation of colloidal particles affect waste form degradation?

2.3.3.2

How may radionuclides that are released from the waste form be transported in colloids or other suspended particle form?

2.3.4
What are the predicted ranges of residence times of a unit volume of groundwater in contact with a unit area of waste form as a function of time?

2.3.4.1
For spent fuel, how does the fuel rod cladding change the predicted effective residence time of a unit volume of groundwater in contact with a unit area of waste form?

2.3.4.2
For reprocessed fuel, how may alterations in physical form (e.g., cracking) alter the predicted effective residence time of a unit volume of groundwater in contact with a unit area of waste form?

2.3.5
How will packing, container materials (including overpacks, canisters, and any special corrosion-resistent alloys or spent fuel rod cladding, if applicable) and/or their alteration products interact with the waste form to cause its alteration and/or effect release of radionuclides?

2.3.6
For spent fuel, what are the potential damage and failure mechanisms for the fuel rod cladding?

2.3.6.1
What is the predicted rate of failure for each of the potential failure mechanisms for spent fuel?

2.3.6.2
What is the predicted size of cladding breach associated with each of the potential spent fuel cladding failure mechanisms?

2.3.6.3
For fuel rods with defected cladding, how will the presence of defects alter the radionuclide retention capability of the spent fuel waste form?

2.3.7
How will the design of the waste form accomodate all potential natural and waste package induced conditions?

2.4
How and at what rates will radionuclides migrate through failed waste packages?

2.4.1
What will be the convective flows in the waste package as a function of time?

2.4.2
What are the transport and retardation processes important to the flux of radionuclides with time in waste package packing materials?

2.4.3
How will the radionuclide species (i.e., particles, colloids, and solubles) change with time in the waste package?

2.4.4
What will be the solubility as a function of time of species incorporating radionuclides in the vicinity of the waste package packing materials?

2.4.5
Will alpha radiation in the waste package packing materials affect chemistry and hence transport and radionuclide species identification?

2.4.6
Will microbes affect transport in waste package packing materials? If so, how?

2.5
How does the waste package design address releases of radioactive materials to unrestricted areas within the limits specified in 10 CFR 20?

2.5.1
How will the waste package shielding contribute to the maintenance of radiation doses, levels, and concentrations within the limits of 10 CFR 20?

2.5.2
How will the waste package design provide assurance that necessary safety functions will be carried out in the geologic repository area?

2.5.2.1

How will the waste package design protect against natural phenomena and environmental conditions anticipated at the geologic repository area?

2.5.2.2
How will the waste package design protect against the dynamic effects of equipment failure and similar events?

2.5.2.3
How will the waste package be designed to perform its safety functions during and after credible fires or explosions in the geologic repository area?

2.5.3
How will the waste package design provide protection against radiation exposures and offsite releases prior to permanent closure?

2.6
How does the design of the waste package accomodate the requirement that the waste should be retrievable at any time up to 50 years after emplacement?

2.6.1
What features of the waste package container will be provided to facilitate transportation and retrievability before emplacement or retrievability from the underground facility after emplacement?

2.6.2
What features of the waste package packing will facilitate retrievability of the waste package after emplacement?

2.6.3
What labels or other means of identification will be provided for the waste package to facilitate retrievability?

2.6.3.1
How will the waste package design provide that the identification on the waste package will not impair the integrity of the waste package?

2.6.3.2
How will the waste package design provide that the identification information on the waste package will be legible at least to the end of the period of retrievability?

2.6.3.3
How will the waste package design provide that each waste package identification will be consistent with the waste package's permanent written record?

2.7
How will the waste package design preclude explosive, pyrophoric, and chemically reactive materials?

2.7.1
How will the waste package design preclude free liquids in an amount that could compromise the ability of the waste package to achieve the performance objectives related to containment of HLW (because of chemical interaction or formation of pressurized vapor) or the prevention of spillage and spread of contamination in the event of waste package perforation during the period through permanent closure?

2.7.2
How will the waste package design ensure that the radioactive wastes will be in solid form in a sealed container?

2.7.3
How will the waste package design ensure that particulate waste forms will be consolidated (for example, by incorporation into an encapsulating matrix) to limit the availability and generation of particulates?

2.7.4
How will the waste package design ensure that either (a) all combustible radioactive wastes have been reduced to a non-combustible form or (b) a fire involving the waste packages containing combustibles will not (1) compromise the integrity of other waste packages, (2) adversely affect any structures, systems or components important to safety, or (3) compromise the ability of the underground facility to contribute to waste isolation?

2.8
What are the conditions that might affect criticality in the vicinity of the waste package?

2.8.1
How will the waste form radionuclide inventory and the overall design (including shielding) of the waste package be controlled to ensure that criticality will not be reached during the handling and storage of waste packages during the operational phase of the repository?

2.8.2

By what means could actinides be concentrated in the packing materials to create a potential for criticality after emplacement of the waste packages?

2.9 How will the design of the waste package accomodate the monitoring of the package without adversely affecting waste package integrity?

2.10

How will the the waste package design ensure that the interaction of dissolved gases (e.g. methane) in basalt with the waste package will not compromise the life of the waste package?

2.10.1

How will the waste package design ensure that the interaction of dissolved gases (e.g. methane) in basalt with the waste package will not adversely affect the release rate of radionuclides from the waste package after waste package after waste package failure?

DISCUSSION

The rationale for each specific 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 in determining compliance with the provisions of (a) 10 CFR 60.113, "Performance of the geologic repository operations area through permanent closure" that address waste package performance, (b) those portions of 10 CFR 60.135, "Criteria for the waste package and its components" which merit further elaboration, and (c) 20 CFR 60.143, "Monitoring and testing waste packages."

2.0 WASTE PACKAGE

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 after the groundwater has migrated up the thermal gradient through the packing material and has corroded the container to the degree that it fails. Therefore, an understanding of (1) the time, rate, and nature of the groundwater contacting and affecting the components of the waste package and (2) the time, rate, and nature of the release and migration of radionuclides from the waste form out through the layered components of the waste package is essential to being able to demonstrate compliance with this performance objective. Waste package specific issues 2.1 through 2.4 and associated sub-issues address such flow-in, flow-out phenomena as they affect waste package design and post-emplacement performance prediction, while issues 2.5 through 2.9 address other pre- and post-emplacement concerns.

2.1

When, how, and at what rate will groundwater penetrate the packing around the waste package and contact the container.

Before groundwater contacts the waste it must penetrate the packing and then any containers separating the packing from the waste form. Depending on the type of materials used, the packing may significantly affect the time and rate at which groundwater reaches the container, and may be designed to delay or reduce such contact. Further, for packing materials other than crushed basalt of the same composition as the repository site the packing is likely to alter the groundwater's chemical composition and thereby affect the processes by which groundwater will degrade the container. Regardless of whether 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.

2.1.1

What are the possible mechanisms and associated flow rates by which groundwater will penetrate packing materials around waste package containers?

In order to assess the effects of packing on the rate and chemical composition of groundwater reaching the containers, it will be necessary to determine how the groundwater 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.

2.1.2

What will be the physical characteristics (e.g., temperature, pressure, and flow rates) of the groundwater reaching the waste package container as a function of time?

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

2.1.3

What will be the chemical characteristics (e.g., Eh, pH, and chemical composition) of the groundwater reaching the waste package container as a function of time?

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

2.1.3.1

How will the chemical characteristics of the groundwater reaching the waste package container be affected by radiolysis?

Groundwater migrating through the packing toward the waste package container will be exposed to gamma irradiation (alpha irradiation as well if the container has been breached). This can result in a variety of effects involving hydrolysis of the water and formation of colloidal sodium and chlorine. Because this can have a marked effect on the environment and performance of the containers, it must be taken into account in waste package design and performance prediction.

2.1.3.2

How will the chemical characteristics of the groundwater contacting the waste package container be affected by chemical reaction with the packing and container materials?

The chemical composition, Eh, and pH of the groundwater can be affected by reaction with the packing and container materials with the result that the rate of penetration of the container and reaction with the waste form can be enhanced or retarded. Such changes should be taken into account in the waste package design and performance prediction.

2.1.4

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

This issue recognizes that the packing materials may not a priori 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 based on test data, will be needed to demonstrate that the performance of the package does not change in ways that unacceptably degrade the performance of the waste package as a whole.

2.1.5

How will the partial pressure of oxygen vary with time in the vicinity of the waste package packing and container?

This question is covered in a general sense in item 2.1.3 above. It is highlighted here to emphasize 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.

2.1.5.1
How will the time dependence of oxygen removal from the waste package packing materials vary as a function of groundwater migration and composition, temperature, pressure, radiolysis and other parameters?

This issue is intended to address the changes in chemical characteristics within the packing which may influence the quantity of oxygen available at the container surface as a function of time. Such changes may result from processes such as corrosion (oxygen depletion) and diffusion and radiolysis (oxygen replenishment).

2.1.5.2
How will the time dependence of oxygen removal from the waste package packing materials vary as a function of the composition and physical structure (e.g., density, cracks and pore distribution) of the packing?

This issue is intended to address the changes in physical characteristics within the packing which may influence the quantity of oxygen available at the container surface as a function of time. Such changes may result from densification of the packing as a result of lithostatic/hydrostatic pressure or porosity and crack formation from steam generation or wet/dry cycling.

2.1.6
How will the design features of the packing accomodate all potential natural and waste package-induced conditions?

This issue is intended to draw upon the analyses developed for the preceding issues to assess the predicted performance of a specific packing material as affected by method of emplacement, configuration, waste package components, or natural components of the repository. Factors that should be accounted for include, but are not restricted to, the packing material porosity, aggregate size and size distribution, the method of emplacement of the packing, and the emplacement configuration.

Waste package issue 2.2 and associated sub-issues are derived from performance number 5; when, how, and at what rate will groundwater contact the waste form?

2.2

When, how, and at what rate will groundwater penetrate the waste package container?

One of the performance objectives in 10 CFR 60 addresses the interval during which the containment of HLW is substantially complete (10 CFR 60(a)(1)(ii)(A)). Therefore, this issue addresses the fact that 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. To assess the period of time during which the container will remain intact, mechanical and chemical failure modes must be considered both individually as well as synergistically.

2.2.1

What will the physical properties of the waste package container materials be as affected by temperature, radiation, interaction with the packing materials, groundwater migration, and other effects?

This issue recognizes that container properties may not a priori 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. For example, the effect of radiation on the yield strength of the container material will be subject to scrutiny.

2.2.2

What will the chemical properties of the waste package container materials be as affected by temperature, radiation, interaction with the packing materials, groundwater migration, and other effects?

The rationale for needing this information is comparable to the discussion in 2.2.1 above.

2.2.3

What are the possible mechanical failure modes for the waste package container?

Container breach may occur through a variety of mechanisms, including crushing due to lithostatic stresses, perhaps altered by hydrostatic effects or by corrosion processes. The following sub-issues have been developed to assess the importance of potential failure modes.

2.2.3.1

What will be the mechanical loads on the waste package container as a function of time?

The containers may be subjected to mechanical loads and stresses from the geologic environment, the waste package induced environment or from container fabrication. Examples of such stresses could be lithostatic loads, thermal stresses and residual stresses, respectively. To assess the importance of the potential mechanical failure modes, an understanding of the mechanical loads on and resulting stresses in the container will be necessary.

2.2.3.1.1

What will be the magnitude of the lithostatic/hydrostatic loads on the waste package container and the resultant stress developed within the container as a function of time?

The major contribution of stress on the container will probably result from the surrounding rock (lithostatic/hydrostatic loads). These loads may also vary with time. Therefore, to determine their effect on the mechanical failure modes, an evaluation of the resulting stresses in the container will be necessary.

2.2.3.1.2

What will be the magnitude of the thermal stresses developed within the waste package container as a function of time?

All waste containers will be exposed to elevated temperatures from the heat produced as a result of radioactive decay. The period of duration of this condition and the magnitude of the temperature attained will vary depending on the waste form and the radionuclides inventory.

To assess the effect of temperature on the mechanical failure modes, an understanding of the thermal stresses developed in the container will be necessary.

2.2.3.2

How will the packing materials around the waste package container affect the loading?

Packing material placed around the container may minimize the mechanical loads permanently or temporarily or may transmit or even intensify (by swelling) the loads on the container. Therefore, the effects of packing (if utilized) must be evaluated.

2.2.4
What are the potential corrosion failure modes for the waste package container?

To determine the time and nature of likely container breach, it will be necessary to demonstrate that the failure mode or combination of failure modes 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.

2.2.4.1
What are the rates of corrosion as a function of time for the various corrosion modes of the waste package container?

This issue is intended to help develop the overall corrosion rate in order to determine the time until waste package failure.

2.2.4.2
What are the effects of radiation on the corrosion failure modes and associated corrosion rates for the waste package container?

This issue is intended to address the possibility that the presence of radiation may enhance the container corrosion rate and produce failure sooner than expected in the absence of a radiation environment.

2.2.4.2.1
What is the predicted rate of radiolytic generation of hydrogen, oxygen and other species due to gamma radiation in the vicinity of the waste package container?

It is necessary to identify the type and amount of species likely to be produced by radiolysis in order to characterize the effect of the radiation environment on the container.

2.2.4.2.2
How will the generation of hydrogen, oxygen, and other species affect the corrosion modes and rates of the waste package container?

As a continuation of 2.2.4.2.1, this issue specifically addresses the effect of the radiolytically generated species on the rate and mode of corrosion.

2.2.4.3

What effects will the packing materials around the waste package container have on the corrosion mechanisms and rates 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 2.1.2 through 2.1.5.2 from that perspective to ensure completeness.

2.2.4.4

Will microbes affect corrosion of the waste package container, 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.

2.2.5

What are the anticipated physical dimensions of waste package 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.

2.2.6

What will be the physical characteristics (e.g., temperature, pressure, and flow rate) of the groundwater penetrating the waste package container and reaching the waste form as a function of time?

This issue is intended to account for the changes in the physical characteristics of the groundwater reaching the waste form as a result of interactions with the container.

2.2.7

What will be the chemical characteristics (e.g., Eh, pH and chemical constituents of the groundwater penetrating the waste package container and reaching the waste form as a function of time?

This issue is intended to account for the changes in chemical characteristics of the groundwater reaching the waste form as a result of interactions with the container.

2.2.8 How will design of the waste package container accomodate all potential natural waste package-induced conditions?

This issue is intended to draw upon the analyses developed for the preceding container-related issues in order to evaluate the performance in the repository environment of the container design selected. Factors that should be considered include, but are not restricted to, container fabrication (especially heat treatments and welding processes), and emplacement (canistering) of the waste form (if the waste form canister also serves as a long-term containment barrier).

Waste package issue 2.3 is a restatement of performance issue number 6: It is listed below as a "1st-tier" waste package specific issue because this (performance) issue is addressed only under the subject heading waste package, (it is not addressed in other technical positions or other technical disciplines).

2.3

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

One of the performance objectives in 10 CFR 60, (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, 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.

2.3.1

What are the physical, chemical, and mechanical properties of the waste form, how do those properties of the waste form change with time, and how will such changes 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 various concerns including, but not restricted to, devitrification of glass waste forms, or degradation of any waste forms due to radioactive decay or other processes 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.

2.3.2
What is the solubility of the waste form under the range of potential repository conditions?

The range of solubility of the waste form matrix, whether it is high level waste glass or spent fuel, must be known or estimated to assess which mode of dissolution as a function of time will control radionuclide releases.

2.3.2.1
What are the possible dissolution mechanisms of the waste form under the range of potential repository conditions?

Under the range of possible repository conditions several dissolution mechanisms may be active. For example, devitrification of the glass or oxidation of the spent fuel may result in physical failure of the waste form by cracking and spalling, or radionuclides may be leached chemically either by a solubility-limited or bulk waste form dissolution mechanism.

2.3.2.1.1
Which waste form dissolution mechanisms or mechanism are most likely?

This issue is intended to examine the dissolution mechanisms identified in the previous issue to determine the controlling mechanism as a function of waste form and time, recognizing that the controlling dissolution mechanism may vary with time.

2.3.2.1.2
What are the rates of dissolution associated with the potential waste form dissolution mechanisms?

The dissolution rates of individual radionuclides may be a function of the waste form matrix or of the solubilities of the individual radionuclides. The rate of dissolution for each radionuclide will provide the source term for near and far-field radionuclide migration determinations.

2.3.2.2
What non-radioactive dissolution products are likely to be produced from the waste form?

It will 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.

2.3.2.3
What are the solubilities of the radionuclides released from the waste form?

For dissolution by leaching, the solubilities of each individual radionuclide will determine whether that radionuclide will be controlled by solubility-limited or bulk waste form dissolution.

2.3.2.4
What will be the chemical species of the radionuclides released from the waste form?

The solubility and the rate of release and migration of a radionuclide from the waste package will be a function of the chemical species of the radionuclide (e.g., oxide, nitride, ionic sub-species). This information is necessary to predict compliance with 10 CFR 60.113(a)(1)(ii)(5), concerning release from the engineered barrier system.

2.3.3
What colloids or other suspended particles will be produced from the waste form?

Several of the potential low-solubility species in radioactive wastes can form colloids or become part of other colloidal substances released from the waste form. It is necessary to account for such species in the calculation of source terms and the determination of how waste package design and performance will assure compliance with 10 CFR 60.113(a)(1)(ii)(B), concerning release from the engineered barrier system.

2.3.3.1
How may the formation of colloidal particles affect waste form degradation?

It is possible to under-predict or over-predict the rate of waste form degradation and release of radionuclide if colloid formation is neglected. It should be taken into account, therefore, in the waste package/waste form design and performance prediction.

2.3.3.2
How may radionuclides that are released from the waste form be transported in colloids or other suspended particle form?

For low-solubility species it is possible that the rate of transport through the leached waste package container out through the packing, and into the near-field, can be increased if colloids and suspended precipitates form at or near the waste form surface. The formation and transport of suspended matter containing low-solubility radio-elements should, therefore, be accounted for in waste package design and performance prediction.

2.3.4

What are the predicted ranges of residence times of a unit volume of groundwater in contact with a unit area of waste form as a function of time?

This question addresses the extent to which groundwater contacting the waste form will be migrating. 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.

For slightly soluble species, the slow diffusion and slow movement of groundwater around the waste form may be more important in controlling the net rate of dissolution than the rate at which substances inside the waste material reach the surface of the waste form. If the solubility is sufficiently large, the kinetics of the interaction between the solid waste constituents and the groundwater may dominate. These considerations should be addressed in the waste package/waste form design and performance prediction.

2.3.4.1

For spent fuel, how does the fuel rod cladding change the predicted effective residence time of a unit volume of groundwater in contact with a unit area of waste form?

For spent fuel the Zircaloy or stainless steel cladding may serve as an additional barrier or impediment to the contact of groundwater with the radioactive waste and subsequent release of radionuclides. For credit to be taken for such a barrier, the effect of cladding breaches on residence times and release rates should be considered in waste package design and performance analysis.

2.3.4.2

For reprocessed fuel, how may alterations in physical form (e.g., cracking) alter the predicted effective residence time of a unit volume of groundwater in contact with a unit area of waste form?

In a way analogous to spent fuel cladding, physical alterations in the reprocessed fuel waste form (e.g., cracking of borosilicate glass) could affect the predicted effective residence time. Such phenomena should be taken into account in waste package/waste form design and performance prediction.

2.3.5

How will packing, container materials (including overpacks, canisters, and any special corrosion-resistent alloys or spent fuel rod cladding, if applicable), and/or their alteration products interact with the waste form to cause its alteration and/or affect release of radionuclides?

Regardless of the initial in-situ composition of the groundwater in a basalt repository, the groundwater will change in chemical characteristics as it migrates through and reacts with the waste package packing and container materials and to the surface of the waste form. Packing and container materials and reaction products that are transported with the groundwater to the waste form could conceivably interact with the waste form and affect the release of radionuclides from the waste form. Such effects should be accounted for in waste package design and performance prediction.

2.3.6

For spent fuel, what are the potential damage and failure mechanisms for the fuel rod cladding?

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

2.3.6.1

What is the predicted rate of failure for each of the potential failure mechanisms for spent fuel?

It is expected that the spent fuel rod cladding will be subjected to a limited number of failure mechanisms involving chemical effects such as hydriding or oxidation, mechanical effects such as fracturing due to the overloading, or synergistic effects such as stress/corrosion cracking. It is possible that to some degree the cladding may be damaged if not actually breached, during the time it is stored in spent fuel pools or elsewhere, prior to containment in a waste package for burial, or during handling. Estimates should be provided of the number of failures that may occur due to each identified failure mechanism so that this information can be factored into the determination of the release of radionuclides from the waste form.

2.3.6.2

What is the predicted size of cladding breach associated with each of the potential spent fuel cladding failure mechanisms?

The rationale for this issue is analogous to that for issue 2.2.5 for the size of breach in the waste package container, viz., the rate of leaching and dissolution of the radionuclides from the waste form may be affected by the size of the flow path.

2.3.6.3 For fuel rods with defected cladding, how will the presence of defects alter the radionuclide retention capability of the spent fuel waste form?

For a significant barrier effect to be claimed for breached cladding, it will be necessary to show to what extent the rate of release and leaching of radionuclides from the spent fuel is affected by the presence of defects of varying number, type, size, and time of occurrence.

2.3.7 How will the design of the waste form accomodate all potential natural and waste package induced conditions?

This issue is intended to draw upon the analyses developed for the preceding waste form-related issues to ensure that all aspects of the waste form functional requirements have been considered in the waste form design and performance predictions. Design features of the waste form that should be considered include, but are not restricted to the composition of waste glass, the arrangement of spent fuel rods within the container, and any synergistic effects that may ensue due to additional materials placed within the container (e.g., steel support members or sand fill).

2.4 How and at what rates will radionuclides migrate through failed waste packages?

This issue recognizes that radionuclide release from containers may vary between general release from a uniformly failed container to a highly concentrated release from a small breach in what is effectively a point source.

2.4.1 What will be the convective flows in the waste package as a function of time?

The concerns underlying this issue have been expressed in 2.1.1, 2.3.4, and other related issues.

2.4.2 What are the transport and retardation processes important to the flux of radionuclides with time in waste package packing materials?

Depending on the choice of materials, the packing surrounding the container may have considerable influence on the nature and rate of release of certain radionuclides, in particular, by 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 absorption or precipitation of the radionuclides and the kinetics of those processes. These phenomena, coupled with the groundwater migration rates through the packing, constitute the transport and retardation processes.

2.4.3

How will the radionuclide species (i.e., particles, colloids and solubles) change with time in the waste package?

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.

2.4.4

What will be the solubility as a function of time of the species incorporating radionuclides in the vicinity of the waste package packing materials?

The rationale for this issue appears under Issues 2.4.3 and 2.3.2 above.

2.4.5

Will alpha radiation in the waste package packing materials affect chemistry and hence transport and radionuclide 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, perhaps through bounding analyses.

2.4.6

Will microbes affect transport in waste package 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.

2.5
How does the waste package design address releases of radioactive materials to unrestricted areas within the limits specified in 10 CFR 20?

It is the purpose of the regulations contained in 10 CFR 20 to limit the occupational radiation exposure of individuals to as low as is reasonably acheivable. The waste package design and performance prediction should address this requirement.

2.5.1
How will the waste package shielding contribute to the maintenance of radiation doses, levels, and concentrations within the limits of 10 CFR 20?

The degree to which the waste package container contributes to the "as low as reasonably achievable" occupational exposure goal of 10 CFR 20 should be assessed as required by 10 CFR 60.131(a)(3). The amount of shielding provided will be a function of the type and thickness of the materials used in the waste package container.

2.5.2
How will the waste package design provide assurance that necessary safety functions will be carried out in the geologic repository area?

The means by which the waste package design assures that necessary safety functions are provided in the geologic repository operations area should be assessed as required by 10 CFR 60.131(b).

2.5.2.1
How will the waste package design protect against natural phenomena and environmental conditions anticipated at the geologic repository area?

The means by which the waste package design protects against natural phenomena and environmental conditions anticipated at the geologic repository area should be assessed as required by 10 CFR 60.131(b)(1).

2.5.2.2
How will the waste package design protect against the dynamic effects of equipment failure and similar events?

The means by which the waste package design protects against the dynamic effects of equipment failure and similar events should be assessed as required by 10 CFR 60.131(b)(2). Such assessment should include but not be limited to missile impacts and crane or other equipment failures that could result in a dropped package.

2.5.2.3

How will the waste package be designed to perform its safety functions during and after credible or explosions in the geologic repository area?

The means by which the waste package design provides assurance that the waste package structures, systems, and components important to safety perform their safety functions during and after credible fires and explosions in the geologic repository operations area should be assessed as required by 10 CFR 60.131(b)(3).

2.5.3

How will the waste package design provide protection against radiation exposures and offsite releases prior to permanent closure?

The rationale for this issue appears under Issue 2.5.

2.6

How does the design of the waste package accomodate the requirement that the waste should be retrievable at any time up to 50 years after emplacement?

The rule (10 CFR 60.111(b)) states that the geologic repository operations area shall be designed so that any of the emplaced waste could be retrieved on a rasonable schedule starting at any time up to permanent closure (which is defined as 50 years after waste emplacement operations are initiated).

The rule (10 CFR 60.135.(b)(3)) further requires that the waste packages shall be designed to maintain waste containment during transportation, emplacement and retrieval.

To accomodate this requirement, with whatever waste package design DOE proposes, it must allow for operations required to be performed on the waste package for retrievability purposes.

2.6.1

What features of the waste package container will be provided to facilitate transportation and retrievability before emplacement or retrievability from the underground facility after emplacement?

During transportation of the waste in a container from the waste processing facility to the underground facility, the container acts a shield to protect personnel involved in the operation and serves to facilitate handling. When retrievability is required, the container is also required to provide features for operations of the waste from the underground facility to locations designated in DOE's plan for the follow-on action for the retrieval waste, such as reprocessing, repacking and/or storage. For operational personnel safety and to facilitate transportation and retrievability, the waste package container must, therefore, provide design features for such operations.

2.6.2
What features of the waste package packing will facilitate retrievability of the waste package after emplacement?

DOE's waste package design may or may not include packing. If packing is included as part of the waste package design, the presence of the packing must not cause undue delay (or negate the operation) of waste retrieval after the package has been emplaced.

2.6.3
What labels or other means of identification will be provided for the waste package to facilitate retrievability?

The rule (10 CFR 60.135(b)(4)) specifically requires that a label or other means of identification be provided for each waste package. Identification of individual waste packages is a necessary part of a quality assurance plan and such identification of individual assemblies is standard in the nuclear industry.

The identification is required to maintain traceability of the waste package and its contents during the retrieval period.

2.6.3.1
How will assurance be provided that the identification on the waste package will not impair the integrity of the waste package?

The rule (10 CFR 60.135(b)(4)) specifically requires that the identification shall not impair the integrity of the waste package. The objective of the identification is to facilitate actions required for retrieving the waste when called for. Since the waste form at retrieval time still requires the protection of the waste package container for containment, the identification must not impair the integrity of the waste package container.

2.6.3.2

How will assurance be provided that the identification information on the waste package will be legible at least to the end of the period of retrievability?

The waste and the container come from different sources at different times. Therefore, it will be necessary to include information on the waste package container to determine if retrieval of packages is required. This information must be legible to the end of the period of retrievability.

2.6.3.3

How will assurance be provided that each waste package identification will be consistent with the waste package's permanent written record?

Consistency of waste packages identification with the waste package's records (as stated in 10 CFR 60.135(b)(4)) is required to assure that the actions taken at retrieval and after retrieval are appropriate for wastes identified

2.7

How will the waste package design preclude explosive, pyrophoric and chemically reactive materials?

Materials that are explosive or phyrophoric have the potential for seriously damaging waste package integrity and releasing radioactivity in an uncontrolled and unexpected manner.

Chemically reactive materials are included in 10 CFR 60.135(b) in recognition of the fact that there are other types of rapid chemical reactions which may occur in addition to the rapid oxidation reactions associated with explosions and burning of explosives and pyrophonic materials. Therefore, any chemical (for example, an active reducing agent) which could react rapidly and thereby damage a waste package's integrity is also undesirable. The NRC staff recognizes that most materials are chemically reactive if conditions (pressure, temperature, and concentrations of other chemical reactants) are appropriate. Thus, it is reasonable to consider the potential conditions that waste package materials could be expected to encounter during handling, emplacement, retrieval and long-term storage in demonstrating whether or not the waste package materials fall within this category.

2.7.1

How will waste package design preclude free liquids in an amount that could compromise the ability of the waste package to achieve the performance objectives related to containment of HLW (because of chemical interactions or formation of pressurized vapor, or the presentation of spillage and spread of contamination in the event of waste package perforation during the period through permanent clsoure?

Ree liquids, when subjected to radiation can degrade and release gases. The liquid may also vaporize because of temperatures within a waste package. These two phenomena could pressurize a waste package to the point where it would leak or explode.

2.7.2
How will the waste package design ensure that the radioactive waste will be in solid form in a sealed container?

This is one of the three criteria for HLW waste form (10 CFR 60.135(c)). This issue is consistent with the liquid requirement. The requirement of a waste in solid form also simplifies the analysis (and verification) of chemical and physical phenomena occuring within a waste package.

2.7.3
How will the waste package design ensure that particulate waste forms will be consolidated (for example, by incorporation into an encapsulating matrix) to limit the availability and generation of particulates?

This issue is derived from one of the three criteria for HLW waste forms (10 CFR 60.135(c)). To minimize dispersibility and human exposure in the event of an accident (such as a handling accident) small radioactive particles released during an accident should be limited because they are difficult to retrieve. They are more hazardous than consolidated waste because they may be responsible. Consolidation also eliminates unnecessarily high leach rates in groundwater that might result from high-surface areas presented by particulates.

2.7.4
How will the waste package design ensure that either (a) all combustible radioactive waste have been reduced to a noncombustible form or (b) a fire involving the waste package containing combustibles will not (1) compromise the integrity of other waste package, (2) adversely affect any structures, systems, or components important to safety, or (3) compromise the ability of the underground facility to contribute to waste violation?

2.8
What are the conditions that might affect criticality in the vicinity of the waste package?

10 CFR 60.131(b)(7) requires all systems to be designed so that criticality will be impossible unless two unlikely, independent, and concurrent or sequential changes have occurred. The waste package should be designed to ensure criticality, safety under all normal and postulated accident conditions.

2.8.1

How will the waste form radionuclide inventory and the overall design (including shielding) of the waste package be controlled to ensure that criticality will not be reached during the handling and storage of waste package during the operational phase of the repository?

The waste package design should preclude the possibility of attaining criticality due to any advertent or inadvertent mishandling.

2.8.2

By what means could actinides be concentrated in the packing materials to create a potential for criticality after emplacement of the waste package.?

To enable the NRC staff to reach the finding required by 60.131(b)(7) mentioned in 2.5 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.

2.9 How will the design of the waste package accomodate the monitoring of the package without adversely affecting waste package integrity?

The objective of 10 CFR 60.143(a) is to establish an in-situ monitoring program to observe the performance of the waste packages in their actual repository environment and demonstrate that they conform to design and regulatory requirements.

The attributes of the type of program acceptable to NRC are discussed in a Staff Technical Position on post-emplacement monitoring.

2.10

How will the waste package design ensure that the interaction of dissolved gases (e.g. methane) in basalt with the waste package will not compromise the life of the waste package?

If dissolved gases (e.g methane) are detectable in a candidate basalt site , it must be shown that under a radiated environment similar to that expected in the basalt repository, the interaction of these gases with the waste package will not shorten the expected waste package life claimed by DOE.

2.10.1

How will the waste package design ensure that the interaction of dissolved gases (e.g. methane) in basalt with the waste package will not adversely affect the release rate of radionuclides from the waste package after waste package failure?

If dissolved gases (e.g. methane) are detectable in a candidate basalt site, it must be shown that under a radiated environment similar to that expected in the basalt repository, the interaction of these gases with the product released from the failed waste packages does not adversely affect the release rate of radionucldes to a level exceeding that specified in 10CFR60.