SITE TECHNICAL POSITION

Hydrology Issues For The Nevada Nuclear Waste Storage Investigations Project

NNWSI STP-1.0

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Background

In review of a license application for a high-level waste geologic repository, the NRC staff is required to determine whether the site and design meet the Technical Criteria (Subpart E) of 10 CFR Part 60. The NRC staff determination will be based on the answers to, and supporting analyses of, technical questions concerning hydrology, geochemical retardation, waste form and 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 (The Act) has established a schedule for site characterization and selection. Specifically, the Act requires publication of Site Characterization Plans (SCP's) 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 site technical position papers will precede and supplement the SCA's.

Because of the complexity and long lead times for site characterization investigations, it is essential that activities be organized to make possible an NRC determination of site acceptability. Proper organization necessitates early identification of technical questions (issues) relevant to the specific site. Therefore, this document establishes the NRC position as to the essential issues relevant to hydrology for the Nevada Nuclear Waste Storage Investigations (NNWSI) Project. Future Site Technical Positions (STP's) and other NRC documents relevant to hydrology will address NRC staff concerns regarding selected issues and acceptable technical approaches for addressing those 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 the special meanings described in the following paragraphs.

A Site Issue is a question about a specific site that must be addressed and resolved to complete the licensing assessment of site and/or design suitability in terms of 10 CFR Part 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 overall geologic repository system. A set of performance issues are derived directly from performance objectives in 10 CFR Part 60.

Significant Conditions and Processes (includes potential adverse conditions of 10 CFR Part 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 bouyancy), or 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 Part 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 Part 20?

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 farfield to the accessible environment?

11. What is the pre-waste emplacement groundwater travel time along the fastest path of radionuclide travel from the disturbed zone to the accessible environment?

12. Have the NEPA Environmental/Institutional/Siting requirements for nuclear facilities been met?

While these performance issues were developed originally for the Basalt Waste Isolation Project (BWIP), upon examination the staff considers them applicable equally to the NNWSI project.

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 staffs' 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 developing this STP. Questions about the significant conditions and processes as they pertain to hydrology constitute the site issues identified in this position.

Information on the hydrologic system collected during site characterization at NNWSI will be part of the total repository system information needs of the NRC staff required to assess the performance issues. Issues identified in the following section delineate information on the hydrology of NNWSI 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.

Technical Position

It is the position of the NRC staff that based on our current level of knowledge of the NNWSI project, assessment of the Technical Criteria of 10 CFR Part 60 in terms of the performance issues requires that, at a minimum, the following issues concerning hydrology be addressed.

1.0 Hydrology

1.1 What is the nature of the present groundwater system?

1.1.1 What is (are) the conceptual model(s) of the present groundwater system of the geologic setting?

1.1.1.1 What are the hydrogeologic limits of the groundwater system (boundaries, boundary conditions as well as recharge and discharge locations, and mechanisms and amounts of recharge) of the geologic setting that are significant to estimating the hydrogeologic conditions surrounding Yucca Mountain?

1.1.1.2 What are the distributions of measured and interpolated hydrogeologic parameters?

1.1.2 What is (are) the conceptual model(s) of the present Yucca Mountain groundwater system (including both the far-field and disturbed zone)?

1.1.2.1 What are the hydrogeologic limits of the Yucca Mountain groundwater system that are significant to repository performance?

1.1.2.2 What are the recharge and discharge locations, mechanisms, and amounts for the Yucca Mountain groundwater system?

1.1.2.3 What is the hydrochemistry of the Yucca Mountain groundwater system?

1.1.2.4 What is the relationship between the Yucca Mountain groundwater system and any deeper, regional system?

1.1.2.5 What are the hydrogeologic units within that portion of the Yucca Mountain groundwater system that constitutes the unsaturated zone?

1.1.2.5.1 What are the hydrogeologic processes and important hydrogeologic parameters in the unsaturated zone?

1.1.2.5.2 What is the three-dimensional distribution of both measured and interpolated hydrogeologic parameters in the unsaturated zone?

1.1.2.5.3 How and to what extent is groundwater flow in the unsaturated zone affected by structural, hydro-stratigraphic and lithologic heterogeneities?

1.1.2.6 What are the hydrogeologic units within that portion of the Yucca Mountain groundwater system that constitutes the saturated zone?

1.1.2.6.1 What are the hydrogeologic processes and important hydrogeologic parameters in the saturated zone?

1.1.2.6.2 What is the three-dimensional distribution of both measured and interpolated hydrogeologic parameters in the saturated zone?

1.1.2.6.3 How and to what extent is groundwater flow in the saturated zone affected by structural, hydrostrat-igraphic, and lithologic heterogeneities?

1.1.3 What mathematical models are used to predict groundwater flow?

1.2 What is the nature of the present surface water system?

1.2.1 What are the physical characteristics of the surface water system at Yucca Mountain?

1.2.2 What is the potential for flooding within the controlled area at Yucca Mountain?

1.3 What are the types, probabilities, and nature of natural changes that would affect groundwater flow?

1.3.1 What are the types, probabilities, and nature of climatic changes that would affect groundwater flow?

1.4 What are the types, probabilities, and nature of human-induced changes (excepting repository-induced changes) that would affect groundwater flow?

1.4.1 How does the value of water resources in the area compare with values in other surrounding areas of similar size, and what is the potential for future use?

1.4.2 What are the types, probabilities and nature of water resource development and use that would affect groundwater flow?

1.5 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from natural changes?

1.5.1 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from climatic changes?

1.5.2 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from geologic changes?

1.6 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from human-induced changes, excepting repository-induced changes?

1.6.1 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from water resource development?

1.7 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from repository-induced changes?

1.7.1 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from mechanically-induced changes?

1.7.2 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from thermally-induced changes?

Discussion

The rationale for each issue is described in the subsequent 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 (logic tree) are related directly to the performance issues that are listed in the background section above. Other issues are related by technical argument to the issue(s) directly above in the logic tree.

1.1 What is the nature of the present groundwater system?

Groundwater is the primary transporting agent for radionuclide migration from a geologic, high-level waste repository. Accordingly, knowledge of the components of the groundwater system will be necessary for complete evaluation of all performance issues. For example, the potential for inflow of groundwater into the underground facility during the operational phase likely will be a consideration in evaluating Performance Issues 1 and 2. In the context of longer term performance, Performance Issues 3 through 5 relate directly to inflow of groundwater into the underground facility while Performance Issues 6 through 10 relate directly to release of radionuclides from the underground facility via the groundwater pathway (this does not necessarily assume groundwater is the only release pathway). Performance Issue 11 is based on a requirement for site suitability; that the pre-waste emplacement groundwater travel time along the fastest path of radionuclide travel to the accessible environment be greater than 1,000 years. Finally, potential impacts of the repository on the present groundwater system will likely be a consideration in evaluating Performance Issue 12. Evaluation of these Performance Issues depend on an understanding of the components of the groundwater system which are identified, relative to varying levels of scale and detail, in the following issues.

1.1.1 What is (are) the conceptual model(s) of the present groundwater system of the geologic setting?

The conceptual model of the groundwater system of the geologic setting, which includes Yucca Mountain, provides the hydrogeologic framework for interpreting the distribution of recharge and discharge areas, general order of magnitude regional flux, and general configuration of the groundwater flow system. It also provides a basis for quantitative, deterministic models of all or portions of the groundwater flow system of which Yucca Mountain is a part.

1.1.1.1 What are the hydrogeologic limits of the groundwater system (boundaries, boundary conditions, as well as recharge and discharge locations, and mechanisms and amounts of recharge) of the geologic setting that are significant to estimating the hydrogeologic conditions surrounding Yucca Mountain?

This is the information necessary to estimate the mass balance of the groundwater system of the geologic setting as well as to establish the general characteristics of groundwater flow into and out of the Yucca Mountain area.

1.1.1.2 What are the distributions of measured and interpolated hydrogeologic parameters?

Flow paths and flow rates are in part a function of the hydraulic properties of an aquifer. The distribution of measured and interpolated hydraulic properties reflect the heterogeneities of the groundwater system. Consequently, these properties will determine to a large extent flow paths and travel times. Measured values are generally more reliable than values obtained indirectly but it is impossible to measure hydrogeologic parameters everywhere, therefore interpolated values or values obtained indirectly from models also must be used in some calculations. An areal description of hydraulic head is necessary to establish hydraulic gradients used in travel time calculations. Hydraulic heads will be used as initial conditions in any quantitative modeling process.

1.1.2 What is (are) the conceptual model(s) of the present Yucca Mountain groundwater system (including both the far-field and disturbed zone)?

Conceptual models are the basis for any quantitative calculation of either groundwater travel times or radionuclide release rates from the repository to the accessible environment. Conceptual models also will serve as the basis for assessing the effect of potential, future perturbations of the groundwater system on radionuclide release rates.

Conceptual models of the Yucca Mountain area groundwater flow system are essential to the analysis of both the saturated and unsaturated zones. These conceptual models should be based on sufficient hydrogeologic data derived from the characterization of all aspects of the flow system which significantly influence pre-emplacement groundwater travel times and post-emplacement radionuclide transport from the repository to the accessible environment. Accordingly, this necessitates conceptualization of both the disturbed zone and far field. All defensible conceptual models of the groundwater flow system need to be enumerated and analyzed.

1.1.2.1 What are the hydrogeologic limits of the Yucca Mountain groundwater system that are significant to repository performance?

Both the unsaturated and saturated environments in Yucca Mountain are expected to have dynamic flow systems. The extent of the flow system within which is included all plausible flow paths from the repository to the accessible environment should be defined. Hydrogeologic conditions both within the flow system and at any boundaries defined when quantifying conceptual models should be determined accurately because these conditions are critical to the calculations of groundwater travel times and transport rate of radionuclides.

1.1.2.2 What are the recharge and discharge locations, mechanisms, and amounts for the Yucca Mountain groundwater system?

The temporal and spatial distribution and rate of recharge to and discharge from the groundwater flow system within Yucca Mountain controls, to a large extent, the flux of groundwater in both the unsaturated and saturated zones. The analysis of groundwater flux helps to define the expectable repository impacts because the flux determines the travel time to the accessible environment.

1.1.2.3 What is the hydrochemistry of the Yucca Mountain groundwater system?

In the potentially complex hydrogeologic terrain of Yucca Mountain, delineations of flow paths, travel times, and sources of moisture may be facilitated or supported by the hydrochemistry of the flow systems within both the saturated and unsaturated zones. Valid conceptual models should depend on the interpretation of hydrochemistry and hydrogeology. However, hydrochemical data alone are insufficient as the basis for understanding a flow system.

Hydrochemical data are required also for radionuclide transport considerations. Dissolved ion interactions are important to dissolution and precipitation of radionuclides. Geochemical issues are identified in NNWSI Site Technical Position 3.0, "Geochemistry Issues for the Nevada Nuclear Waste Storage Investigations Project."

1.1.2.4 What is the relationship between the Yucca Mountain groundwater system and any deeper, regional system?

The identification of all existing groundwater systems is important to an evaluation of long term repository site performance. Deep carbonate rocks beneath and in the vicinity of Yucca Mountain are known to influence regional groundwater flow. Flow paths in the carbonate rock aquifer system are long;

transmissivities are relatively high, and regional discharge areas may be localized. An underlying carbonate aquifer, if present, may constitute the most rapid flow path to the accessible environment.

1.1.2.5 What are the hydrogeologic units within that portion of the Yucca Mountain groundwater system that constitutes the unsaturated zone?

In general, the Yucca Mountain groundwater system can be divided into two distinct zones separated by a water table, although this distinction will become more complex if zones of perched water are proven to occur in significant amounts. The unsaturated zone, above the water table, requires a separate evaluation in which emphasis is placed on characterizing those properties which are most important to its conceptualization. Further division of the unsaturated zone into specific hydrogeologic units is necessary to provide a more detailed and accurate picture of the flow system and to permit interpolation of measured data. Those hydrogeologic units susceptible to perched water conditions should be identified. The relationships between hydrogeologic units are fundamental to determining repository performance.

1.1.2.5.1 What are the hydrogeologic processes and important hydrogeologic parameters in the unsaturated zone?

Groundwater flow rates are a function of the hydraulic properties of, and processes occurring within, the aquifer. Our ability to analyze groundwater movement in deep unsaturated zones is not as sophisticated as our ability to analyze saturated flow. Thus, it is necessary to identify thoroughly the important physical processes to be incorporated in the conceptual model of the unsaturated zone. Hydrogeologic parameters relevant to these processes should then be identified and measured for each hydrogeologic unit in which they are important.

1.1.2.5.2 What is the three-dimensional distribution of both measured and interpolated hydrogeologic parameters in the unsaturated zone?

The distribution of measured hydrogeologic parameters in the unsaturated zone will play an important role in determining the reliability (uncertainty) of analyses of groundwater flow paths and travel times. Such considerations are important in the structurally and lithologically heterogeneous fractured terrain of the Yucca Mountain area.

1.1.2.5.3 How and to what extent is groundwater flow in the unsaturated zone affected by structural, hydrostratigraphic, and lithologic heterogeneities

The extent or degree of control of groundwater flow rates and directions by structural, hydrostratigraphic, and lithologic heterogeneities influences the confidence, or lack thereof, in demonstrated flow paths and travel times based on a given set of measured data. It is important to determine the presence or absence of fractures within the unsaturated zone. Where they are present, their hydraulic function needs to be understood and evaluated. It is important also to determine the presence or absence of zones of perched water and if present, delineate the extent of such zones. This specific issue, in concert with Issue 1.1.2.5.2, relates directly to identifying representative elemental volumes of fractured rock wherein similar values of effective porosity and unsaturated hydraulic conductivity should be expected.

1.1.2.6 What are the hydrogeologic units within that portion of the Yucca Mountain groundwater system that constitutes the saturated zone?

As stated previously, the Yucca Mountain groundwater system can be divided generally into two distinct zones separated by a water table. The saturated zone, below the water table, requires a separate evaluation so that emphasis may be placed on characterizing those properties which are most important to its conceptualization. Further division of the zone into specific hydrogeologic units is necessary to provide a more detailed and accurate picture of the flow system and to permit interpolation of measured data.

1.1.2.6.1 What are the hydrogeologic processes and important hydrogeologic parameters in the saturated zone?

The need for this type of information pertaining to the unsaturated zone was discussed previously under Issue 1.1.2.5.1. Although the movement of water is driven by the same physical forces (e.g., energy gradients) whether in a saturated or unsaturated environment, there are basic differences in the nature of hydrogeologic parameters which define water flow. The methods and techniques used to characterize these parameters in the two zones also differ. For example, in the unsaturated zone hydraulic conductivity is not constant with respect to moisture content. Therefore, development of an understanding of relationships between the hydrogeologic processes and related hydrogeologic parameters is fundamental to determination of site safety and evaluation of performance issues.

1.1.2.6.2 What is the three-dimensional distribution of both measured and interpolated hydrogeologic parameters in the saturated zone?

The three-dimensional distribution of measured hydrogeologic parameters in the saturated zone will play an important role in determining the reliability (uncertainty) of analyses of groundwater flow paths and travel times because the distribution of measured parameters will determine essentially the geometry of flow paths and travel times as predicted by quantitative models. The distribution of data will be important in the structurally and lithologically heterogeneous, fractured terrain of the Yucca Mountain area. Interpolated values, if judged to be reliable, can be useful in supplementing field data.

In addition, the three-dimensional distribution of measured hydraulic head is important not only in establishing hydraulic gradients necessary for travel time calculations but in establishing the characteristics of vertical flow. Hydraulic head distribution is necessary in any quantitative modeling process.

1.1.2.6.3 How and to what extent is groundwater flow in the saturated zone affected by structural, hydrostratigraphic, and lithologic heterogeneities?

Heterogeneities of lithology, structure, or more generally, hydrostratigraphy are potentially the most important factors governing the groundwater flow rates and directions in the saturated zone of the Yucca Mountain area. The extent to which the saturated zone is heterogeneous will determine the confidence in deterministic model flow paths and travel times for a given distribution and density of field data. This issue, in conjunction with Issue 1.1.2.6.2, influences the definition of representative elemental volumes of fractured rock which display similar hydrogeologic characteristics.

1.1.3 What mathematical model(s) are used to predict groundwater flow?

Mathematical models serve two purposes: First, they quantify conceptual models of groundwater flow and they verify compatibility of conceptual models with field measurements. Second, they can predict the future migration rate of radionuclides. It is necessary to show that the mathematical model(s) used are applicable to the site (representative of the physics of the hydrogeological processes being described). For example, some processes which will need to be considered in mathematical models relative to NNWSI include saturated flow, unsaturated flow, fracture flow, multi-phase flow and heat flow. In addition, mathematical models will be applied at varying scales to evaluate repository system and subsystem performance in relation to the performance issues. Mathematical models frequently are embodied in computer codes.

1.2 What is the nature of the present surface water system?

Performance Issues 1 and 2 relate design criteria and conceptual design of the geologic repository to: a. Releases of radioactive materials to unrestricted areas (within limits specified in 10 CFR Part 20); and b. The retrievability option. These primarily are operational considerations. An understanding of the nature of the present surface water system is essential to determine the potential for flooding of surface and underground facilities. Analysis of potential flooding resulting from the surface water system will be an important consideration in evaluating Performance Issues 1 and 2.

1.2.1 What are the physical characteristics of the surface water system at Yucca Mountain?

In general, surface runoff at Yucca Mountain drains through various washes eastward to Fortymile Canyon and westward into Crater Flat to drain eventually into the Amargosa River. The potential for flooding within the controlled area at Yucca Mountain is in part a function of the physical characteristics of the surface water drainage system. For example, specific data on drainage areas and flow patterns for various channels, channel cross sections and stage-discharge relationships are the type of information necessary to define the physical characteristics of the surface water drainage system. In addition, either occupancy within or modification of flood plains are considered relevant physical characteristics of the surface water drainage system.

1.2.2 What is the potential for flooding within the controlled area at Yucca Mountain?

Flooding within the controlled area (including surface and underground facilities) could affect isolation of the waste and will be a consideration in the evaluation of repository performance as discussed in Issue 1.2. Typically, evaluation of potential flooding includes identification of historical flood events and calculation of peak flows (including peak velocities and flood stages for flood events ranging in magnitude from a 100-year flood to a probable maximum flood). In addition, evaluation of failure of existing or planned man-made surface water impoundments needs to be included in the analysis of flooding potential.

1.3 What are the types, probabilities, and nature of natural changes that would affect groundwater flow?

Natural processes which may change site conditions in the future and that would change the existing groundwater system need to be considered in determining whether long term performance of the repository will comply with radionuclide release standards. Specifically, future effects of such natural processes on groundwater flow need to be considered in evaluating Performance Issues 3 through 10 (see Issue 1.5). Identification of the types of processes is the necessary first step. Determining probabilities of occurrence of the various types of processes identified is the next step; this step may facilitate the elimination of some processes from further consideration. The nature of these changes is the necessary base for consequence assessment.

Identified below is one particular natural process which is subject to change over time and is applicable to NNWSI (Issue 1.3.1; climate). Other natural processes which could change over time are included in the general category of geologic processes. Issues related to the types, probabilities, and nature of geologic changes are outside the scope of this Site Technical Position and are included in NNWSI Site Technical Position 5.0, "Geology Issues for the Nevada Nuclear Waste Storage Investigations Project". However, effects on the groundwater system of plausible future geologic changes will be a consideration under Issue 1.5.2 of this Site Technical Position.

1.3.1 What are the types, probabilities, and nature of climatic changes that would affect groundwater flow?

Climatic variations are known to be important natural changes that could affect groundwater flow. Changes in climate have occurred in the past over the same lengths of time in which repository performance will be assessed. Pluvial climates of the Great Basin increased the availability of moisture for runoff and associated hydrologic effects. Therefore, climatic changes which can affect groundwater flow paths, rates and radionuclide releases need to be identified, quantified, and evaluated with respect to probability of occurrence and importance. This serves as a basis for consequence assessment.

1.4 What are the types, probabilities, and nature of human-induced changes (excepting repository-induced changes) that would affect groundwater flow?

Human-induced changes that would affect groundwater flow need to be considered in assessing long term repository performance. Specifically, future effects of plausible human-induced changes on groundwater flow need to be considered in evaluating Performance Issues 3 through 10 (see Issue 1.6). Identification of the types of changes, probability of occurrence, and description of the nature of changes are necessary. If warranted based on probability of occurrence, an assessment of the effects on repository performance also is necessary. Information provided by studies addressing this issue provide the basis for consequence assessment.

1.4.1 How does the value of water resources in the area compare with values in other surrounding areas of similar size, and what is the potential for future use?

Evaluation of the value of water resources within and surrounding the Yucca Mountain area coupled with the historical development of water use and demand will provide a basis for establishing the probability and potential magnitude of future water resource development which could impact repository performance.

1.4.2 What are the types, probabilities and nature of water resource development and use that would affect groundwater flow?

Groundwater and surface water exploitation or manipulation could affect groundwater flow rates and paths. Identification of the types of water use activities that might occur as well as determination of the probabilities and nature of those water use activities provides a basis for determining necessary consequence assessments (see Issue 1.6.1).

1.5 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from natural changes?

The expected effects of plausible natural changes over time on groundwater flow paths, velocities, fluxes and discharge rates relates directly to the evaluation of Performance Issues 3 through 10.

1.5.1 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from climatic changes?

Pluvial climates of the Great Basin increased the availability of moisture for runoff and associated hydrologic effects. Therefore, the effects of such climatic changes on the groundwater system need to be evaluated with respect to Performance Issues 3 through 10.

1.5.2 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from geologic changes?

As stated previously under Issue 1.3, issues related to the types, probabilities, and nature of changes in geologic processes which could affect repository performance are discussed in NNWSI Site Technical Position 5.0, "Geology Issues for the Nevada Nuclear Waste Storage Investigations Project". In general, geologic processes which may affect the groundwater system include regional tectonic movements and associated local faults, folds and fractures. Evaluation of future effects on the groundwater system resulting from plausible geologic changes will be a consideration in evaluating Performance Issues 3 through 10.

1.6 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from human-induced changes, excepting repository-induced changes?

The expected effects of plausible, human-induced changes over time on groundwater flow paths, velocities, fluxes and discharge rates relate directly to the evaluation of Performance Issues 3 through 10.

1.6.1 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from water resource development?

Groundwater and/or surface water exploitation or manipulation, whether for human, industrial or agricultural use, could affect groundwater flow rates and paths. For example, given that the repository horizon at Yucca Mountain will be in the unsaturated zone the effect of any large-scale groundwater withdrawals likely would be evaluated in relation to Performance Issue 10. However, construction of any near-by surface impoundments, if deemed plausible, would need to be evaluated in relation to the effect on groundwater flow into, within, and out of the disturbed zone (Performance Issues 3 through 9).

1.7 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from repository-induced changes?

During the process of developing the repository, physical changes will be made in the repository block. In addition, during and after waste emplacement, thermal effects will begin to affect the moisture regime of the repository environment. For example, the environment of the repository (fractured tuffs in the unsaturated zone) creates the potential for moisture migration in both liquid and vapor phases along fractures, faults or other pathways of preferential permeability. The thermal effects may create physical environments in which some minerals become unstable. Considerations such as these should be assessed with respect to the effect on repository performance. Specifically, future effects on groundwater flow into, within, and out of the disturbed zone resulting from repository-induced changes need to be considered in evaluating both operational (Performance Issues 1 and 2) and long-term performance (Performance Issues 3 through 10).

1.7.1 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from mechanically-induced changes?

During construction of shafts and the underground facility physical changes will be made in the host rock. The effect of construction on fractures, faults or other pathways of preferential permeability and resulting effects on groundwater flow into, within, and out of the disturbed zone should be assessed with respect to operational and long-term repository performance.

1.7.2 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from thermally-induced changes?

During and after waste emplacement heat generated by the waste will begin to affect the moisture regime of the repository environment. Thus, the potential for multi-phase moisture migration along pathways of preferential permeability is created. The effect of this thermal load on moisture movement into, within, and out of the disturbed zone should be assessed with respect to operational and long-term repository performance. It should be noted that the thermal loading is anticipated to decay with time and is not likely to be a factor during the full period of performance of the repository system.