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AUG 31 1984

MEMORANDUM FOR: Hubert J. Miller, Chief
Repository Projects Branch
Division of Waste Management, NMSS

FROM: Malcolm R. Knapp, Chief
Geotechnical Branch
Division of Waste Management, NMSS

SUBJECT: UMBRELLA SITE TECHNICAL POSITIONS CONCERNING GEOCHEMISTRY ISSUES AT BWIP, NNWSI, AND A SALT SITE (OPS PLAN 5314216.54/NNWSI, 5314217.54/SALT)

In response to detailed OPS Plan Milestones 5314216.54/NNWSI, and 5314217.54/Salt, I am transmitting revised drafts of the NNWSI and Salt umbrella technical positions. Your comments of August 7, 1984, and August 17, 1984 have been considered and incorporated into the current drafts as appropriate. Also, the current drafts were revised with close informal contact with appropriate RP project managers and staff, and reflect the informal guidance received up to August 29, 1984. The BWIP USTP will be transmitted no later than September 6, 1984, in order accommodate informal RP comments received on August 30, 1984.

If you or your staff have any questions please contact the appropriate GT site lead (BWIP/David Brooks-X74603, NNWSI/Linda Kovach-X74693, and Salt/Walt Kelly-X74571).

Malcolm R. Knapp, Chief
Geotechnical Branch
Division of Waste Management, NMSS

WM Record File ~~102.6~~ 106.3
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DRAFT

UMBRELLA SITE TECHNICAL POSITION

GEOCHEMICAL ISSUES

FOR THE NEVADA NUCLEAR WASTE

STORAGE INVESTIGATIONS

BACKGROUND

In the review of an application for Con--ruction Authorization for a HLW geologic repository, the NRC is requirec 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 form and package performance, geologic stability, and facility design. During the process of Site Characterization, the DOE will perform the laboratory and field investigations to develop the information needed to address these basic technical questions.

The investigations needed to characterize a geologic repository are complex and require 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 (SCP) by the DOE at an early stage of the process. Subsequent to receipt of an SCP the NRC must prepare a formal Site Characterization Analysis (SCA) for each site. NRC single-issue technical position papers, documented site reviews, and interagency technical meetings 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 (specific issues) relevant to the specific site. Therefore, this document establishes the NRC position as to the essential technical questions relevant to the geochemistry of a hypothetical repository at the Nevada Nuclear Waste Storage Investigations (NNWSI). Other Site Technical Positions will address both NRC staff concerns regarding selected specific issues and acceptable technical approaches for addressing those specific issues.

In identifying these essential issues, the staff has used a performance analysis approach. In that approach, three terms, site issue, performance issue and significant conditions and processes, have their special meanings described in the paragraphs below.

A Site Issue is a question about a specific site that must be addressed and resolved to complete the licensing assessment of site suitability and/or design suitability in terms of 10 CFR 60. Site issues are not necessarily controversial questions.

A Performance Issue is a broad question concerning the operation and long-term performance of the various components of the repository system. A set of performance issues are derived directly from the performance objectives in 10 CFR 60.

Significant Conditions and Processes (includes potential adverse conditions of 10 CFR 60) are those that must be considered in the assessment of a performance issue and either (1) exist before repository disturbance, (2) could cause future changes, or (3) result from change. They may be natural (e.g., faulting), repository-induced (e.g., thermal buoyancy), and human-induced (e.g., withdrawal of water resources).

In its performance analysis approach, the NRC staff first breaks down the performance objectives of 10 CFR 60 into a set of performance issues corresponding to the individual performance of the various components of the repository system. As developed in NUREG-0960, performance issues for a geologic repository 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?

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 far field 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?

While these performance issues were originally developed for the BWIP, the staff considers that they also apply to the NNWSI site.

The next step in the performance analysis approach is identification of the significant conditions and processes that bear on assessment of each of the performance issues. Judgment is involved in determining which conditions and processes are considered significant. Knowledge gained from the staff's review of various related technical data and documents, site visits, technical meetings and research efforts contributed heavily to the particular selection of significant conditions used in development of this STP. Questions about the significant conditions and processes as they pertain to the geochemistry constitute the site issues identified in this position.

Because the geochemistry of the potential NNWSI site may significantly affect repository performance, information on geochemistry during site characterization will be part of the total repository system information needs of the NRC staff required to assess the performance elements. Issues identified in the following section delineate information on geochemistry issues at the potential NNWSI site needed by the NRC staff to assess adequately the performance issues. The sequential order in which issues are identified should not be interpreted as the order of relative importance.

Issue STPs have been developed in five technical areas (1.0 GROUNDWATER; 2.0 WASTE FORM/WASTE PACKAGE; 3.0 GEOCHEMISTRY; 4.0 REPOSITORY DESIGN; and 5.0 GEOLOGY). The site issues developed in each STP are designated and numbered in accordance with the above numbering system. The sequential order in which technical areas have been numbered should not be interpreted as the order of relative importance.

Technical Position

It is the position of the NRC staff that, based on our current level of knowledge of the NNWSI site, assessment of the Technical Criteria of 10 CFR 60 with regard to the performance elements of NUREG-0960 requires that, at a minimum, the following issues concerning geochemistry be addressed.

3.0 Geochemistry

3.1. WHAT ARE THE PRESENT GEOCHEMICAL CONDITIONS?

3.1.1 What are the present geochemical conditions of the geologic setting in the saturated/unsaturated zone?

3.1.1.1 What are the present conditions of temperature and pressure in the host rock, in the saturated/unsaturated zone?

3.1.1.2 What is the present mineralogy/petrology/chemistry of the host rock, in the saturated/unsaturated zone?

3.1.1.3 What is the present mineralogy/petrology/chemistry of the secondary minerals along potential release pathways of the host rock, in the saturated/unstaurated zone?

3.1.1.4 What are the present geochemical conditions of the groundwater in the host rock of the saturated/unsaturated zone?

3.1.2 What is the mineralogy/petrology/chemistry of the backfill/ seals/packing to be emplaced?

3.2 WHAT ARE THE CHANGES IN THE GEOCHEMICAL CONDITIONS/PROCESSES AS THE RESULT OF WASTE EMPLACEMENT?

3.2.1 What are the changes in the geochemical conditions of the geologic setting?

3.2.1.1 What are the changes in the conditions of temperature and pressure in the host rock, in the saturated/unsaturated zone?

3.2.1.2 What are the changes in the mineralogy/petrology/chemistry of the host rock in the saturated/unsaturated zone?

3.2.1.2.1 How are the mineral assemblages of the Yucca Mountain tuffs affected by anticipated changes in the temperature and pressure?

3.2.1.2.2 What is the anticipated spatial distribution of alteration products due to increased temperatures and altered fluid flow paths?

3.2.1.3 What are the changes in the geochemical conditions of the groundwater due to increased temperature and radiolysis within the saturated/unsaturated zone?

3.2.1.3.1 What are the changes in the rock/groundwater ratio in the host rock of the saturated/ unsaturated zone?

3.2.1.3.2 How will the various fluid flow regimes in the saturated/unsaturated zone affect the geochemical conditions of the groundwater due to the potential non-equilibrium conditions between the host rock and groundwater?

3.2.2 What are the changes in the geochemical conditions of the backfill/seals/packing as a result of waste emplacement under saturated/unsaturated conditions?

3.2.2.1 What are the changes in the conditions of temperature and pressure in the backfill/seals/packing?

3.2.2.2 What are the changes in the mineralogy/petrology/chemistry of the backfill/packing/seals as the result of waste emplacement?

3.2.2.2.1 How are the mineral assemblages of the backfill/packing/seals affected by anticipated changes in temperature and pressure?

3.2.2.2.2 What is the anticipated spatial distribution of alteration products due to increased temperatures and altered fluid flow paths?

3.2.2.3 What are the changes in the geochemical conditions of the groundwater entering the backfill/seals/packing due to increased temperature and radiolysis within the saturated/unsaturated zone?

3.2.2.3.1 What are the changes in the rock/groundwater ratio in the backfill/seals/packing in the saturated/unsaturated zone?

3.2.2.3.2 How will the various fluid flow regimes in the saturated/unsaturated zone affect the geochemical conditions of the groundwater in the backfill/seals/packing due to the potential non-equilibrium conditions between the backfill/seals/packing and groundwater?

3.3 WHAT ARE THE FUTURE GEOCHEMICAL PROCESSES/CONDITIONS THAT WILL AFFECT RELEASE AND TRANSPORT OF RADIONUCLIDES TO THE ACCESSIBLE ENVIRONMENT?

3.3.1 How does the solubility/concentration of radionuclides under various flow regimes affect radionuclide release and transport?

3.3.1.1 How does precipitation/co-precipitation affect radionuclide concentration?

3.3.1.2 How does speciation affect radionuclide solubility/concentration?

3.3.1.3 How do colloids/particulates/organics affect radionuclide solubility/concentration?

3.3.2 How does backfill/seals/packing/disturbed zone/far field mineralogy under various flow regimes influence radionuclide migration/retardation?

3.3.3 What is the importance of reaction and sorption kinetics on radionuclide release and transport in the disturbed zone/far field under various flow regimes?

3.3.4 How do redox conditions of the groundwater and redox buffering potential of the minerals affect radionuclide speciation/migration/retardation?

3.3.5. How does gamma and alpha radiolysis affect radionuclide release and transport?

3.3.6 How do colloids/particulates under various flow regimes affect radionuclide migration/retardation in the disturbed zone/far field?

3.3.7 How do organics/microbes affect radionuclide migration/retardation under various flow regimes in the disturbed zone/far field?

3.3.8 How does matrix diffusion affect radionuclide migration/retardation in the disturbed zone/far field?

3.3.9 How does vapor/aerosol transport affect radionuclide migration/retardation in the disturbed zone/far field?

DISCUSSION

Issue 3.1 covers the initial geochemical environment of the repository, i.e., the geochemical baseline for the repository. Issue 3.2 covers changes to the initial geochemical environment, which will be caused by construction of the underground facility and waste emplacement, and then changed further during heating due to decaying waste. Issue 3.3 deals with the waste package/geologic environment interactions and the transport of waste radionuclides to the accessible environment.

The rationale for each issue is described in the following discussion. In the discussion, the broadest issues, i. e., those that would appear in the first tier of a hierarchy of issues and sub-issues, are related directly to the performance issues that are listed in the Background section above. Sub-issues are related by technical argument to the issue(s) directly above them in the logic tree.

3.1 WHAT ARE THE PRESENT GEOCHEMICAL CONDITIONS?

An understanding of the geochemical conditions preceding waste emplacement is necessary in order to evaluate the suitability of a repository for containing waste and retarding the release of radionuclides from the disturbed zone to the accessible environment (performance issue 10). Adverse conditions within the far field are likely to remain unchanged after waste emplacement, whereas favorable present conditions in the near field may alter to potentially adverse conditions following waste emplacement. Since the geological media is the primary barrier to release of radioactive waste to the accessible environment, it is necessary to understand the pre-emplacement conditions to establish a baseline for prediction of geochemical conditions in the saturated and unsaturated zones under typical repository scenarios. This information is necessary to assess performance issues 9 and 10.

3.1.1 What are the present geochemical conditions of the geologic setting, in the saturated/unsaturated zone?

The geologic setting includes all the lithologic units of the Yucca Mountain Tuff in which the respository is constructed, the surrounding sedimentary, metamorphic and igneous rocks, and groundwater. The geologic setting is considered to be an important barrier in geologic waste isolation. For this reason, it is necessary to understand the present geochemical conditions so that host rock behavior under repository-induced conditions can be predicted with confidence.

3.1.1.1 What are the present conditions of temperature and pressure in the host rock, in the saturated/unsaturated zone?

Temperature and pressure are important parameters for understanding the chemical stability of the minerals in the host rock, and interstitial and bound water behavior. Therefore, baseline measurements are necessary for determining the magnitude of changes for these parameters under the stressed environment induced by a repository.

3.1.1.2 What is the present mineralogy/petrology/chemistry of the host rock, in the saturated/unsaturated zone?

The host rock is the primary barrier in geologic waste isolation. The composition of the geologic setting will influence the stability of a repository and the migration of radionuclides. Knowledge of the mineralogy, petrology, and chemical composition will lead to an understanding of the genesis and future geochemical stability of the host rock, aid in the evaluation of the effects of waste/rock interactions, and provide information for interpreting the groundwater chemistry.

3.1.1.3 What is the present mineralogy/petrology/chemistry of the secondary minerals along potential release pathways of the host rock, in the saturated/unsaturated zone?

The mineralogy/petrology/chemistry of the secondary minerals along fractures in the Yucca Mountain tuff may differ significantly from that of the bulk host rock. The existing spatial distribution of alteration products may be indicative of potential pathways for release of radionuclides to the accessible environment. If the movement of water through the geologic setting is predominantly via fractures, then a knowledge of the mineralogy/petrology/chemistry of the secondary minerals lining the fractures will play an important role in assessing the retardation capacity of the host rock. Understanding tuff alteration and secondary mineralization will 1) aid in interpreting the pre-emplacement groundwater chemistry and retardation properties of the fractures, and 2) provide a baseline for predicting the chemical alteration of the groundwater and host rock that may occur as the result of waste emplacement.

3.1.1.4 What are the present geochemical conditions of the groundwater in the host rock of the saturated/unsaturated zone?

Geochemical conditions, in particular temperature, pressure, pH, redox conditions, ionic strength, and presence of complexing ligands, determine which chemical species of radionuclides are most likely to form and determine what reactions are likely to occur. Reactions of radionuclides in solution with components of the backfill, seals, and packing, and the disturbed zone and far field host rock, including adsorption and precipitation, will determine the limiting concentrations of soluble species. Present conditions will be necessary for determining conditions in the far field, and will serve as a baseline for predicting changes resulting from increased temperature and pressure in the nearfield.

3.1.2 What is the mineralogy/petrology/chemistry of the backfill/seals/packing to be emplaced?

Backfill, seals and packing, as discussed here, refer to materials used to fill shafts, tunnels, and disposal rooms. The large man-made cavities, including fracturing around these cavities, represent broad and potentially short pathways to the accessible environment for radionuclides released from the waste package. The pathways should be blocked with engineered barriers that promote geochemical retardation of radionuclide migration to the accessible environment. The mineralogy/petrology/chemistry of the backfill, seals, and packing will influence their abilities to seal these cavities and prevent water ingression and radionuclide migration.

3.2 WHAT ARE THE CHANGES IN THE GEOCHEMICAL CONDITIONS/PROCESSES AS THE RESULT OF WASTE EMPLACEMENT?

The geochemical conditions/properties of the tuff surrounding the repository will be affected by construction of the underground facility and the emplacement of nuclear waste. Construction and increased temperatures in the vicinity of the repository may alter the properties of the tuff to the extent that water is more/less accessible to the waste package and backfill (performance issues 3, 4), affecting the release and transport of radionuclides to the accessible environment (performance issues 8, 9, 10). It is important to address the geochemical changes in both the saturated and unsaturated zones since the presence of water often has significant effects on the resulting conditions/processes.

3.2.1 What are the changes in the geochemical conditions of the geologic setting?

Repository construction and waste emplacement will cause changes in temperature, pressure, and groundwater behavior which may affect mineral assemblages and their ability to act as barriers for waste isolation. Therefore, information on the geochemical conditions following waste emplacement is needed to determine the ability of the repository to contain waste.

3.2.1.1 What are the changes in the conditions of temperature and pressure in the host rock, in the saturated/unsaturated zone?

The magnitudes of thermal and pressure gradients over time and space must be determined to understand the possibility of thermally induces stresses on the host rock. Fractures may occur which could alter the present conditions of groundwater flow through the geologic setting. These parameters also significantly affect mineral alterations and groundwater chemistry, and must be understood for prediction of changes in mineralogy and groundwater chemistry.

3.2.1.2 What are the changes in the mineralogy/petrology/chemistry of the host rock in the saturated/unsaturated zone?

Mineral assemblages may be affected by repository construction and changes induced by waste emplacement. Many minerals exist in metastable states and the changes in temperature, pressure, water chemistry, and/or degree of saturation may affect the stability of the minerals in a rock. These changes can influence the sorptive behavior of the host rock, its groundwater flow paths and the physical stability of the repository.

3.2.1.2.1 How are the mineral assemblages of the Yucca Mountain tuffs affected by anticipated changes in the temperature and pressure?

Many minerals exist in metastable states and the change of temperature, pressure and/or degree of saturation may alter the stability of the minerals in a rock. The alteration products, although often pseudomorphic after the original minerals, generally have different physical/chemical properties, which can affect the initial retardation capacity of the host rock. The effects will depend on the amount and chemistry of water present, and may vary significantly between the saturated and unsaturated zones.

3.2.1.2.2 What is the anticipated spatial distribution of alteration products due to increased temperatures and altered fluid flow paths?

As temperatures of the backfill and disturbed zone/far field host rock increase with time, minerals and ionic species in solution will change in an attempt to re-equilibrate with the new conditions. Minerals may dissolve or precipitate thereby altering the mineral distribution along the flow paths. The resultant changes will depend on temperature, groundwater conditions and fluid flow regimes (i.e. diffusion/convection and/or fracture flow). Precipitation of minerals may in turn alter the fluid flow path, and ultimately the migration of radionuclides to the accessible environment.

3.2.1.3 What are the changes in the geochemical conditions of the groundwater due to increased temperature and radiolysis within the saturated/unsaturated zone?

Geochemical conditions, in particular temperature, pressure, pH, redox conditions, ionic strength, and the presence of complexing ligands, determine which chemical species of radionuclides are most likely to form and determine what reactions are likely to occur. Reactions of radionuclides in solution with the existing components of the disturbed zone and far field host rock, including adsorption and precipitation, will determine the limiting concentrations of soluble species. Changes in temperature and pressure alter the geochemical conditions of the groundwater which determine the mineral stabilities and may affect radionuclide migration. An assessment of the prevailing geochemical conditions following waste emplacement must be made in order to predict radionuclide migration.

3.2.1.3.1 What are the changes in the rock/groundwater ratio in the host rock of the saturated/unsaturated zone?

The mineral stability will depend on the amount of water present in the disturbed zone and far field. The degree of induced mineral alteration may vary significantly between the saturated and unsaturated zones. Perched water tables or zones of increased saturation (due to heating and cooling effects) immediately surrounding the repository may generate mineral zonations that could have a significant effect on the performance of the repository with regard to radionuclide migration.

3.2.1.3.2 How will the various fluid flow regimes in the saturated/unsaturated zone affect the geochemical conditions of the groundwater due to the potential non-equilibrium conditions between the host rock and groundwater?

Chemical equilibrium in rock/water interactions is generally assumed in saturated media where fluid velocities are sufficiently slow to allow equilibration of the rock and water. In the unsaturated zone, it is possible for water to be transported by pulses of fracture flow, porous media flow, and/or by matrix diffusion. The velocity could vary according to the flow regime. If water passes quickly through the rock, there may not be sufficient time for equilibration of the groundwater, which could substantially affect the anticipated geochemical conditions or composition of the groundwater after waste emplacement. Reaction kinetics become important under these conditions and should be carefully considered.

3.2.2 What are the changes in the geochemical conditions of the backfill/seals/packing as a result of waste emplacement under saturated/unsaturated conditions?

Backfill, seals, and packing will be affected by physical changes induced by waste emplacement, such as changes in temperature, pressure, and degree of saturation. Changes in backfill, seals, and packing mineralogy/petrology/chemistry may affect its stability and its ability to retard radionuclides by sorption or ion exchange.

3.2.2.1 What are the changes in the conditions of temperature and pressure in the backfill/seals/packing?

The magnitudes of thermal and pressure gradients over time and space must be determined to understand the possibility of thermally induced stresses on the backfill. Fractures may occur which could alter the present conditions of groundwater flow through the geologic setting. These parameters also significantly affect mineral alterations and groundwater chemistry, and must be understood for prediction of changes in mineralogy and groundwater chemistry.

3.2.2.2 What are the changes in the mineralogy/petrology/chemistry of the backfill/packing/seals as the result of waste emplacement?

Mineral assemblages may be affected by changes induced by waste emplacement. Many minerals exist in metastable states and the changes in temperature, pressure, water chemistry, and/or degree of saturation may affect the stability of the minerals in the backfill, packing, and seals. These changes can influence the sorptive behavior of the backfill, packing, and seals and their groundwater flow paths.

3.2.2.2.1 How are the mineral assemblages of the backfill/seals/packing affected by anticipated changes in temper ure and pressure?

Many minerals exist in metastable states and the change of temperature, pressure and/or degree of saturation may alter the stability of the minerals in the backfill, seals, and packing. The alteration products, although often pseudomorphic after the original minerals, generally have different physical/chemical properties, which can affect the initial retardation capacity of the backfill. The effects will depend on the amount and chemistry of water present, and may vary significantly depending on degree of saturation.

3.2.2.2.2 What is the anticipated spatial distribution of alternation products due to increased temperatures and altered fluid flow paths?

As temperatures of the backfill increase with time, minerals and ionic species in solution will change in an attempt to re-equilibrate with the new conditions. Minerals may dissolve or precipitate thereby altering the mineral distribution along the flow paths. The resultant changes will depend on temperature, groundwater conditions and fluid flow regimes (i.e. diffusion/convection and/or fracture flow). Precipitation of minerals may in turn alter the fluid flow path, and ultimately the migration of radionuclides to the accessible environment.

3.2.2.3 What are the changes in the geochemcial conditions of the groundwater entering the backfill/seals/packing due to increased temperature and radiolysis within the saturated/unsaturated zone?

Geochemical conditions, in particular temperature, pressure, pH, redox conditions, ionic strength, and the presence of complexing ligands, determine which chemical species of radionuclides are most likely to form and determine what reactions are likely to occur. Reactions of radionuclides in solution with the existing components of the backfill/seals/packing including adsorption and precipitation, will determine the limiting concentrations of soluble species. Changes in temperature and pressure alter the geochemical conditions of the groundwater which determine the mineral stabilities and may affect radionuclide migration. An assessment of the prevailing geochemical conditions following waste emplacement must be made in order to predict radionuclide migration.

3.2.2.3.1 What are the changes in the rock/groundwater ratio in the backfill/seals/packing in the saturated/unsaturated zone?

The mineral stability will depend on the amount of water present in the backfill, seals, and packing. The degree of induced mineral alteration may vary significantly between the saturated and unsaturated zones. Perched water tables or zones of increased saturation (due to heating and cooling effects) immediately surrounding the repository may generate mineral zonations that could have a significant effect on the performance of the repository with regard to radionuclide migration.

3.2.2.3.2 How will the various fluid flow regimes in the saturated/unsaturated zone affect the geochemical conditions of the groundwater in the backfill/seals/packing due to the potential non-equilibrium conditions between the backfill/seals/packing and groundwater?

Chemical equilibrium in rock/water interactions is generally assumed in saturated media where fluid velocities are sufficiently slow to allow equilibration of backfill, seals, and packing and water. In the unsaturated zone, it is possible for water to be transported by pulses of fracture flow, porous media flow, and/or by matrix diffusion. The velocity could vary according to the flow regime. If water passes quickly through the backfill, seals, and packing, there may not be sufficient time for equilibration of the groundwater, which could substantially affect the anticipated geochemical conditions or composition of the groundwater after waste emplacement. Reaction kinetics become important under these conditions and should be carefully considered.

3.3 WHAT ARE THE FUTURE GEOCHEMICAL PROCESSES/CONDITIONS THAT WILL AFFECT RELEASE AND TRANSPORT OF RADIONUCLIDES TO THE ACCESSIBLE ENVIRONMENT?

Geochemical processes, and conditions at the waste package surface, in the backfill, seals, and packing the disturbed zone and the far field will profoundly affect the release and transport of radionuclides from the repository to the accessible environment (performance issues 6 through 10). Release involves waste package degradation and solubilization of the radionuclides in the waste form. Transport involves mechanical and chemical processes which promote or inhibit radionuclide migration from the repository to the accessible environment. During release and transport, radionuclides will react with the groundwater, the waste container, the backfill, seals, packing and surrounding rocks. The nature of these reactions will determine the significance and extent of the migration of each radionuclide in the waste form.

An understanding of the processes in both the saturated and unsaturated zones is critical since the possibility of radionuclide transport through both zones exists. Conditions and processes may differ significantly in the two zones, even though the same rock type and structures may exist in both zones. The presence or absence of a water saturated rock may significantly alter the geochemical conditions/processes in addition to the changes resulting from potentially different transport mechanisms in each zone.

Geochemical conditions may vary depending on the fluid transport regime within the unsaturated zone if the groundwater is not in equilibrium with the host rock. If fractured media flow is the prevalent means of fluid flow in the unsaturated zone, then kinetics of geochemical processes may become more important than equilibrium processes. Based on the kinetics, certain reactions and/or processes may become insignificant in providing a means of radionuclide retardation. If matrix diffusion or porous media flow is the most likely means of fluid flow, then equilibrium processes will be important. These issues must be addressed prior to evaluation of the sub-issues, in determining the rates of release of radionuclides to the accessible environment.

3.3.1 How does the solubility/concentration of radionuclides under various flow regimes affect radionuclide release and transport?

The release rates and concentrations of waste radionuclides in solution may be determined to a significant extent by their solubilities. Dissolution of radionuclides from the waste form is controlled by the physical characteristics of the waste form (e.g., structure and surface area); chemical and radiolytic properties of the waste form; composition, redox conditions and pH of water; and temperature and pressure. In order to determine the concentrations of radionuclides in the disturbed zone and the far field (under different geochemical conditions) through time, their solubilities need to be determined.

The concentration of the released radionuclides in the groundwater may vary with differing flow regimes. The solubility of the radionuclides will affect the migration to the accessible environment. The effects of speciation and precipitation on the transport of radionuclides should be carefully assessed.

3.3.1.1 How does precipitation/co-precipitation affect radionuclide concentration?

Under va[illegible]ing conditions, radionuclides in solution may precipitate in the presence of certain inorganic ligands (e.g., carbonate, hydroxyl, sulfide). Parameters controlling precipitation include groundwater composition, rock composition, redox conditions, and pH. Certain radionuclides may co-precipitate by substitution with non-radioactive species such as iron.

3.3.1.2 How does speciation affect radionuclide solubility/concentration?

The identities and solubilities of the solid phases and indentities of the solution species likely to form under geologic conditions are needed to determine solution concentrations of radionuclides in a repository groundwater system. Different species of the same element will remain in solution in different concentrations and migrate at different rates.

3.3.1.3 How do colloids /particulates/organics affect radionuclide solubility/concentration?

Some radionuclides, especially hydrolyzable ones, may readily form colloids or pseudocolloids under certain geochemical conditions. These colloids may result from interactions with the waste package, backfill, seals, and packing, or host rock. The formation of colloidal species may affect the concentrations and thus the migration of radionuclides in solution.

3.3.2 How does backfill/seals/packing/disturbed zone/far field mineralogy under various flow regimes influence radionuclide migration/retardartion?

The mineralogy of the backfill, seals, packing, and the disturbed zone/far field may play a key role in the retardation of the radionuclides if highly sorptive minerals are present. A good estimate of the location, volume and accessibility of minerals along the likely flow paths is necessary to assess the effect of mineralogy on the radionuclide migration/retardation. Sorption kinetics must be addressed if radionuclide transport occurs in such a way that equilibrium conditions cannot be assumed.

3.3.3 What is the importance of reaction and sorption kinetics on radionuclide release and transport in the disturbed zone/far field under various flow regimes?

The occurrence of reactions is predicted by chemical equilibrium. However, reaction rates are generally not instantaneous as predicted by equilibrium, but kinetically controlled (time dependent). An understanding of kinetic effects would help in predicting reaction rates and the steady state conditions expected in the repository system.

3.3.4 How do redox conditions of the groundwater and redox buffering potential of the minerals affect radionuclide speciation/migration/retardation?

Radionuclide retardation is a key factor in controlling the release of radionuclides to the accessible environment. Radionuclide retardation is dependent on the radionuclide speciation and the redox conditions/buffering potential of the groundwater and the minerals in the host rock/backfill/seals/packing. Knowledge of the redox conditions/buffering potential of the Fe-Ti oxides and sulfides are necessary to determine the processes and geochemical conditions that will affect the release of radionuclides.

3.3.5 How does gamma and alpha radiolysis affect radionuclide release and transport?

Gamma and alpha radiolysis products may affect the redox conditions of the backfill/seals/packing and disturbed zone/far field host rock by causing generation of hydrogen, oxygen, and other species that will affect anticipated reactions. These conditions may influence radionuclide speciation and transport.

3.3.6 How do colloids/particulates under various flow regimes affect radionuclide migration/retardation in the disturbed zone/far field?

If the transport pathways involve relatively large openings, geochemical conditions leading to the formation and geochemical stability of colloids and fine particulates may become very important to the prediction of rates of transport of radionuclides. The formation of radionuclide bearing colloids and particulates may enhance the migration of radionuclides to the accessible environment under certain fluid flow regimes. It is necessary to address the likelihood of colloid/particulate formation and transport in the backfill and disturbed zone/far field host rocks. The issue of radionuclide transport by organics or microbes as well as their modification of baseline transport parameters must be addressed.

3.3.7 How do organics/microbes affect redionuclide migration/retardation under various flow regimes in the disturbed zone/far field?

Organics and microbes may be introduced into a repository during construction by contamination from the surface or from the host rock itself. Radionuclide-organic complexes can have different migration behaviors than inorganic complexes, and some organic radionuclide complexes are known to migrate at significantly greater rates than predicted by laboratory measurements. The presence of certain microbes can affect the reactions that occur and reaction rates. Microbes may be especially important in redox reactions. The likelihood of significant amounts of organics or microbes being present for reacting with radionuclides and influencing their migration behavior should be addressed.

3.3.8 How does matrix diffusion affect radionuclide migration/retardation in the disturbed zone/far field?

Diffusion of radionuclides through the host rock matrix is one possible geochemical process of radionuclide retardation. The likelihood of fluid movement via matrix diffusion and the relative importance as a radionuclide retardation mechanism must be addressed.

3.3.9 How does vapor/aerosol transport affect radionuclide migration/retardation in the disturbed zone/far field?

Spent fuel may contain radionuclides in gaseous phases that could be transported to the accessible environment via fractures or inter-connected pore spaces in the unsaturated zone. Aerosols may be formed due to the drying-wetting effect in the disturbed zone, which may promote transport of soluble radionuclides in a vapor phase. These processes should be understood to assess the role of vapor transport in radionuclide migration.