

COMPLIANCE DETERMINATION STRATEGY

RRT 3.2.3.1 FAVORABLE CONDITION: NATURE AND RATES OF GEOCHEMICAL PROCESSES

APPLICABLE REGULATORY REQUIREMENTS:

10 CFR 60.122(b)(1)
10 CFR 60.21(c)(1)(ii)(B)
10 CFR 60.21(c)(1)(ii)(F)
10 CFR 60.31(a)(1)(i)
10 CFR 60.31(a)(2)

TYPES OF REVIEW:

Acceptance Review (Type 1)
Safety Review (Type 3)
Detailed Safety Review Supported by Independent Tests, Analyses, or Other Investigations (Type 5)

RATIONALE FOR TYPES OF REVIEW:

Acceptance Review (Type 1) Rationale:

This regulatory requirement topic (RRT) is license application-related because, as specified in the license application content requirements of 10 CFR 60.21(c) and in the regulatory guide of the U.S. Nuclear Regulatory Commission (NRC) on "Format and Content for the License Application for the High-Level Waste Repository" (FCRG), it must be addressed by the U.S. Department of Energy (DOE) in its license application. Therefore, the staff will conduct an acceptance review of the license application for this regulatory requirement topic.

Safety Review (Type 3) Rationale:

This regulatory requirement topic is related to containment and waste isolation. It concerns the presence of natural geochemical processes operating during the Quaternary Period within the geologic setting which, when projected, are favorable conditions because they do not adversely affect the waste isolation capabilities of the site. Although the presence of a given favorable condition is not a specific requirement (see NUREG-0804, 1983, p. 151), a consideration and identification of the aggregate of favorable conditions (as identified in 10 CFR 60.122 (b)) at the site is a regulatory requirement found in 10 CFR 60.21(c)(ii)(b) for which a determination of compliance is necessary in order to make a safety determination for construction authorization as defined in 10 CFR 60.31(a) (i.e., regulatory requirements in Subparts E, G, H, and I). Therefore, the staff will conduct a Safety Review of the license application to determine compliance with this regulatory requirement topic.

The language of 10 CFR 60.122(b)(1) makes no explicit reference to repository perturbations (e.g., heating and introduction of exotic materials) affecting projected Quaternary processes. Projections are to be based on the record of geologic history and are not to include the modifying effects of an emplaced geologic repository for high-level radioactive waste. This interpretation is confirmed by statements of consideration in NUREG-0804: "[The Commission's] interest in specifying that the geologic setting shall

have an exhibited 'stability' since the start of the Quaternary Period was to assure only that the processes be such as to enable the recent history to be interpreted and to permit near-term geologic changes to be projected over the relevant time period with relatively high confidence. This concept is best applied by identifying as potentially adverse conditions, those factors which stand in the way of such interpretation and projection... ." (NRC, 1983, p. 22). Also from NUREG-0804 is: "the new definition of 'anticipated processes and events' includes the assumption that processes operating in the Quaternary Period continue to operate but with perturbations caused by the presence of emplaced radioactive waste superimposed thereon. ... What the Commission has intended was the structural, tectonic, hydrogeologic, geochemical, and geomorphic processes be such as to enable the recent history to be interpreted and to permit near-term geologic changes to be projected with relatively high confidence," (NRC, 1983, p. 53). Here the distinction between Quaternary processes and repository-induced perturbations is explicit. The latter are superimposed on the projection of the former in identifying anticipated processes and events. Projection of Quaternary processes is not intended to include repository perturbations.

With regard to this "favorable condition," performance is to be judged with respect to the favorable aspects of the nature and rates of physical processes. Potentially adverse aspects of the nature and rates of geochemical processes will be considered as "potentially adverse conditions" (10 CFR 60.122 (c)) and will be addressed in the following sections of the License Application Review Plan: 3.2.1.4, Evidence of Dissolution; 3.2.3.5, Geochemical Processes; 3.2.3.6, Not Reducing Groundwater Conditions; 3.2.3.7, Gaseous Radionuclide Movement.

A list of general geochemical processes and their likely contribution to this favorable condition is given in the following table.

Geochemical Processes Which When Projected Are Likely or Unlikely to Contribute to the Favorable Condition of Not Affecting or Favorably Affecting Waste Isolation*

| | | | | | |
|---|-----|------------------------|-----|------------------|---|
| precipitation | L | diffusion | L/U | volatilization | U |
| dissolution | U | dehydration | L/U | nucleation | L |
| sorption | L | oxidation | U | anion exclusion | U |
| desorption | U | reduction | L/U | osmosis | U |
| speciation | L/U | hydrolysis | U | melting | U |
| solution | L/U | radiolysis | U | crystallization | L |
| gelation | L/U | microbial processes | U | coprecipitation | L |
| evaporation | L | radioactive decay | L | devitrification | U |
| condensation | U | isotopic fractionation | U | ion exchange | L |
| alteration | L | metamictization | U | Ostwald ripening | U |
| flocculation | L | catalysis | U | corrosion | U |
| expansion | U | contraction | U | filtration | L |
| *L = process is <u>likely</u> to contribute to the favorable condition U = process is <u>unlikely</u> to contribute to favorable condition L/U = contribution of process to the favorable condition depends on circumstances (see text) | | | | | |

This list of processes is generalized and is not exhaustive. Processes rated to be likely to contribute to the favorable condition have reasonably occurred in the Quaternary, and the projection of the nature and rates of these processes to the future would likely have no effect or favorably affect waste isolation at the site. Geochemical processes rated unlikely to contribute to the favorable condition were not significant in the Quaternary or are likely to have potentially adverse impacts on radionuclide isolation. Processes rated L/U are likely to contribute to isolation either favorably, unfavorably, or not at all under different scenarios or for different aspects of performance, or their likely role in repository isolation is uncertain.

An examination of the geochemical system in the region of Yucca Mountain indicates that under natural conditions during the Quaternary, geochemical processes have been slow, and mostly undramatic. The specific processes identified in the above table are manifested by several, more general, larger-scale processes. Larger-scale processes of significance that can be identified from the geologic record at Yucca Mountain and that are likely to have occurred during the Quaternary include:

- soil zone processes such as soil formation, caliche formation, generation of CO₂ and organic acids and colloids (Quade et al., 1989);
- variations in vadose-zone water chemistry due to episodes of drying and recharge;
- dissolution of volcanic glass in recharging water and generation of a dilute, silica-rich sodium-bicarbonate solution (White et al., 1980);
- transport of solutes in flowing water and discharge at springs (Claassen, 1985);
- ion exchange, surface adsorption, and coprecipitation;
- growth of clay minerals, zeolites, and oxy-hydroxide minerals (Broxton et al., 1987);
- oxidation of reduced components, e.g., Fe-Ti oxides (Vaniman et al., 1992);
- evaporation and salt formation at discharge sites, e.g., playa lakes;
- atmospheric ground-surface deposition of carbonate and other dust (Stuckless et al., 1992).

Processes that are likely to be favorable to waste isolation include sorption, precipitation, and slow rates of rock alteration such that rock mechanical characteristics will be unaffected. Also, the alteration (weathering) that has occurred in the Quaternary has generally produced phases (e.g., zeolites and clays and oxy-hydroxides) that would tend to be more sorptive than primary glass or feldspar or ferromagnesian minerals. The occurrence of zeolites between the repository horizon and the water table at Yucca Mountain has been widely cited as a likely favorable condition. Concerning water chemistry, the high aqueous silica content is likely to contribute favorably to the stability of glass waste forms, and the neutral to moderately alkaline pH and relatively low concentrations of Cl⁻, SO₄²⁻, NO₃⁻, and F⁻ of the natural system are generally favorable conditions with regard to metal container stability (passivation).

The *rates* of geochemical processes in the Quaternary may also vary widely. Dissolution rates of minerals in recharging water are sufficiently fast generally to maintain dilute, silica-rich, sodium-bicarbonate solutions. The rates of aqueous complexation and surface sorption (speciation) of naturally occurring radioactive elements (e.g., U-235, C-14) and chemical homologs of other radioelements can be practically instantaneous on a geologic time scale. In contrast, dissolution rates are slow enough to preserve metastable volcanic glass as a major phase in rock units around the repository horizon. The slow

nucleation and growth of quartz sustains high aqueous silica concentrations in the groundwater, which are probably required to stabilize the secondary zeolite assemblage.

Rates during the Quaternary, when projected, may be useful for estimating lower limits for geochemical rates during the period of regulatory concern. However, rates of geochemical processes will be accelerated due to repository heating according to Arrhenius-type relations. An examination of the effect of projected Quaternary rates on performance may be mostly irrelevant, even for the moderately far field. Repository heating will be rapid and cooling will be slow, so elevated temperatures will predominate during the temporal period and over the spatial area of regulatory concern. The repository temperature at the water table about 200 meters below the waste horizon will be perhaps 65 to 75°C at 10,000 years (as opposed to 30 to 35 °C at present) under the SCP design thermal loading. Radionuclide migration in the geologic setting is likely to occur (after container breach) when the geologic setting is relatively hot. Repository heating will significantly modify the nature and rates of geochemical processes affecting waste isolation relative to the projection of Quaternary rates. Relating the projection of the nature and rates of Quaternary geochemical processes to repository performance thus offers some conceptual difficulties as well as technical uncertainties.

**Detailed Safety Review Supported by Independent Tests, Analyses, or Other Investigations (Type 5)
Rationale:**

Any finding made under this regulatory requirement topic may be considered highly uncertain due to a Key Technical Uncertainty (KTU) in the projection of the nature and rates of favorable or neutral geochemical processes in the geologic repository setting for Yucca Mountain.

This KTU is considered to require a Type 5 review because there is a high potential risk of non-compliance with the performance objectives of 10 CFR 60.112 and 10 CFR 60.113. The staff considers that there may be the highest potential risk of non-compliance with this regulatory requirement topic because, for the Yucca Mountain site, this KTU is the most difficult to resolve. Therefore, there might be a high residual risk of noncompliance with the performance objectives specified below because little can be done to reduce the risk, or compensate for the risk using, for example, favorable site conditions or engineered features. This concern about high risk of noncompliance will necessitate analyses above and beyond those required for a Type 3 or Type 4 review to assure that the uncertainty, and the associated effects on performance assessment, have been minimized to the extent possible. The potential for high residual risk of noncompliance in light of this KTU is sufficient that a Detailed Safety Review supported by independent tests, analyses, or other investigations is justified.

Key Technical Uncertainty Topic: Ability to project the nature and rates of Quaternary geochemical processes.

Description of Uncertainty: Although the nature and rates of Quaternary geochemical processes can be described qualitatively (see discussion above), projection of these processes requires an understanding of the physico-chemical controls on the processes. Principles of chemical thermodynamics and reaction kinetics provide the framework for projections; however, many uncertainties exist with regard to important thermodynamic and kinetic data and reaction mechanisms. Significant uncertainty surrounds even the reactions that play key roles in controlling groundwater and mineral chemistry. Several examples serve to illustrate these uncertainties.

Distribution of species between minerals and aqueous solutions is the primary mechanism for retardation of the migration of radionuclides by aqueous transport. Hence, this distribution is a favorable site

characteristic. Distribution of species between solid and liquid phases has occurred in the natural system at Yucca Mountain through the Quaternary involving processes such as surface adsorption, ion exchange, and coprecipitation. The processes of distribution of species are commonly assumed to be instantaneous and reversible in models for repository performance. However, at the present state of understanding and data, the mechanisms controlling species distributions at Yucca Mountain have not been well established.

Particular uncertainty is associated with the questions of whether or not the distribution of species is instantaneous and reversible, and if reversible, what are the appropriate distribution coefficients and other thermodynamic data. Potassium-argon dates on the order of 10 million years on clays and zeolite minerals at Yucca Mountain (WoldeGabriel et al., 1992) could indicate that species distributions between aqueous solutions and these "sorbing" phases is not universally instantaneous. On the other hand, laboratory ion exchange experiments indicate that equilibrium is achievable in two days (Pabalan, 1991). If solid-liquid species distributions for the natural Quaternary system can not be well understood and quantified, then projections of these favorable processes will be uncertain.

In a geologic repository, the water chemistry will affect corrosion mechanisms, waste form degradation processes, solubilities of waste element containing solids, and radionuclide speciation in solution and on surfaces. Gas-water-rock interactions in the natural system have controlled water chemistry in the Quaternary. A general, mostly qualitative, understanding of the controls on water chemistry in the natural system at Yucca Mountain has been developed. However, projection of controls on water chemistry requires a mechanistic understanding of those controls. The extent to which gas-water-rock interactions maintain a relatively stable and/or predictable chemistry is uncertain. Though they share many characteristics, water samples collected from saturated-zone tuffaceous aquifers at Yucca Mountain differ significantly from one another in their chemical characteristics. Sparse water chemistry data for samples collected from the unsaturated zone show an even broader range of characteristics. These observed variations reflect different controls and equilibria for different parts of the system, which are not well understood. Considerable uncertainty exists with regard to the controls on water chemistry and its stability.

Stability of the geochemical environment facilitates projection of the rates of processes. The rates of processes during the Quaternary (especially the slow ones like glass alteration) are uncertain. It is uncertain that projection of these rates to the future can provide meaningful estimation of the rates of processes that will favorably contribute to waste isolation in the repository.

Performance Objectives at Risk:

10 CFR 60.112
10 CFR 60.113(a)(1)
10 CFR 60.113(b)

Explanation of Nature of Risk: Geochemical processes affect containment, waste form behavior, solubilities of waste elements, and the retardation of radionuclide transport. All of these processes are critical to determination of compliance with the overall system and subsystem performance objectives. It is unlikely that the behavior of the geochemical system with superimposed repository conditions can be adequately evaluated, or that repository performance can be assessed with reasonable assurance, if uncertainties in geochemical reactions and data preclude projections of favorable or benign Quaternary processes.

Description of Resolution Difficulty: Synthesis and interpretation of a large amount of site characterization data, and experimental studies of geochemical reactions will be required to develop the capacity to project the nature and rates of Quaternary geochemical processes at Yucca Mountain. While significant accomplishments have been achieved and are recorded in the literature, much remains to be discovered. Ultimately decisions will have to be made based on incomplete data and understanding, because understanding of the fundamental geochemical processes and many of the fundamental data requirements are outstanding problems in geochemistry, and are unlikely to be fully resolved prior to any reasonable time of compliance determination.

Summary: The following assumptions have been made in assigning a Type 5 level of review for this CDS:

- (1) Site characterization activities are expected to identify geochemical processes that have occurred during the Quaternary.
- (2) Geochemical processes are expected to influence the ability of the repository to isolate radioactive wastes. However, only a subset of Quaternary geochemical processes will favorably affect or not affect repository performance, hence the favorable condition can be presumed to exist.
- (3) The rates associated with the geochemical processes are generally slow.
- (4) The physico-chemical conditions of Yucca Mountain have not changed dramatically during the Quaternary in such a way as to affect major changes in the nature or rates of geochemical processes. Nevertheless, there have been episodic events such as diffuse release of volcanic gases or changes in the height of the water table which affected localized or temporal changes in the Yucca Mountain geochemical system.

Reassessment: The level of review for this section of the license application may have to be reassessed in the future for a variety of reasons which can not all be anticipated. Possible causes requiring reassessment include:

- (1) Analyses demonstrating that geochemical processes as they occurred in the Quaternary are an inappropriate measure of the capacity of the repository to isolate wastes;
- (2) Analyses demonstrating that regardless of the nature and rates of Quaternary geochemical processes, their projection will simply not affect repository performance.

REVIEW STRATEGY:

Acceptance Review:

In conducting the Acceptance Review of the favorable condition concerning the nature and rates of geochemical processes, the reviewer should determine if the information presented in the license application and its references for demonstrating compliance with the applicable regulatory requirements is complete in technical breadth and depth as identified in regulatory guide "Format and Content for the License Application for the High-Level Waste Repository" (FCRG). The reviewer should determine that all appropriate information necessary for the staff to review the likelihood and type of hazard posed by this favorable condition is presented, such that assessments required by the regulatory requirements

associated with total system and subsystem performance objectives or other technical criteria can be performed.

The reviewer should determine whether the information in the license application is presented in a manner such that the assumptions, data and logic leading to a demonstration of compliance with the requirements are clear and do not require the reviewer to conduct extensive analyses or literature searches. The reviewer also should determine that controversial information and appropriate alternative interpretations of controversial issues and models have been adequately described and considered.

Finally, the reviewer should determine if DOE has either resolved all NRC staff objections that apply to this regulatory requirement topic, or provided all information requested in Section 1.6.2 of the FCRG for unresolved objections. The reviewer should evaluate the effect of any unresolved objections, both individually and in combination with others, on (1) the ability of the reviewer to conduct a meaningful and timely review, and (2) the ability of the Commission to make a decision regarding construction authorization within the three-year statutory period.

Safety Review:

This regulatory requirement topic is limited to consideration of the projection of Quaternary geochemical processes that have no effect or a favorable effect on waste isolation. It does not address projections of repository performance as required in 10 CFR 60.21(c)(1)(ii)(C). These "projection" type of analyses will be covered in other sections of the license application (see Appendix A). The specific aspects of the license application on which the reviewer will focus are discussed below, and the Acceptance Criteria are identified in Section 3.0 of this review plan.

In conducting the Safety Review, the reviewer should determine if the information presented in the license application and its references is an acceptable demonstration of compliance with the applicable regulatory requirements. At a minimum, the reviewer should assess the adequacy of the data and analyses presented in the license application to support DOE's demonstration regarding 10 CFR 60.122(b)(1). Specifically, the DOE will need to: (1) provide information to determine whether, and to what degree, the favorable condition is present; (2) assure the sufficiency of the lateral and vertical extent of data collection; and (3) evaluate the information presented under Items (1) and (2) above, with assumptions and analysis methods that adequately describe the presence of the favorable condition and ranges of relevant parameters.

DOE will also need to provide an explanation of the measures applied to assess the presence or absence of evidence for the nature and rates of Quaternary geochemical processes. Analyses and models used to predict future conditions and changes in the geologic setting should be supported by an appropriate combination of field tests, in-situ tests, laboratory tests which are representative of field conditions, monitoring data, and natural analog studies. For purposes of determining the presence or absence of this favorable condition, investigations should extend from the surface to a depth sufficient to determine critical pathways for radionuclide migration from the underground facility, and to a depth sufficient to demonstrate a suitable understanding of the favorable qualities of Quaternary geochemical processes such that reasonable bounds can be placed on the different conceptual models.

In conducting the aforementioned evaluations, the reviewer should determine that DOE uses: (1) analyses that are sensitive to evidence of the favorable condition; and (2) assumptions which are not likely to underestimate its effects. In general, the reviewer will assess the adequacy of DOE's investigations of the favorable condition, both within the controlled area and outside the controlled area (including the geologic setting) as necessary in the manner outlined in Section 60.21(c)(1)(ii)(B).

To conduct an effective review, the reviewer will rely on staff expertise and independently-acquired knowledge, information, and data such as the results of research activities being conducted by the NRC Office of Regulatory Research, in addition to that provided by DOE in its license application. It is incumbent upon the reviewer to have acquired a body of knowledge regarding these and other critical considerations in anticipation of conducting the review to assure that the Quaternary geochemical processes program of the DOE is sufficient in scope and depth to provide the information necessary for resolution of the concerns.

Detailed Safety Review Supported by Independent Tests, Analyses or Other Investigations:

A detailed safety review, independent modeling, and use of the results of staff investigations, will be needed for the KTU regarding projection of the nature and rates of Quaternary geochemical processes. This will ensure that DOE has adequately demonstrated items listed in the previous section (see "Safety Review," second paragraph).

For the KTU regarding the projection of the nature and rates of Quaternary geochemical processes independent tests, analyses or other investigations will be conducted by NRC staff to evaluate the analytical data and analyses reported by DOE to determine the implications for projection of Quaternary geochemical processes.

Examples of specific review activities that will be required include: (1) review and analysis of site characterization results determining the nature and rates of Quaternary geochemical processes; (2) review and analysis of projections of the Quaternary geochemical processes; and (3) review and analysis of the impact of the projection of Quaternary geochemical processes on waste isolation. The analysis should focus on the sensitivity, resolution, and detection capabilities of the different techniques; the degree to which the separate techniques can provide independent assessments of the various features and characteristics of concern; and the degree to which the techniques provide information which either corroborates or contradicts results of the other techniques. It may also be appropriate to assess the quality and traceability of data and information by using staff with specific expertise in the review of quality assurance programs.

RATIONALE FOR REVIEW STRATEGY:

In view of the complexity of the KTU addressed above, it is appropriate that the NRC conduct the independent activities described in order to (1) develop the licensing tools and technical basis necessary to judge the adequacy of DOE's license application, (2) assure sufficient independent understanding of the basic physical processes taking place at the geologic site, or (3) maintain an independent but limited confirmatory research capability under NRC auspices.

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APPLICABLE REGULATORY REQUIREMENTS FOR EACH TYPE OF REVIEW:

Type 1:

10 CFR 60.122(b)(1)
10 CFR 60.21(c)(1)(ii)(B)
10 CFR 60.21(c)(1)(ii)(F)
10 CFR 60.31(a)(1)(i)
10 CFR 60.31(a)(2)

Type 3:

10 CFR 60.122(b)(1)

Type 5:

10 CFR 60.122(b)(1)

REFERENCES:

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