COMPLIANCE DETERMINATION METHOD FOR REVIEW PLAN NO. 3.2.1.10 POTENTIALLY ADVERSE CONDITION: EVIDENCE OF EXTREME EROSION

3.0 REVIEW PROCEDURES AND ACCEPTANCE CRITERIA

3.1 Acceptance Review

In conducting the Acceptance Review for docketing, the staff will compare information in the license application (LA) concerning the potentially adverse condition (PAC) on evidence of extreme erosion during the Quaternary Period (henceforth referred to only as "extreme erosion") with the corresponding section of the FCRG and with the staff resolution status of objections to the LA submittal in the Open Item Tracking System (OITS) and determine if this information meets the following criteria:

(1) The information presented in the LA is clear, is completely documented consistent with the level of detail presented in the corresponding section of the FCRG, and the proper references have been provided.

(2) The U.S. Department of Energy (DOE) has either resolved, at staff level, the Nuclear Regulatory Commission (NRC) objections to LA submittal that apply to this regulatory requirement topic or provided all information requested in Section 1.6 of the FCRG for unresolved objections, namely, DOE has:

- Identified all unresolved objections.
- Explained the differences between NRC and DOE positions that have precluded resolution of each objection.
- Described all attempts to achieve resolution.
- Explained why resolution has not been achieved.
- Described the effects of the different positions on demonstrating compliance with 10 CFR Part 60.

(3) DOE has presented information and analyses in review areas listed in Section 3.2.1 through 3.2.1.5. If DOE has not presented information in these areas an explanation for not providing the information should be presented.

(4) Unresolved objections, individually or in combination with others, will not prevent either the reviewer from conducting a meaningful Compliance Review or NRC from making a decision regarding construction authorization within the three-year statutory period.

3.2 Compliance Reviews

The compliance determinations undertaken by NRC staff will consider whether Acceptance Criteria specified for the appropriate aggregate of the following Compliance Reviews have been met. The staff is expected to employ its professional judgment and other expert opinion to evaluate the DOE demonstration of compliance with the regulation. The staff does not expect each of the topics discussed

below will be addressed and reviewed individually. However, it is expected that a majority of the topics will need to be addressed by DOE to provide adequate documentation of the presence or absence of the PAC—Evidence of Extreme Erosion During the Quaternary Period. Results of the compliance determinations should be documented by the staff to provide the basis for actual Evaluation Findings in the Safety Evaluation Report (SER).

3.2.1 Safety Review of 10 CFR 60.21(c)(1)(ii)(A),(B),(F) as they related to 10 CFR 60.122(c)(16)

Using its professional judgment or other expert opinion, the staff will determine whether the assessment of presence or absence of extreme erosion has been accomplished in an acceptable manner, and whether description of the geology of the site properly supports the assessments required by 10 CFR 60.21(c)(1)(ii)(A),(B), and (F) as they relate to 10 CFR 60.122(c)(16). For 10 CFR 60.21(c)(1)(ii)(A) specifically, the staff will review and evaluate information provided by DOE in the LA to support DOE analysis of the geology of the site as related to extreme erosion and determine whether the analysis has been conducted in a manner acceptable for supporting review of 10 CFR 60.122(c)(16).

For 10 CFR 60.21(c)(1)(ii)(B) the staff will review and evaluate information provided by DOE in the LA to support analyses of the degree to which extreme erosion has been characterized and found to be present. The staff will review and evaluate information provided by DOE in the LA to demonstrate either the absence of extreme erosion or the extent to which its presence may have been underestimated or undetected, taking into account the degree of resolution achieved by the investigation. The staff will also determine whether the analyses and investigations have been accomplished in an acceptable manner and whether lateral and vertical extent of the investigations are acceptable for supporting review of 10 CFR 60.122(c)(16).

For 10 CFR 60.21(c)(1)(ii)(F) the staff will review and evaluate information provided by DOE in the LA to support analyses and models used to predict future conditions and changes in the geologic setting as related to extreme erosion. The staff will also determine whether the analyses and models are properly supported by an appropriate combination of methods such as field and laboratory tests, monitoring data, or natural analog studies for assisting review of 10 CFR 60.122(c)(16).

In accomplishing the Safety Review of 10 CFR 60.21(c)(1)(ii)(A),(B), and (F) as they relate to 10 CFR 60.122(c)(16), the staff will need to determine whether the following Acceptance Criteria have been met:

(1) Assumptions and analysis methods used by DOE to evaluate the information presented to determine the absence or acceptably describe the presence of evidence of extreme erosion during the Quaternary Period encompass appropriate ranges of relevant parameters.

(2) DOE can demonstrate that the extent of characterization is sufficient to define evidence of extreme erosion in the geologic setting and to assure that potential effects on critical pathways for radionuclide migration are adequately described.

(3) DOE can demonstrate that the scope of investigations has bounded the range of conceptual models of extreme erosion during the Quaternary Period as supported by the available data.

(4) Results of DOE investigations are not in conflict with published results from various staff and investigations or other independent studies, or the conflicts are adequately explained.

(5) DOE has demonstrated that it has determined the highest credible magnitude for erosive process rates during the Quaternary Period for the Yucca Mountain (YM) vicinity.

(6) DOE has demonstrated that evidence of extreme erosion is (is not) present by showing that erosive processes active during the Quaternary would (would not) be capable of exhuming a waste package in the 10,000-year reference life of the repository or change the distance from the repository to the accessible environment.

The staff evaluation should be conducted with the following assumptions in mind:

- Waste will be emplaced at a depth approximately 200 meters below the YM crest. Therefore, the favorable condition (FAC) on Minimum Waste Emplacement Depth [License Application Review Plan (LARP) Section 3.2.1.2] will be assumed by the staff to not be present based on current DOE design plans (U.S. Department of Energy, 1995).

- At YM erosion is thought to be a concern with respect to performance only in the washes of ephemeral streams. These washes were formed mainly by the downcutting action of flash flooding and debris transport events. The incised bottoms of the washes are closest to the elevation of the proposed repository. Erosion at ridge crests or on interfluves should have little effect on repository performance during the reference 10,000 year timeframe. Landslides could temporarily block washes and produce short-lived catchments, but these would not be expected to significantly affect performance. In fact, this scenario is explicitly covered in LARP Section 3.2.2.7. PAC—Natural Phenomena and Groundwater and should not be a part of the Extreme Erosion PAC review.

- The estimated range of precipitation that occurred in the site vicinity during the last 45,000 years is a reasonable model for the range of precipitation that will occur at the site during the next 10,000 years. This time spans the interval from the Wisconsin glacial maximum through the present interglacial period. A perusal of the data indicates that fossil records show no evidence for an average annual precipitation increase of more than 40 percent of modern amounts. Future precipitation is expected to continue to be controlled by the rain-shadow conditions that produce the modern-day climate of the Great Basin (Dewispelare, 1993). The amounts and type of precipitation expected during the next 10,000 years will control the nature of future flooding events.

Based on the evidence presented, the reviewer should be able to ascertain whether extreme erosion is present or absent or the degree to which it is present, or if it may be present but underestimated, or present but undetected. A discussion of extreme erosion should include both the long-term average as well as averages for shorter periods, approximating the 10,000 year reference life of the repository. The staff considers that any erosional process which could affect repository performance during that period should be addressed. This will include examination of erosional processes in addition to regional denudation. Topics such as scarp retreat, base level changes, surface fluvial erosion rates, aggradation rates, climate change, etc. should be addressed in order to provide adequate documentation on the condition of extreme erosion during the Quaternary Period.

Any data used in a statistical evaluation by DOE should be included in the LA so that the NRC reviewers can evaluate the data using the same or comparable statistical techniques and can assess the uncertainty ascribed by DOE to the calculations. Independent NRC processing of selected data should determine that the DOE results can be reproduced and should determine that the sensitivity of the results to the various input parameters are accurately described by DOE.

The reviewer should determine whether alternate conceptual models of factors such as paleoclimate, paleohydrology, and geomorphology are identified and discussed. Reliance on a single line of evidence should be viewed with skepticism. Information and discussion should be sufficient to demonstrate the validity of the DOE argument and conclusions. The reviewer should determine that appropriate references, particularly for age dates, do not include personal communication or unpublished information as part of their bases. The reviewer should determine whether data and manipulations of data which lead to a quantitative conclusion include a statistical evaluation of the uncertainty in analytical method and the data itself is properly documented. The information presented in the LA should include the data from which conclusions are drawn or, at a minimum, first-order references in which the data resides [such as in a Topical Report (TR)]. Unsubstantiated, or inadequately documented DOE arguments should be rejected by the staff because they can not be validated. The staff reviewer should be satisfied that the range of techniques and analyses employed by DOE sufficiently characterizes the erosional events and processes with little likelihood that significant erosion has been undetected and hence unevaluated for potential effect on waste isolation.

NRC has suggested, for regulatory purposes, that a timeframe of 2.0 million years be used for the Quaternary Period (Nuclear Regulatory Commission, 1983 p. 373) while DOE has suggested in some publications (DOE, 1993) a timeframe of 1.6 million years for the Quaternary Period. DOE should document that use of the shorter period will result in no material change in its analysis of the evidence of extreme erosion during the Quaternary Period. The timeframe suggested by NRC was meant to ensure that a reasonably long period which encompasses numerous shorter periods (duration of "shorter periods" is comparable to the 10,000-year period of regulatory interest of the repository) be investigated for possible events of extreme erosion of both long and short duration. The reviewer should determine if the timeframe investigated by DOE and the logic used by DOE to establish such a timeframe of reference are adequate to encompass the full range of erosive events and processes which acted during the Quaternary Period. A 1.6-million year timeframe, as proposed by DOE, would still allow for the evaluation and inclusion of numerous "shorter periods" and, depending on the range of processes and events described by DOE in the LA, might be considered adequate to describe the evidence of extreme erosion during the Quaternary Period.

To make compliance determinations, the staff should understand the program of exploration, laboratory testing, analysis, and characterization implemented by DOE. This review will include, but may not be limited to, aspects discussed below under Subsections 3.2.1.1, 3.2.1.2, 3.2.1.3, 3.2.1.4., and 3.2.1.5. These subsections present several areas of review, including field exploration methods, laboratory testing, conceptual modeling, computer modeling, and site characterization. It is not required that each of the areas of review below be evaluated by the reviewer, rather, an appropriate combination of the review areas, depending on the breadth of the DOE LA submittal, shall be conducted to provide reasonable assurance that the condition "evidence of extreme erosion" has been appropriately investigated and characterized as present or absent by DOE.

3.2.1.1 Field Exploration For Evidence of Extreme Erosion

For any field exploration information presented by DOE, the staff will review the DOE field exploration program to determine its sufficiency to establish bounds for the characteristics of evidence of extreme erosion in the geologic setting including age, character, and importance of identified evidence. A surficial or geomorphic map which identifies any areas of extreme erosion and demonstrates a thorough evaluation of erosive events and processes within the geologic setting, particularly for the controlled area and nearby, should be a part of the DOE submittal unless comparable maps generated by other investigations can be shown to provide the appropriate information. Uncertainty in assumptions, exploration and evaluation techniques, and conclusions should be treated explicitly by DOE in the LA.

Field Mapping—For any field mapping information presented by DOE the staff will review and assess the results relative to the definition of the distribution and characteristics of extreme erosion in the geologic setting. As applicable the staff will use the following review procedures and acceptance criteria in the assessment

(1) The areal extent of geologic mapping, in concert with other aspects of the field exploration program, is sufficient to define extreme erosion or the lack thereof in the geologic setting both within and outside the controlled area, including its absence or the degree to which it is present, or if it may be present and underestimated, or present but undetected. The aggregate of topics which may be supported by mapping include: (i) stream erosion; (ii) base level change; (iii) nature of erosive/sedimentary environment; (iv) short-term and long-term erosion rates in areas such as Solitario Canyon, Fortymile Wash, and YM slopes; (v) importance and likelihood of highly erosive but suspected infrequent events such as the debris flow evidenced on Jake Ridge in the early 1980's; (vi) importance of climate stability or change on erosion rates; (vii) presence or absence of types of erosion which might affect waste isolation, (viii) mapping of surficial features to allow the evaluation of sediment provenance and quantity including describing erosive events and processes, and (ix) description of pertinent landforms or features.

(2) The scale of mapping, including scales of aerial photographs used as base maps, is sufficient to provide the accuracy and precision required for locating and mapping any landforms resulting from extreme erosion, or geomorphic features which demonstrate slope stability and the absence of extreme erosion. Map scale should allow for the identification of land features resulting from erosive events and processes which if they were to occur in the future might affect waste isolation (i.e., downcutting or incision in the tens of meters).

(3) Location and identification of landforms or features described by DOE should be detailed enough for field verification of mapped characteristics and landforms. DOE should demonstrate that such features and characteristics are accurately located, described, and reported. The means for reporting should be sufficient to identify the location of the landform or deposit and to facilitate field verification by NRC (if desired).

(4) Alternative interpretations of the acquired data are provided when appropriate. Because geomorphology and the explanation of origin of landforms are interpretive science, there are usually multiple hypotheses to explain the action of the natural processes which sculpted the geologic features. Where viable, but conflicting, explanations for the origin, timing, and extent of an erosional or depositional feature are raised, DOE should demonstrate that it has sufficiently

investigated each of the hypotheses. DOE discussions should demonstrate that conclusions are reasonable for a particular set of events.

(5) Uncertainties in data acquisition, accuracy of location, data representativeness, data reduction, age-dating, identification of strata and lithologies, stratigraphic relationships, and analytical methods are presented and discussed. The means used to reduce uncertainty and the resultant residual uncertainty are reported.

Geophysical Testing—For any geophysical testing data presented by DOE the staff will review and assess the results (e.g., seismic reflection, seismic refraction, seismic tomography) conducted at and around YM that were used to assess characteristics and distribution of events and processes of extreme erosion. Geophysical techniques are one of the means which can be used to define buried, otherwise unreachable strata and lithologies, particularly of aggradational and depositional features. As applicable the staff will use the following review procedures and acceptance criteria in the assessment if geophysical tests are used in the evaluation of this PAC.

(1) The number and location of geophysical tests, in concert with other aspects of the field exploration program, are sufficient to define the evidence of the PAC in the controlled area including its absence or the degree to which it may be present, present but underestimated, or present but undetected.

(2) Detection capabilities of the testing methods are evaluated and appropriately reported by DOE. For example, it is probable that geophysical testing could be used to identify the thickness and extent of various Quaternary Period alluvial deposits contained in Fortymile Wash and its tributaries. Geophysical results of this type would be expected to be correlated with and enhanced by results of borehole sampling of appropriate horizons in the geophysically defined strata.

(3) Resolution capabilities of the geophysical methods are evaluated and appropriately reported by DOE. Determination of the thickness and quality of depositional layers may be critical to developing the erosive history of YM slopes during the Quaternary Period; the correct evaluation of such properties depends upon the resolution characteristics of the instrumentation.

(4) Techniques for collection of geophysical field data are shown to be appropriate, limitations of the techniques are understood and are accounted for, and limitations and inherent uncertainties are accounted for in the final analyses.

(5) Capabilities and limitations of the geophysical data processing techniques are evaluated and appropriately reported by DOE. Uncertainties in interpretation should be discussed along with alternate explanations of structure and characteristics.

(6) The reproducibility and sensitivity of the results to the various input parameters are accurately described by DOE and are presented in an appropriate format to facilitate verification by independent processing of selected geophysical data which might be performed by NRC staff.

(7) Alternative interpretations of the acquired data are provided when appropriate. The sedimentation histories of Fortymile Wash and its tributaries are presented in the DOE TR on extreme erosion (U.S. Department of Energy, 1993) with alternate hypotheses including erosional removal of sediment down to the depth of the bedrock channel for the entire basin, and alternately, a set of

cut-and-fill sequences in the Quaternary Period and the Holocene without enough erosion to remove all the basin sediments. Where such alternate explanations are viable, DOE should demonstrate the validity of its evaluation and final conclusion of presence or absence (if necessary, carry the consequence of multiple hypotheses through to its final consequence evaluations in the assessment of repository performance).

(8) Uncertainties in data acquisition, data representativeness, data reduction; age-dating, identification of strata, lithology and stratigraphic relationships, and analytical methods should be presented and discussed. The means used to reduce uncertainty and the resultant residual uncertainty are reported.

Drill Core and Borehole Logging—For any drill core and borehole logging information presented by DOE as applicable, the staff will use the following review procedures and acceptance criteria in the assessment of DOE program of drilling core recovery and borehole logging which results in data used in the evaluation of extreme erosion.

(1) The program of drilling and subsequent drill core analyses used during site characterization, in concert with other aspects of the field exploration program, is sufficient to define the PAC (in the sediments of Fortymile Wash, for example, where recovery of meaningful alluvial core is expected to be extremely difficult) including its absence or the degree to which it is present, present but underestimated, or present but undetected. Such drilling and subsequent subsurface data acquisition may be an important part of a demonstration that erosion and its extremes are adequately researched and that the full range of available information has been utilized to arrive at the conclusions included in the LA.

(2) The drilling techniques used, and their associated limitations, are accurately evaluated and reported by DOE. Information on field verification of drilling techniques during the acquisition of the data is available to the reviewer. The use of drill core analyses and borehole logging records in concert with age determinations in order to establish sediment quantities and provenance in the Fortymile Wash drainage basin, for example, is rigorously documented and the methods used to age-date deposits or structures are accurately presented.

(3) DOE evaluation of the core logs accurately reflects the character of the lithology encountered by the drilling. The DOE evaluation places emphasis on amounts and areas of alteration, locations of lithologic and stratigraphic contacts, and general lithologic descriptions. The core logging and analyses are based on standard industry practices for borehole logging. DOE should demonstrate that the core recovered is a representative sample of the field conditions.

(4) Comparison of the results of geophysical logging with the core and accompanying descriptive core logs shows results which are consistent.

(5) Alternative interpretations of the acquired data are provided when appropriate. [See (7) discussed under Geophysical Testing, earlier].

(6) Uncertainties in data acquisition, data representativeness, data reduction, age-dating, identification of strata, lithologies and stratigraphic relationships, and analytical methods are presented and discussed. The means used to reduce uncertainty and the resultant residual uncertainty are prominently reported.

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Other Exploration Programs—For any other exploration techniques used by DOE in evaluating evidence of extreme erosion , as applicable, the staff will use the following review procedures to determine the acceptability of the results (e.g., trenching, acquisition of meteorologic and climatologic data).

(1) The number and location of planned tests and data acquisition, in concert with the field exploration program, are sufficient to define the evidence of extreme erosion in the geologic setting.

(2) The DOE in the LA utilizes defensible evidence in its discussion of the presence or absence of erosion during the Quaternary Period and its subsequent classification as extreme or not extreme. Detection capabilities of the methods used are evaluated and appropriately reported by DOE.

(3) Techniques for collection of field data are shown to be appropriate, limitations of the techniques are understood and are accounted for, and limitations and inherent uncertainties are carried through the required analyses. Any samples acquired in the field exploration and characterization activities are well-documented as to location, collection method, analytical method, and statistical inference. Data corroborating the discussions either are a part of the LA or are readily accessible in electronic format such as in the DOE computerized database. It is desirable that the LA contain appropriate maps as well as providing accessible, usable, electronic copies of such data in appropriate format (such access might be provided to the staff reviewer within the purview of the DOE electronic databases).

(4) Capabilities and limitations of the data processing techniques are evaluated and appropriately reported by DOE.

(5) Techniques which are controversial are appropriately supported in the LA with documentary evidence demonstrating the test of validity of the technique utilized. The reasons for application to the current problem as well as short-comings, limitations, and any inherent uncertainty are presented. Documentation of the technique in a peer reviewed journal is not to be considered, *a priori*, by the NRC reviewer as acceptable evidence of validity.

(6) Alternative interpretations of the data are provided when appropriate. When controversial or "cutting edge" techniques are used, objective evidence and evaluation of the validity and accuracy of the technique in the context of the conclusionary interpretation embraced by DOE is presented in the LA.

(7) Uncertainties in data acquisition, data representativeness, data reduction, age-dating, identification of strata, lithologies and stratigraphic relationships, and analytical methods should be presented and discussed. The means used to reduce uncertainty and the resultant residual uncertainty are reported.

3.2.1.2 Laboratory Testing To Support Evaluation Of Erosion

For any laboratory analyses which are a part of the DOE compliance demonstration, the staff reviewer should determine that the laboratory testing program is sufficient to establish the ages of the various pieces of evidence for and against extreme erosion, including the ages of any stable surfaces used to discount extreme erosion as a factor at the site. Additionally, NRC staff should evaluate for sufficiency

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any laboratory evidence used to demonstrate the absence of extreme erosion in the recent geologic evolution (past 2.0 million years) of the geologic setting.

The staff will selectively review and assess procedures and results from the various laboratory testing programs used by DOE, including those from such tests as chemical analyses and age determinations. As applicable, the staff will use the following review procedures and acceptance criteria to determine the acceptability of the DOE demonstration of compliance:

(1) Approaches used in sampling various pieces of evidence of extreme erosion are either standard or, if not standard, are documented such that the sampling procedure can be repeated by those trained in the technique.

(2) Procedures used in the subsequent analyses are either standard or, if not standard, are documented such that the tests can be repeated by those trained in the technique. Techniques for sampling and analysis which rely on subjective judgment of the analyst and which are not easily described and accomplished by peers are not acceptable tests. For example, the selection of boulders and the subsequent laboratory methods used to determine cation-ratio ages for desert varnish on YM and nearby areas (U.S. Department of Energy, 1993) are replicable by NRC while using the DOE described technique.

(3) Resolution capabilities of the methods used are evaluated and appropriately reported. If state-of-the-art dating techniques, such as cation-ratio dating of desert varnish or cosmogenic methods are used, the reviewer should determine that DOE presents a cogent explanation of the theoretical basis of the technique and a scientifically valid explanation for the technique's applicability to the particular problem. When possible, multiple techniques are applied to the same geologic feature to support age determinations.

(4) Where calibration curves are used, DOE should provide sufficient documentation to permit a thorough evaluation of their bases and application.

(5) Results of all analyses are documented by DOE such that a technical reviewer can follow the steps used to arrive at a given conclusion.

(6) If DOE test results are culled or rejected, the technical bases for such rejection are clearly established and reported by DOE. An assessment of whether culling or rejection of data has unreasonably biased the results is included.

(7) Uncertainties in the analyses, including instrument analytical, sampling, data reduction, and data representativeness uncertainties, are appropriately reported and are a part of the uncertainty described in the data analyses. For example, cation-ratio age dating of desert varnish requires sophisticated instrumentation for analyses; the instrument(s) should be calibrated and their accuracy determined and reported in the LA in order for appropriate staff assessment of uncertainty of DOE results and conclusions.

(8) Alternative interpretations of the acquired data are provided when appropriate. [See Section 3.2.1.1 Item (7) under Geophysical Testing]

3.2.1.3 Conceptual Modeling To Explain Erosion

For any DOE conceptual models of extreme erosion during the Quaternary Period the staff should determine that the formulation and application of the models are sufficient to assure that an appropriate range of reasonable and realistic models has been considered. As applicable, the staff will use the following review procedures and acceptance criteria in determining that DOE conceptual models are acceptable.

(1) Interpretations drawn from the separate exploration, laboratory, or computer techniques corroborate one another, or differences are adequately explained. The relationships between calibration curve data and field-sampled data for calibrated age dating techniques, expected to be used in evaluating extreme erosion during the past 2.0 million years, are well documented and thoroughly explained.

(2) A range of reasonable and conservative alternative interpretations is presented when contradictions in interpretations do exist. For example, theories and explanations for Quaternary changes in climate in the geologic setting which differ from widely understood and accepted temperature and precipitation regimes established in the Southwest and in the rest of the world must be defended by DOE through reference or original data.

(3) Uncertainties in the interpretations of extreme or other erosive processes and events are adequately documented and addressed by DOE. An analysis of the representativeness of the data from which conclusions are drawn is presented. All uncertainties, including analytical and calculational, are to be documented and discussed. Assumptions are to be clearly stated and any deviations from normally accepted analytical or calculation techniques are to be explained. Uncertainties introduced by programs [such as semi-quantitative program (SSQ) used in cation-ratio dating analyses by DOE in their TR on extreme erosion (U.S. Department of Energy, 1993)] or equipment chosen by DOE (with the knowledge of inherent uncertainties) are defended by inclusion of appropriate supporting data, discussion of appropriateness of analytical method, evaluation of uncertainty and likely residual uncertainty, and unequivocal conclusions based on the information presented.

(4) DOE basic assumptions are clearly described and subsequent conceptual models are consistent with the understanding of field and laboratory data. Conceptual hypotheses for initiating events and processes, such as Quaternary Period climate temperatures, are consistent with the results of work elsewhere in the world. For example, YM should experience its coldest Quaternary Period temperatures in cycles and ages similar to those of the rest of the world.

(5) Model descriptions clearly reflect the degree of resolution of the experimental and investigative techniques applied to acquire data for the modeling, including the degree of resolution of data related to what could be present but undetected due to limitations of the methods applied.

(6) Models provide an adequate qualitative and quantitative explanation of features which are present or could be present but undetected. The level of uncertainty in the models is described and the effect of such uncertainties on the validity of the conclusions is explained.

(7) DOE numerical models and their results are comparable to results of analyses of other scientists. Models and results are compatible with results of analyses using independent models, such as

those developed by the NRC or elsewhere. DOE findings based on their models are not significantly different from conclusions which follow from widely accepted hypotheses.

(8) Conceptual models are compatible with those proposed for other geologic and physical phenomena, such as tectonics and climate (e.g., the extent and severity of past glaciations and their effect on local climate at YM).

(9) Models either fit within the range of reasonable and acceptable alternative models or, if they are bounding models, clearly demonstrate that features which may be present and undetected are taken into account.

3.2.1.4 Computer Modeling To Evaluate Extreme Erosion

For any computer modeling which is a part of the compliance demonstration of DOE the staff will determine that models of Quaternary Period extreme or other erosion is sufficient to assure an appropriate range of reasonable and realistic models have been considered. As applicable, the staff will use the following review procedures and acceptance criteria to determine the acceptability of the results of DOE computer modeling.

(1) Modeling incorporates reasonable and realistic bounds on the range of permissible parameters and input data. Computer models must follow from and be compatible with the appropriate conceptual models.

(2) Codes used are shown to be mathematically correct and to adequately represent the phenomena base on appropriate technical assumptions and simplifications.

(3) Resultant output of the models and codes can be readily compared to results from other similar models and codes.

(4) Ranges or bounds of the results are correctly reported along with the results of sensitivity and uncertainty analyses. [See Item (9) under Conceptual Models, Section 3.2.1.3]

(5) Alternative models and interpretations are provided when appropriate.

(6) Uncertainties in the analyses, including data sampling, reduction, representativeness, biases, and instrument analytical uncertainties, are appropriately reported and are a part of the uncertainty described in the data analyses.

3.2.1.5 Characterization of Evidence of Extreme Erosion

NRC staff will determine that the aggregate of the field exploration, laboratory testing, and conceptual and computer modeling is sufficient to assure that the broad range of erosive processes and events operating during the Quaternary Period has been investigated and evaluated within the geologic setting, as appropriate, and at Yucca Mountain, Nevada. Staff will determine whether characterization is sufficient to assure that an appropriate description and subsequent evaluation of potential effects of similar extreme or other erosion on waste isolation can be accomplished.

As applicable, the staff will use the following review procedures and acceptance criteria to determine the acceptability of DOE characterization of the presence or absence of extreme erosion.

(1) A time span of sufficient length to represent the approximately 2.0 million year duration of the Quaternary Period is investigated by DOE. Any deviation from investigating the entire 2.0 million years (assigned to the Quaternary Period by NRC staff) is justified by DOE.

(2) The areal extent of DOE investigations and characterization of erosive processes and events during the Quaternary Period is sufficient to identify extreme erosion which might affect waste isolation. Areas outside the controlled area should be investigated if extreme erosion there could affect waste isolation or the larger area provides the range of erosive events and processes which have occurred in the geologic setting during the Quaternary Period.

(3) The scale of DOE investigations is sufficient both in field studies and evaluations to assure that important erosive events and processes or features have not been missed. Events and processes that operated at a larger scale in earlier portions of the Quaternary (during mid-glacial cycles, for example) should be evaluated and discussed. If events and processes are dependent on a specific climate, for example, the reviewer should determine that DOE assesses and discusses whether such a climate (climate change) is expected to occur in the 10,000-year period of regulatory interest.

(4) Characterization efforts encompass alternative methods of age-dating, laboratory, and evaluatory techniques in order to provide a conservative estimate of the nature, rate, and extent of erosive processes and events during the Quaternary Period.

(5) Any discussions of processes and events during the Quaternary Period are shown to be substantiated in the literature or by DOE field studies. The reviewer should determine that DOE provides hard evidence for conclusions. For example, particular constructs designed to explain climate change at YM during the Quaternary Period which are not in agreement with other scholarly documentation should be extremely well supported and documented.

(6) Uncertainties in the data collection, sampling, representativeness, analyses, and evaluation including instrument analytical uncertainties are appropriately reported and are a part of the uncertainty described in the conclusions. For example, cation-ratio age dating of desert varnish requires a series of assumptions to allow for the dating technique to be applicable in the erosion context. The reviewer should determine that the uncertainties contained in the assumptions are presented and any resultant biasing of the results and conclusions is explained.

(7) DOE has characterized erosion thoroughly at the proposed YM repository and nearby by discussing, at a minimum, the following:

- Short-term (c. 10,000 years and less) and long-term erosion rates (up to length of Quaternary Period) on hillslopes and in valleys. The established long-term rates should be compared to any possible short-term catastrophic rates of erosion which have occurred within the geologic setting (not necessarily only at YM). The likelihood of such extreme erosion having occurred and remaining undetected or the inability of such erosion to have ever occurred at YM should be discussed. The NRC reviewer should determine that DOE has mapped the repository relative to the elevations of the surrounding topography in order

to identify those aspects of the proposed repository which would be most vulnerable to extreme erosion. The reviewer should be especially interested in DOE evaluation of erosion in those areas where the depth to the horizontal projection of the repository horizon is less than 100 m (e.g., valleys in SE portion of the controlled area). In these areas, erosion less than that required to unearth the repository might act to "short circuit" the distance to the accessible environment if extreme erosion were to occur in the valleys.

- Aggradational and degradational history of Fortymile Wash and its tributaries. The interpretational history of Fortymile Wash drainage system and its sedimentation are internally consistent and in agreement with the paleoclimate and erosional history of the surrounding region and hillslopes. The reviewer should determine that DOE has investigated erosion in at least one tributary channel to Fortymile Wash by conducting a sediment balance in the tributary basin. Many erosive events and processes are recorded in the visible desert landscape; however, it is possible that erosive events and processes that are recorded in the various sediments of the interfluvial basins in the YM area cannot be directly evaluated. The amount of erosion during a bounded time period may be derivable from back calculations from the volume of known, and dated sediment in a particular basin. The volume of sediment within the basin should approximate (balance with) the volume of material expected to be deposited if the degradation rate on the hillslopes is similar to that proposed by DOE in calculations of average regional denudation rates. A geologic map which indicates aggradational features relative to degradational erosional landscapes should be presented.

- Backwasting or scarp-retreat potential, particularly on west facing slopes on the Solitario Canyon side of YM. The reviewer should determine that DOE has investigated and documented any episodes of backwasting on the YM slopes adjacent to Solitario Canyon. Field measurements of slope conditions and talus accumulation leading to back calculation of likely erosion rates should be a part of the DOE presentation.

- Evidence of surface stability including soil catenas, sediment properties, effect of paleoclimate, significance of appropriately age-dated boulder stripes, or other surface features should be presented. The location of relatively age-dated, indurated soil surfaces on the Solitario Canyon side of YM, for example, should be shown on a geologic map of the vicinity. Appropriate conclusions should be expressed regarding the significance of such relatively ancient and stable soil deposits. Similarly, concretionary features on the east-facing slopes evident in the form of calcified boulder stripes should be discussed for their relevance to the demonstration of slope and landform stability during the Quaternary in the YM vicinity.

- The effects of local and regional base level change on the nature of erosion in the YM vicinity should be investigated and reported in the LA. The regional base level represented by Fortymile Wash should be contrasted with the downcutting potential of tributaries of Fortymile Wash and the apparent aggrading nature of the Fortymile Wash during the recent Quaternary.

- The effects of climate change on the nature of erosion during the Quaternary Period and in the regulatory future in the YM vicinity should be discussed including a demonstration of the severity of Quaternary climate changes and the suspected impact on erosion rates in the

YM vicinity. If DOE believes that the YM vicinity evidences a different response to Pleistocene glaciation than is interpreted elsewhere in the Southwestern United States or the world, the LA should contain the corroborating data and appropriate discussions to defend such conclusions.

- The effects of erosional events and processes which have initiated significant erosion within the geologic setting during the Quaternary Period and which could occur in the repository's future in YM should be discussed. DOE should demonstrate, for example, that an erosive event of such magnitude as the catastrophic draining and subsequent extreme erosion at Lake Tecopa could not occur at YM. DOE should state why such extreme erosion could not have occurred at YM in the past.

- Complementary evidence for the extent and magnitude of erosion during the Quaternary Period within the geologic setting and at YM. The reviewer should determine that DOE has demonstrated that investigations rely on multiple techniques which support and complement evaluatory results. Reliance on and discussion of only one technique to demonstrate absence of extreme erosion in the YM area is not acceptable without significant support.

3.3 Rationale For Review Procedures and Acceptance Criteria

3.3.1 Rationale for Safety Review of 10 CFR 60.21(c)(1)(ii)(A),(B),(F) and 10 CFR 60.122(c)(16)

The reviewer will base the compliance determination Safety Review for evidence of extreme erosion on standard scientific and industry practice. The staff is expected to employ its professional judgment and other expert opinion to evaluate the DOE demonstration of compliance with the regulation. Qualifications and experience of the reviewers will be of critical importance to the review process. Success of the review will be strongly dependent on professional judgement of the reviewers, who must possess a thorough knowledge of geology of the site and its geologic setting. The Safety Review of 10 CFR 60.122(c)(16) will incorporate the requirements of 60.21(c)(1)(ii)(A), (B), and (F) as they relate to extreme erosion through acceptance criteria based on the regulatory requirements of 10 CFR 60.122 and 10 CFR 60.21. The criteria emphasize assessment of methods for determining absence of extreme erosion or describing what may be present, or present but undetected, or underestimated such that assumptions used in performance assessment and design regarding evidence of extreme erosion will not lead to underestimation of potential effects of this process.

If extreme erosion, defined by NRC as "substantial changes in landforms over a relatively short time interval (Nuclear Regulatory Commission, 1983)" is not expected to occur at YM, within or outside the controlled area, then the PAC is absent and no further consideration of effects of extreme erosion need to be included in the overall system performance assessment. The staff believes that "substantial changes in landforms over a relatively short time interval" are any changes which could affect the isolation of the waste in the 10,000-year regulatory timeframe. Two important scenarios which DOE should consider in order to evaluate the presence or absence of extreme erosion are as follows: (i) evidence of any erosion to the extent that waste, as buried in the proposed repository, could be exhumed in a 10,000-year timeframe would be considered extreme, and (ii) evidence of any erosion, particularly channel-deepening, whose effect might be to shorten distance for radionuclides travelling from the underground repository to the accessible environment during the 10,000-year regulatory timeframe. If such extreme erosion is evident within the geologic setting, then, DOE must demonstrate that the effects of such erosion, if it

were to occur either within or outside the controlled area, would not affect the isolation of the waste significantly.

Once erosion in the geologic setting and at YM is well documented and understood, it can be determined if extreme erosion is present or absent based on criteria which should be established by DOE in their submittal. If DOE chooses to demonstrate that evidence of extreme erosion is not present in the YM controlled area, it should provide evidence of slope stability (e.g., stability might be evidenced by the boulder stripes on YM and elsewhere within the region which might represent ancient relict deposits indicative of the lack of erosion). DOE should also define both long-term and short-term erosion rates, and should assess the lack of potential for extreme erosion within the controlled area and nearby. These assessments should factor in the physical constraints on such erosion (e.g., the aggrading nature of Fortymile Wash indicates that a major drainage change would have to occur before erosion which might be extreme could occur on Fortymile Wash and its tributaries). NRC reviewers should determine that features such as the boulder stripes are mapped in detail, their origin explained, alternate hypotheses for their development investigated, and their age relatively established using a variety of well established geomorphologic, soils, stratigraphic, cosmogenic, and other dating methods.

An important result of the review of this PAC will be an understanding of conceptual models for extreme erosion which may be used to develop various mathematical models for application in performance assessment, including consideration of probability and consequences of potential extreme erosion (if present) during the period of performance. There is expected to remain an unknown residual uncertainty in the results and in the models used to explain the results.

The final results of this phase of the staff review must rely on the professional judgement, experience, and qualifications of NRC review personnel. It is expected that model results may not always be completely validated and verified.

4.0 IMPLEMENTATION

4.1 Review Responsibilities

The review responsibilities for this review plan are as follows:

Lead:	DWM/ENGB	Geosciences/Geotechnical Engineering Section
Support:	DWM/PAHB	Geochemistry

4.2 Interfaces

4.2.1 Input Information

Information derived from activities related to other review plans will provide input important for considering evidence of extreme erosion. A list of review plans for which this interface is anticipated to be particularly important is presented in the following table.

Input Information	*Review Plan No.*
Geologic System—Data on the geomorphology of the region and site. Topographic maps. Surficial deposit maps. Geomorphologic maps. Discussions of the geomorphic processes and associated landforms in the region and the site. Information on aggradation/degradation including history of sedimentation in Crater Flat and Fortymile Wash, in particular.	3.1.1
Hydrologic System—Data on the surface hydrology.	3.1.2
Geochemical System—Data on solution features.	3.1.3
Climatological and Meteorological Systems Descriptions Paleoclimate—Discussions of likely past climates during the Quaternary Period.	3.1.4 3.1.4.X
FAC: Nature and Rates of Physical Processes—Discussion of the rates of erosive processes in the area and at YM.	3.2.1.1
FAC: Minimum Waste Emplacement Depth—Discussion of likely depth from repository location to the overlying surface.	3.2.1.2
FAC: Nature and Rates of Hydrologic Processes—Discussion of likely surface hydrology.	3.2.2.1
FAC: Nature and Rates of Geochemical Processes—Discussion of rate of solutioning.	3.2.3.1
PAC: Changes to Hydrologic System From Climate—Discussion of climate change and associated change in hydrology which might influence anticipated rates of erosion.	3.2.4.2

4.2.2 Output Information

Output from activities associated with this review plan will provide specific information important for use in other review plans as the following table indicates.

Output Information	*Review Plan No.*
PAC: Flooding—Likely rates of erosion, mass wasting, and other degradational phenomena.	3.2.2.5
PAC: Changes in Hydrologic Conditions—Drainage changes resulting from erosion.	3.2.2.9
PAC: Potential For Water Table To Rise and Inundate a Repository—Drainage changes resulting from erosion.	3.2.2.11

Output Information	*Review Plan No.*
Assessment of Compliance With Criteria For Integrated Analyses of Combinations of Favorable Conditions and Potentially Adverse Conditions—Expected rates of erosion during the regulatory period. Determination regarding the existence of this PAC—Anticipated erosion (if extreme) must be considered with other physical changes in the system.	3.2.5
Assessment of Compliance With The Requirements For Cumulative Releases of Radioactive Materials. Models of Erosion—Extreme and/or other erosion rates will be provided for consideration in performance assessment. Assessment of Anticipated and Unanticipated Processes and Events—Extreme and/or other erosion rates will be provided for consideration in performance assessment. Nature and Rates of Quaternary Period Extreme Erosion—Extreme and/or other erosion rates will be provided for consideration in performance assessment.	6.1
Assessment of Compliance With The Individual Protection Requirements. Models of Erosion—Extreme and/or other erosion rates will be provided for consideration in performance assessment. Assessment of Anticipated and Unanticipated Processes and Events—Extreme and/or other erosion rates will be provided for consideration in performance assessment.	6.2

5.0 EXAMPLE EVALUATION FINDINGS

The staff should consider the Example Evaluation Findings presented below together with the Acceptance Criteria set forth in Section 3.0 when making the actual Evaluation Findings resulting from the Acceptance Review for docketing and the Compliance Reviews. The Acceptance Review findings and the actual Evaluation Findings resulting from the Compliance Reviews, including the supporting bases for all findings, should be documented by the staff in the SER.

5.1 Finding for Acceptance Review

The NRC staff finds that the information presented by DOE on the PAC concerned with evidence of extreme erosion is acceptable (not acceptable) for docketing and compliance review.

5.2 Findings for Compliance Reviews

5.2.1 Finding for 10 CFR 60.21(c)(1)(ii)(A),(B),(F) as they relate to 10 CFR 60.122(c)(16)

The NRC staff finds that the PAC related to evidence of extreme erosion has (has not) been acceptably demonstrated to be present and that there is (is not) reasonable assurance that the regulatory requirements of 10 CFR 60.21(c)(1)(ii)(A),(B),(F) as they relate to 10 CFR 60.122(c)(16) will be met.

The staff is developing supporting Example Evaluation Findings for each of the indicated 10 CFR 60.21 regulatory requirements for inclusion in subsequent revisions of this review plan.

6.0 REFERENCES

DeWispelare, A.R., L.T. Herren, M.P. Miklas, and R.T. Clemen. 1993. *Expert Elicitation of Future Climate in the Yucca Mountain Vicinity; Iterative Performance Assessment Phase 2.5*. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Nuclear Regulatory Commission. 1983. *Staff Analysis of Public Comments on Proposed Rule 10 CFR Part 60, Disposal of High-Level Radioactive Waste in Geologic Repositories*.NUREG-0804. Washington, DC: Office of Nuclear Regulatory Research.

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 Waste Management to identify the most current edition of the FCRG in effect.]

Nuclear Regulatory Commission. *License Application Review Plan for the Review of a License Application for a Geologic Repository for Spent Nuclear Fuel and High-Level Radioactive Waste, Yucca Mountain, Nevada*. Washington, DC: Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards.

U.S. Department of Energy. 1993. *Evaluation of the Potentially Adverse Condition—Evidence of Extreme Erosion During the Quaternary Period At Yucca Mountain, Nevada*. Yucca Mountain Site Characterization Project Topical Report OCRWM. YMP/92-41-TPR. Washington, DC: U.S. Department of Energy, p. 71.

U.S. Department of Energy. 1995. *Technical Basis Report for Surface Characteristics, Preclosure Hydrology, and Erosion, Office of Civilian Radioactive Waste Management*. YMP/TBR-001. Rev. 0. Washington, DC: U.S. Department of Energy.