COMPLIANCE DETERMINATION STRATEGY

RRT 3.2.4.2 POTENTIALLY ADVERSE CONDITION: CHANGES TO HYDROLOGIC SYSTEM FROM CLIMATE

APPLICABLE REGULATORY REQUIREMENTS:

60.122(c)(6)
60.21(c)(1)(ii)(B)
60.21(c)(1)(ii)(F)

TYPES OF REVIEW:

Acceptance Review (Type 1)
Safety Review (Type 3)
Detailed Safety Review Supported by Analyses (Type 4)

RATIONALE FOR TYPES OF REVIEW:

Acceptance Review (Type 1) Rationale:

This regulatory requirement topic is license application-related because, as specified in the license application content requirements of 10 CFR 60.21(c) and the regulatory guide "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 is a requirement for which compliance is necessary 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.

This regulatory requirement topic regarding changes in the hydrologic system resulting from climatic changes is one of three processes specified in 10 CFR Part 60 that can affect the groundwater system. The other two are tectonics (Structural Deformation and Groundwater) and future human activity (Human Activity and Groundwater). This regulatory requirement is a potentially adverse condition cited in 10 CFR 60.122(c)(6), and concerns the "potential for changes in hydrologic conditions that would affect the migration of radionuclides to the accessible environment...." It has two components: (1) prediction of "reasonably foreseeable climatic changes" and (2) "potential for changes in hydrologic conditions" resulting from climate change. The hydrologic effects resulting from those climatic changes will be evaluated under Section 3.2.2.9 of the License Application Review Plan (LARP). Thus, the strategy for determining compliance with this section of the license application will deal only with the prediction of "reasonably foreseeable climatic changes."

The analysts interpret the term "foreseeable," in the context of this regulation, to be likely or expected climatic changes as: (1) derived from statistical models based on the observed historical record for the region; (2) inferred from the paleo record of the past 1.6 to 2 million years before the present; (3) predicted from models based on theories such as the Milankovitch hypothesis, or general circulation models with estimates of anticipated CO_2 increase due to human activities; or (4) inferred from a combination of these methods. DOE would not be expected to evaluate implausible scenarios, such as climate change due to comet impact, but needs to provide reasonable climatic bounds based on projection of past climatic variance in the southwestern United States, anticipated air mass controls at the site, or global climatic model (GCM) simulations (or a combination of these). For practical purposes, the analysts consider that the absolute prediction of future climate is not a requirement. However, it will be necessary for DOE to develop scenarios with reasonably supportable distributions or bounding conditions for temperature, precipitation, and other climatic factors.

In Federal regulations (10 CFR Part 60, 10 CFR Part 960, and 40 CFR Part 191) governing the disposal of high-level radioactive waste, numerous references are made to the prediction of future climate at a high-level waste repository site. The current regulatory time frame of interest is 10,000 years (40 CFR Part 191). Thus, the likely climate changes at a proposed site will have to be estimated for a 10,000 year period following permanent closure of a repository.

Background Discussion: The most recent 20,000 years of climatic record in the vicinity of Yucca Mountain, Nevada leads many researchers to believe that precipitation at the Yucca Mountain site has been no more than double its current level during that time span [See discussions in Spaulding et al. (1984), Czarnecki (1985), and Spaulding (1985 and 1990)]. For example, Spaulding (1990) estimates that precipitation in the Yucca mountain region might have been as much as 40% more than present at about 18 ka (thousands of years before present) (Spaulding et al., 1984). Interestingly, Winograd and Szabo (1988) suggest a long-term trend of decreasing precipitation and deepening depth to the water tables in the southern Great Basin which they primarily ascribe to uplift of the Sierra Nevada and Transverse Ranges and subsequent enhancement of the "rain shadow" effect.

Long-term estimates of climatic change are required to accomplish the evaluation of repository performance over the 10,000 year regulatory time frame. The evaluation of past climate during the Pleistocene led Kominz and Pisias (1979, p. 171) to conclude "Pleistocene glacial variations are largely stochastic in nature," which implies that climate prediction is better suited to Markovian techniques than analyses of cause and effect. An expert panel ended their conference on "The Present Interglacial, How and When Will It End?" with the following statement:

> "The global environment of the last several millennia is in sharp contrast with climates that existed during most of the past million years. Warm intervals like the present one have been short-lived and the natural end of the warm epoch is undoubtedly near when considered on the geological time scale. Global cooling and related rapid changes of environment substantially exceeding the fluctuations experienced by man in historical times, must be expected within the next few millennia or even centuries." (Kukla and Matthews, 1972, p. 191).

Researchers of the Swedish high-level waste repository program believe that continental glaciation will return to Sweden, within 5,000 years of the present, causing about 75 percent of Sweden to be under an ice sheet and depressing the land surface about 300 meters (SKB, 1992). If such conditions should occur in Sweden, glaciation would likely be more active in the rest of the world, and the southwest U. S. location at Yucca Mountain, Nevada could possibly experience a cooler and wetter period. There is little

certainty in evaluations of future climate, and no single technique for generating future climatic scenarios is considered "best." GCM specialists recognize the need to refine their models regionally, and only recently has work begun to relate GCMs to hydrologic conditions at the Earth's surface.

The following are four different techniques for describing or modeling future long-term climate change at a proposed high-level radioactive waste geologic repository:

- Historic and paleoclimatic data can be used to develop distributions of climatic variables or parameters.

- General Circulation/Global Climatic Models (GCM) or regional variations thereof can be used to model future climate at a site given certain assumptions and governing equations.

- Synoptic weather patterns used to bound the "likely" and feasible climatic fluctuations at a site and to forecast "likely" response to differing air mass/weather system domination in a changed climate

- A combination of the above three methods can be used, enhanced by statistical analyses to derive a set of plausible climatic scenarios, including the expected chance of occurrence during the 10,000 year period of interest. The development of "reasonable" climatic scenarios based on paleoclimates, GCMs, and analogs of current weather seems to be the only acceptable way to test the performance of the Yucca Mountain site.

Paleoclimatic Data used to Describe Future Climate: Paleoclimatic data provides information about past climates for time frames as long as millions of years. Generally, paleoclimatic data can be found for any site, given the myriad of techniques for determining past climates. In the vicinity of Yucca Mountain, Nevada, packrat middens, lake bottom sediments, tree rings, pollen, cave deposited carbonate, spring silica deposits, soil features, relict hydrologic features, and fracture fillings, among other sources, provide information on climate during the Quaternary Period (approximately last 1.6 million years). Globally, studies of glacial periods, Milankovitch forcing of insolation, deep ocean oxygen isotope measurements, global precession, and global ice sheet fluctuations, among other sources, provide information pertinent to past climate reconstruction on a global scale. The temporal record of the reconstructed climatic, however, is not continuous and a better understanding of fluctuations in the Holocene (past 10,000 years) is provided from studies of packrat middens, tree rings, and lake bottom sediment than is available for the other techniques for the earlier part of the Quaternary period. Paleoclimatic data are used to describe past climate in order to better understand climatic fluctuations, but are not generally used to predict future climate change. It is possible to extract statistically meaningful information from the various paleoclimatic data sources, but the overriding assumption to predict future climates at a given site from such data is that the mechanisms that produced the past climatic change will continue to operate in the future at the same or similar intensities. This "climatic uniformitarianism" is particularly questionable when the likelihood for anthropogenic change in global climate is considered. Apostolakis et al. (1991, p. 99-100) investigated the importance of anthropogenic change on a 10,000 year climate prediction and concluded:

> "A final decision is required on whether anthropogenic climate effects are important at the time scales of performance assessment. If it is assumed that society will act to control anthropogenic effects (i.e. CO_2 emissions), then within, say, 200 years (2 time steps in the analysis presented here) the climatic signal should not exhibit man-made influence."

The use of information on past long-term climate changes to model the proposed repository site could be valuable in conditioning the short-term GCMs and providing bounding temperature/precipitation conditions for appropriately well-constrained climate scenarios. The critical relationship between temperature, precipitation, and infiltration at the repository horizon and below must be better defined than at present in order to calculate and verify likely effects on repository performance due to changes in infiltration quantities which can be related to varying climatic conditions.

Global Climatic Models Used to Describe Future Climate: Present and anticipated GCM model results derived from grid cells a few hundred miles on a side cannot be interpreted meaningfully at repository scales of only a few miles. Also, the effective relationship between global climate change and infiltration change (which might result in a significant rise in the water table) at a proposed site is not well known at present. Giorgi (1990, p. 7) stated "...current GCM's have a resolution (~500 km) which is too coarse to provide adequate detail for regional studies, especially in mountainous areas." According to Hay et al. (1990, p. 3):

> "General circulation models (GCMs) simulate climatic conditions using grid cells representing an area of about 10,000 square kilometers. This resolution is inadequate to assess the effects of climatic change on water resources at a regional scale."

Relative to the relationship between GCM's and local hydrology, Wood et al. (1990, p. 4) report:

> "The approach commonly used is to drive hydrologic models with alternative climate scenarios, that are the output of GCM simulations. This approach suffers the inconsistency in spatial scales between the GCM mesh and the river basin scale. In addition, the ability of the GCM's to reproduce important hydrologic fluxes is unknown."

Another potential problem which precludes using only GCM climate evaluation at a repository scale has been identified by Wilson and Skyllingstad (1990, p. 12) as follows:

> "In addition, GCM modelers caution against interpretation of simulation results for single grid cells, and suggest instead that attention be focused on regional patterns that are only evidenced through coincident variations at multiple GCM grids."

Researchers throughout the world are improving the resolution of their GCM's with the desired goal of predicting short-term atmospheric changes and of evaluating an increase in atmospheric carbon levels within the next 50 years. Presently, no models are being developed with the goal of 10,000 year climatic predictions or comparable hindcasts. Additionally, current GCM models require extensive high-priced computing capability to fabricate even a few years duration of selected dynamic climate scenarios.

Synoptic Weather Variations Used to Describe Future Climate Scenarios: Information developed by studying air-mass climatology should be made a part of climate scenarios which are developed for repository performance assessment. The temporal changes and precipitation variability associated with air-mass dominance is a reasonable means to understanding the behavior of the atmosphere given "cooler" precipitation enhancing temperatures within the current context of warmer yearly average temperature and associated precipitation at the proposed repository site. A study of the effect of air masses, particularly in the winter, on Yucca Mountain precipitation and infiltration could be used as an analog of a future cooler climate at the Yucca Mountain proposed repository site. This climatic analog approach could yield likely bounds of precipitation and attendant infiltration given increased dominance of

precipitation-producing air masses. The technique will not, however, allow for the validated prediction of future climate variability on a 10,000 year time scale. A regression of air mass-induced precipitation data based on field measurements would yield prediction of future quantities of precipitation, but would not determine the likelihood of such air mass dominance becoming the norm at the proposed repository site.

Combination of Paleoclimatic, GCM, and Synoptic Weather and Other Information to Model Future Climates: Apostolakis et al. (1991) present a technique for merging past climatic data with output from GCMs. The approach is Bayesian where a time series model is fitted to the climatic record (assumption is that it represents the true history of climate change). The parameters of the fitted model are considered uncertain and the output from a GCM is used as a new source of information. Bayesian techniques are used to update the model parameters from the combined sources. The final product is a time series model with random parameters; the resultant parameter model is used in a Monte Carlo simulation to study future climate variability and the probability of particular future events (Apostolakis et al., 1991). Four conclusions relative to the Bayesian approach to future climate prediction are noted by Apostolakis et al. (1991, p. 99-100) as follows:

- Determination must be made of importance of anthropogenic effects relative to the time scales of performance assessment.

- Long-term time series results of GCMs as well as expert opinion may be used in establishing priors.

- Other information sources could be included such as analog data from air-mass studies.

- Error in paleoclimatic data should be evaluated and explicitly incorporated in the analysis. (Information content of a long paleoclimatic record overwhelms any information from the relatively noisy GCM output.)

Detailed Safety Review Supported by Analyses (Type 4) Rationale:

The staff considers that there may be high potential risk of noncompliance with applicable regulatory requirements because, for the Yucca Mountain site, there exists a Key Technical Uncertainty regarding climate prediction. Therefore, the staff will conduct a "Detailed Safety Review Supported by Analyses" of the license application to determine compliance with this regulatory requirement topic.

The following Key Technical Uncertainty requires a Type 4 review because there is a high risk of noncompliance with the performance objective specified in 10 CFR 60.112. This concern of high risk of noncompliance will require analyses above and beyond that required for a Type 3 review in order to assure that uncertainties and potential adverse effects on performance have been adequately evaluated and minimized to the extent possible.

Key Technical Uncertainty Topic: The uncertainty associated with predicting precipitation and temperature (climate) at the Yucca Mountain site for 10,000 years into the future.

Description of Uncertainty: The analysts consider that it is very difficult to predict climatic variations (precipitation, temperature, etc.) over the next 10,000 years.

Performance Objective at Risk: 10 CFR 60.112

Explanation of Nature of Risk: Precipitation and temperature change will affect the flux of water in the unsaturated zone which, in turn, may contribute to adverse effects on canister degradation, radionuclide release, and radionuclide transport to the accessible environment. Until subsurface hydrologic conditions and processes are better understood, it will be difficult to evaluate the consequences of significantly increasing the precipitation. The nature and timing of climatic changes may, when considered in the context of all other adverse effects on the performance of the repository, prove to have an adverse effect on performance.

Description of Resolution Difficulty: There are numerous factors that prevent scientists from accurately projecting future climates. Even day-to-day weather predictions are very limited, primarily because atmospheric phenomena are chaotic in nature and behavior. The factors that cause climate change are poorly understood because such changes occur very slowly over time scales that exceed the historical record.

One climatic factor, concerning Earth's orbital and rotational characteristics (Milankovitch cycles), can readily be predicted. Most other factors are not easily evaluated. For example, long-term variations in energy output from the sun are poorly understood, and generally unknown. Short-term periodicity in the form of sunspot cycles is well known, but hypothesized longer-term trends have not yet been confirmed due to the short period of historic astronomical records. Another independent variable in climate change is the effect of volcanism. The stratospheric injection of volcanic ash has a short-term cooling effect on Earth's climate. But it is reasonable to conclude that periods of anomalously high volcanic activity could temporarily offset greenhouse warming effects, or could accelerate cooling trends caused by other phenomena. It is not possible to predict future periods of more intense volcanic activity.

Certain anomalous climatic trends defy prediction. For example, when it occurs, the El Nino Southern Oscillation (ENSO) can significantly influence climate in the western U.S. This phenomenon results from a complex atmospheric-oceanic interaction, and may be more a result of other factors than an independent variable in itself.

Present and future human activities will probably have a strong influence on climate changes. The current trend of increasing atmospheric CO_2 is thought to have produced a very gradual world-wide warming trend in the relatively short time since the start of the Industrial Revolution. Although this trend is reasonably established, it is not possible to predict the range and impacts of future human activities with any certainty.

Summary: The following assumption has been made in developing this rationale and assigning a Type 4 level of review to this CDS:

> (1) Based on what we know today (Spaulding, 1985), the estimated ranges of precipitation and recharge that occurred during the last 45,000 years are reasonable models for the expected ranges of these processes during the next 10,000 years.

Reassessment: The level of review for this section of the license application may have to be reassessed in future if characterization shows the presence of any of the following conditions at Yucca Mountain:

(1) Present-day groundwater fluxes are sufficiently high that waste isolation would be jeopardized by a significant increase in future precipitation, infiltration, and percolation.

(2) Climatic models predict an upper bound for future precipitation that exceeds that from the maximum estimated range of precipitation over the last 45,000 years.

(3) Paleoclimatic data reveal an upper bound for precipitation over the last 45,000 years that exceeds estimates made by Spaulding (1985).

(4) Questions arise regarding the adequacy of DOE's paleo-hydrologic studies for the groundwater basin that includes Yucca Mountain.

REVIEW STRATEGY:

Acceptance Review:

In conducting the Acceptance Review of the potentially adverse condition regarding changes to the hydrologic system resulting from climate, the reviewer should determine if the content of the license application is complete in technical depth and breadth with respect to the information requested by Section 3.2.4. of regulatory guide "Format and Content of the License Application for the High-Level Waste Repository (FCRG). The reviewer should determine whether the license application contains all appropriate information with respect to this potentially adverse condition that the staff needs to support the safety review (described below) and total system and subsystem performance assessments.

The information contained in the license application should be presented in such a way that the assumptions, data, and logic lead to a clear demonstration of compliance with the requirements. The reviewer should not be required to conduct extensive analyses or literature searches. The reviewer should also determine whether an appropriate range of alternative interpretations and models has been described.

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

Safety Review:

This regulatory requirement topic is limited to a determination of "reasonably foreseeable climatic changes." It will focus on the kinds of climatic changes that can occur and estimates of the degree of climatic change to be expected over the next 10,000 years. It is not directly concerned with radionuclide migration, or with other phenomena that may influence the groundwater flow system.

The potential for structural deformation to adversely affect the hydrologic system will be covered under Section 3.2.2.8 of the license application (Structural Deformation and Groundwater). The potential for foreseeable human activities to adversely affect the hydrologic system is considered under Section 3.2.2.6 (Human Activity and Groundwater). Section 3.2.2.7 (Naturally Produced Surface Water Impoundments) of the license application will address the potential for natural phenomena such as landslides, subsidence,

or volcanic activity to create large-scale surface water impoundments that could adversely affect the regional groundwater system. There would also need to be sufficient future precipitation and runoff to create surface water bodies within the impoundments. The potential for the potentiometric surface to rise and flood a repository is covered under Section 3.2.2.11 (Potential for the Water Table to Rise and Inundate a Repository). Section 3.2.2.9 (Changes in Hydrologic Conditions) covers the potential for changes in hydrologic conditions that would affect radionuclide migration to the accessible environment. It does not focus on the individual future events that would cause the hydrologic changes, which would include climatic change, tectonic effects, and human activities. Rather, it addresses the combinations of these processes and the corresponding effects they could have on the migration of radionuclides to the accessible environment. This Section (3.2.4.2) will provide the input needed under Section 3.2.2.9 regarding the likelihood of climate change, and how that would influence future temperature and precipitation.

Following the Acceptance Review, the first step in the NRC review will be to evaluate DOE's analyses to determine if the following basic assumption has been met:

> (1) Based on what is known today (Spaulding, 1985), the estimated ranges of precipitation and recharge that occurred during the last 45,000 years are reasonable models for the expected ranges of these processes during the next 10,000 years.

If the above assumption has been met, the staff review will follow the review strategy described here. If this assumption is not met, the staff review may require a different review strategy for evaluating DOE's demonstration of compliance with the applicable regulatory requirements. It is expected, however, that any deviation from this assumption will be known well in advance of the time a license application is submitted, and this strategy shall be revised in accordance with such new information as it becomes available to the staff.

In conducting the Safety Review, the reviewer will, at a minimum, determine the adequacy of the data and analyses to support DOE's demonstrations regarding 10 CFR 60.122(c)(6). Specifically, DOE will need to (1) provide information to determine whether, and to what degree, the potentially adverse condition is present; (2) provide information to determine to what degree the potentially adverse condition is present, but undetected; (3) assure the sufficiency of the lateral and vertical extent of the data collection; and (4) evaluate the information presented under items (1) and (2) above, with assumptions and analysis methods that adequately describe the presence of the potentially adverse condition and ranges of relevant parameters. 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 staff will determine if DOE has submitted the following: (1) description and explanation of methods for predicting future climates at the Yucca Mountain proposed HLW repository site; (2) descriptions of the plausible climate scenarios for the 10,000 year or other defensible foreseeable time frame, and (3) explanations of the models used to predict future climate and the means to demonstrate the validity of the models for such predictions. DOE will also need to submit data from which paleoclimates can be inferred, such as: (1) information on the approximate range of altitudes at which the water table existed during the Holocene; (2) evidence concerning the highest altitude ever attained by the water table beneath Yucca Mountain - this evidence would probably consist of mineralogic, geochemical and isotopic data from drill cores; it may also include information on the physical and textural properties of volcanic glass and minerals within the tuffs, and how those properties may change during saturation by groundwater; (3) paleoclimatic data on past amounts of recharge and

discharge; and (4) field evidence of Holocene springs that existed near Yucca Mountain. The NRC staff will determine whether appropriate supporting documentation is provided to defend any conclusions arrived at using expert judgement.

DOE will also need to explain how models are supported that are used to assess the presence or absence of the potentially adverse condition. Analyses and models that will be used to predict future conditions and changes in the climatic setting shall be supported by an appropriate combination of methods such as field tests, laboratory tests that are representative of field conditions, monitoring data, and natural analog studies. For purposes of determining the presence or absence of this potentially adverse condition, investigations should extend from the ground surface to a depth sufficient to determine critical pathways for radionuclide migration from the underground facility. Investigations should be sufficient to support demonstrations of the potential effects of climate change on groundwater conditions, 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 potentially adverse condition; and (2) assumptions which are not likely to underestimate its effects. In general, the reviewer will assess the adequacy of DOE's investigations regarding the likelihood of this potentially adverse condition, both within the controlled area and outside the controlled area, as necessary, in the manner defined in 10 CFR 60.21(c)(1)(ii)(B).

Reviewers 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 the DOE in its license application. The reviewer should focus on additional data which can refine knowledge of changes in climate, and should perform, as necessary, additional analyses to confirm the resolution capabilities of the methods. The reviewer must have acquired a body of knowledge regarding these and other critical considerations in anticipation of conducting the review to assure that the climatology, meteorology, and paleoclimatology programs are sufficient in scope and depth to provide the information needed to resolve the concerns.

Detailed Safety Review Supported by Analysis:

A Detailed Safety Review will be needed to evaluate the Key Technical Uncertainty regarding the prediction of climate at the Yucca Mountain site over the next 10,000 years. This will ensure that the DOE has adequately demonstrated Items (1)-(4) listed in the previous section [See Section 2.2.1 of the LARP (Safety Review), 3rd paragraph]. Activities performed in this Detailed Safety Review will help to assure that DOE has adequately addressed and resolved the Key Technical Uncertainties so that they do not lead to noncompliance with the total system performance objective.

Examples of specific review activities that will be required include: (1) examination of the DOE models for climate prediction to test assumptions, validity of input data, presentation of results, and evaluation of results; and (2) determination that DOE's conclusions are within the expected bounds for climate change and embody a conservative approach. The review should focus on the sensitivity, resolution and detection capabilities of the different techniques; and 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 other techniques.

The staff anticipates closely reviewing DOE's models of climatic prediction and change to determine that assumptions and calculations are reasonable and well-supported, and that the results are reasonable when compared with Quaternary paleoclimatology. In order to be able to judge the adequacy of a DOE submittal, the staff will have to be able to evaluate the adequacy of data, data collection methods, and climatic models. In order to be able to accomplish this, the staff will need to investigate and manipulate codes prior to DOE's license application submittal.

The analysts conclude that a safety determination could be made by independently evaluating paleoclimatic information submitted by DOE in the License Application and by acquiring and using codes and models developed by DOE. The analysts do not at this time consider that a higher level of review will be necessary. Although results of climate modeling will always be controversial, there are no known additional major improvements that could be incorporated within global climate models by an NRC-sponsored research program. Other government agencies are actively pursuing research in climate modeling, mainly in connection with the theorized global "greenhouse" warming. Given the scope of those efforts, the NRC staff consider that their results and conclusions should be adequate to support the high-level waste program. Nonetheless, the staff will continue to independently evaluate the progress and acceptability of climate and paleoclimate studies and modeling by all parties, given the significance of this subject with respect to groundwater conditions at Yucca Mountain. The development of "reasonable" climatic scenarios based on paleoclimates, GCMs, and analogs of current weather seems to be the only acceptable way to test the performance of the Yucca Mountain site.

RATIONALE FOR REVIEW STRATEGY:

In view of the complexity of the key technical uncertainty 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 repository, and (3) maintain independent but limited confirmatory research capability under NRC auspices.

Contributing Analysts:

NRC: Neil Coleman, Don Chery

CNWRA: Michael P. Miklas, Jr.

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APPLICABLE REGULATORY REQUIREMENTS FOR EACH TYPE OF REVIEW:

Type 1:

60.122(c)(6)
60.21(c)(1)(ii)(B)
60.21(c)(1)(ii)(F)

Type 3:

10 CFR 60.122(c)(6)

Type 4:

10 CFR 60.122(c)(6)

REFERENCES:

Apostolakis, G., R. Bras, L. Price, J. Valdes, K. Wahi, and E. Webb, 1991. Techniques for Determining Probabilities of Events and Processes Affecting Performance of Geologic Repositories. Sandia National Laboratories for Division of High-Level Waste Management, Office of Nuclear Material Safety and Safeguards, U. S. Nuclear Regulatory Commission. NRC FIN A1165. Vol. 2.

Czarnecki, J.B., 1985. Simulated effects of increased recharge on the ground-water flow system of Yucca Mountain and vicinity, Nevada-California. U.S. Geological Survey Open File, Water Resources Investigations Report 84-4344. 33 pp.

Giorgi, F., 1990. Coupled Regional Climate/Surface Hydrology Modeling, Chapman Conference on Hydrologic Aspects of Global Climate Change, Lake Chelan, Washington, American Geophysical Union.

Hay, L. E., G. McCabe, D. Wolock, and M. Ayers, 1990. Use of Weather Type Analysis to Disaggregate General Circulation Model Predictions, Chapman Conference on Hydrologic Aspects of Global Climate Change, Lake Chelan, Washington, American Geophysical Union.

Kominz, M. A. and N. G. Pisias, 1979. *Pleistocene climate: deterministic or stochastic?* Science. Vol. 004. pp 171 -173.

Kukla, G. J. and R. K. Matthews, 1972. *When will the present interglacial end?* Science. Vol. 178. pp. 190 - 191.

NRC (U.S. Nuclear Regulatory Commission), *Format and Content for the License Application for the High-Level Waste Repository,* Office of Nuclear Regulatory Research [Refer to the "Products List" for the Division of High-Level Waste Management to identify the most current edition in effect].

SKB (Svensk Karnbranslehantering AB), 1992. Final disposal of spent nuclear fuel. Importance of the bedrock for safety. ISBN 91-971906-1-6. pp. 76 - 80.

Spaulding, W. G., 1985. Vegetation and Climates of the Last 45,000 Years in the Vicinity of the Nevada Test Site, South-Central Nevada, USGS Professional Paper 1329, 55 p.

Spaulding, W.G., 1990. Environments of the Last 50,000 Years In the Vicinity of Yucca Mountain, Central-Southern Nevada, High Level Radioactive Waste Management, Proceedings of the International Topical Meeting, April 8-12, 1990, Las Vegas Nevada. pp. 1251 - 1258.

Spaulding, W.F., S.W. Robinson and F.L. Paillet, 1984. Preliminary assessment of climate change during late Wisconsin time, southern Great Basin and vicinity. U.S. Geological Survey Water-Resources Investigations Report 84-4328, 40 pp.

Wilson, L. L. and E. Skyllingstad, 1990. A Multisite Stochastic Daily Precipitation Model Conditioned On Large Scale Atmospheric Circulation Patterns, Chapman Conference on Hydrologic Aspects of Global Climate Change, Lake Chelan, Washington, American Geophysical Union, p.12.

Winograd, J.I. and B.J. Szabo, 1988. *Water table decline in the South Central Great Basin during the Quaternary Period: Implications for Toxic-waste disposal,* in M.D. Carr and J.C. Yount (eds.) *Geologic and Hydrologic Investigations of a Potential Nuclear Waste Disposal Site at Yucca Mountain, Southern Nevada,* U.S. Geological Survey Bulletin 1790, pp. 147-152.

Wood, E. F., D. Lattenmaier, and J. Wallis, 1990. Water Balance Modeling for Climate Impact Studies Using a Hydro-Meteorological Climatic Data Set for the United States, Chapman Conference on Hydrologic Aspects of Global Climate Change, Lake Chelan, Washington, American Geophysical Union, p.4.