Department of Energy
Washington, DC 20585

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References: (1) Ltr, Bell to Brocoum, dtd 1/30/95
(2) Ltr, Holonich to Milner, dtd 8/22/94
(3) Ltr, Barrett to Youngblood, dtd 1/26/94
(4) Ltr, Youngblood to Shelor, dtd 12/30/93
(5) Ltr, Shelor to Holonich, dtd 3/9/93

Dear Mr. Holonich:

The U.S. Department of Energy is responding to the U.S. Nuclear Regulatory Commission staff's comments on the topical report, "Evaluation of the Potentially Adverse Condition 'Evidence of Extreme Erosion During the Quaternary Period' at Yucca Mountain, Nevada" and providing additional information supporting the conclusions reached in the report.

The Department submitted the topical report to the Commission in March 1993 (Reference 5). As a result of the preliminary review of the topical report, the Commission's staff described their concerns with the topical report (Reference 4). The Department responded to these concerns in Reference 3. In early February 1994, the Department and the Commission staff had a site visit to review independent lines of geological evidence which substantiated the Department's position that the potentially adverse condition is not present at Yucca Mountain, Nevada. After formal review of the topical report, the staff restated their concerns and provided nine detailed comments in Reference 2. On October 7, 1994, the Department and the Commission's staff participated in a videoconference to discuss and clarify the staff's comments. After considering the comments and information from the videoconference, the Department developed draft responses to the comments, and these draft responses were discussed with the staff during a teleconference on January 13, 1995.

In the concerns (Reference 2) about the Department's conclusion that the potentially adverse condition is not present, the Commission stated that: (1) the Department's method has not accurately determined erosion rates for time periods in the range of 10,000 and 100,000 years, and the method by which the Department has determined erosion rates may underestimate the actual process rate; (2) the Department has not provided sufficient justification on the acceptability of using the varnish cation ratio dating technique to support the conclusion that the potentially adverse condition is not present; and (3) the data qualification process did not demonstrate that the varnish cation ratio technique was suitable for its intended use.

The Department has provided the enclosed information to answer the concerns and responded in detail to each of the nine comments (Reference 2) from which the concerns were derived. Based on a teleconference between the Department, the Commission, the State of Nevada, and Nye County, Nevada, that took place on January 13, 1995, the Department understands that only the nine comments, and not the concerns, are being tracked by the Commission as open items.

The Department's overall approach to address the Commission's comments has two parts: (1) provide qualitative, independent lines of geologic evidence, based on existing data, that demonstrate the antiquity and long-term geomorphic stability of Yucca Mountain and the surrounding area; and (2) corroborate the ages of the colluvial boulder deposits determined with varnish cation ratio with independent age determinations using appropriate cosmogenic radioisotopes and thereby validate the varnish cation ratio technique.

This response addresses the first part of the approach. The second part will be addressed by the submittal of the cosmogenic dating to the Commission before the end of fiscal year 1995.

Enclosure 1 is a brief executive summary explaining the material contained in the responses, and Enclosure 2 contains the detailed responses to the nine comments and concerns on the topical report. Our responses to each comment discuss information that is relevant to the specific matter, and addresses the basis points for each comment item-by-item to aid the Commission in their review.

Based on the Commission's comments, the Department completed a comprehensive reassessment of its methods, data, and conclusions. The Department looked at the method for calculating rates of hillslope degradation, bedrock erosion, and stream incision, and assessed its ability to measure these processes over time. Multiple, independent lines of geologic evidence, were evaluated. Based on this evaluation, the Department concluded that the potentially adverse condition, "evidence of extreme erosion during the Quaternary Period," is not present at Yucca Mountain. The Department then re-examined its conclusions in light of two questions: (1) have process rates been underestimated, and (2) is the potentially adverse condition present but undetected? The Department estimated the amount of erosion that could occur over the 10,000-year period of intended performance based on the average and maximum erosion rate determined for the Yucca Mountain area. Uncertainties that the Commission believes are inherent in the varnish cation ratio dating technique and present in the age estimates as overestimations were considered. The Department considers that on this basis, many of the uncertainties that the Commission believes are contained in the analysis of extreme erosion are compensated for by this extraordinarily conservative approach.

The Department has also presented a preliminary analysis which: 1) illustrates the sensitivity of the amount of erosion expected during the performance period to changes in erosion rate estimates, and (2) compares the estimated amounts of erosion to the planned depth of the proposed repository. The responses in Enclosure 2 contain references to important information that has become available since Topical Report YMP/92-41-TPR was prepared. This work was carried out under an approved quality assurance program. The work is a composite "Preliminary Surficial Deposits Map" that encompasses most of Yucca Mountain. The map can be cited as a Department of Energy product. The other data are from a study of a debris flow that occurred at Jake Ridge in 1984.

The Department regards the information summarized above and detailed in the responses which follow, when considered in conjunction with the information in the Extreme Erosion Topical Report, as sufficient and adequate to resolve the Commission staff's comments and answer the concerns about the presence of the potentially adverse condition, "evidence of extreme erosion during the Quaternary Period," at Yucca Mountain.

The Department is now conducting a limited investigation for independent, cosmogenic dating of selected outcrops and boulder deposits on both tuff and basalt substrates. The Department expects to provide this information to the Commission by the end of fiscal year 1995. The Department intends to provide a brief report documenting this work to the Commission in a subsequent letter and expects the results of this work to corroborate the ages determined for a sampling of colluvial boulder deposits dated with the varnish cation ratio technique.

The Department will also provide, in a separate transmittal, the references cited in the Department's response (Enclosure 2) and requested in Reference 1 within a month. Enclosure 3 provides a list of the Department's commitments to the Commission contained in this letter.

If you have any questions, please contact Christian Einberg of my staff at (202) 586-8869.

Sincerely,

Ronald A. Milner

Ronald A. Milner, Director
Office of Program Management and
Integration
Office of Civilian Radioactive
Waste Management

Enclosures:
1. Executive Summary
2. Detailed Responses
3. List of DOE Commitments
to the NRC

cc:
W. Barnes, YMSCO
R. Loux, State of Nevada
T. Hickey, NV Legislative Committee
J. Meder, NV Legislative Counsel Bureau
M. Murphy, Nye County, NV
D. Bechtel, Clark County, NV
P. Niedzielski-Eichner, Nye County, NV
B. Mettam, Inyo County, NV
V. Poe, Mineral County, NV
F. Mariani, White Pine County, NV
R. Williams, Lander County, NV
L. Fiorenzi, Eureka County, NV
J. Hoffman, Esmeralda County, NV
C. Schank, Churchill County, NV
L. Bradshaw, Nye County, NV
W. Barnard, NWTRB
E. Lowry, NV Indian Environmental Coalition
R. Holden, National Congress of American Indians

Rec'd with 4/13/95

Executive Summary

The Department of Energy (DOE) submitted the Extreme Erosion topical report (YMP/92-41-TPR) to the U.S. Nuclear Regulatory Commission (NRC) on March 9, 1993. On August 23, 1994, and after formal review of the topical report, the NRC staff provided nine comments and concerns on the topical report. This response package has been developed to provide comprehensive responses to the comments and concerns. The responses have been developed from existing data and present multiple lines of independent geological evidence which support DOE's conclusion that the potentially adverse condition, "evidence of extreme erosion during the Quaternary Period," is not present at Yucca Mountain, Nevada.

DOE has addressed the NRC concerns by describing the multiple conservatisms included in methods for estimating erosion rates, and describing independent lines of evidence in the Quaternary geologic record which support DOE's conclusions. Additionally, DOE has research under way for other studies which will provide independent estimates of the ages of selected boulder deposits using cosmogenic dating techniques. This information is expected to corroborate the results of the varnish cation ratio dating. DOE intends to provide the new data to the NRC by the end of fiscal year 1995.

The measurement of the magnitude of erosion requires measuring materials which have been removed--materials which are no longer present. The erosion rate is an estimation of the rate at which the missing material has been removed.

The NRC has suggested that evaluation of the potentially adverse condition "evidence of extreme erosion during the Quaternary Period" should have focused on the description of short-term, even singular events, rather than longer-term events. If the amount of erosion during the entire Quaternary had occurred in a single event that our techniques were capable of resolving, the probability of the single event occurring during the 10 ka period of regulatory concern would be so low that the event would no longer be sufficiently credible to warrant further consideration.

DOE has chosen a method to evaluate the potentially adverse condition, "evidence of extreme erosion during the Quaternary Period" which incorporates multiple conservatisms. The conservatisms are present in the methods DOE used to measure process magnitudes, establish the calibration curve used in the varnish cation ratio dating, determine ages of boulder deposits, and estimate erosion rates and evaluate variations in those rates. Corroborating evidence from the geologic record was used to support the antiquity and geomorphic stability of the land surface on Yucca Mountain and in the surrounding area and demonstrate conservatism in DOE's evaluation. This information is provided in detail in the responses and summarized below:

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- Average erosion (hillslope degradation) rate estimates were calculated and compared with similar rates worldwide and in other areas of the United States. Average rate estimates were maximized because maximum amounts of incision and minimum ages of surfaces were used in the calculations. The averaging method produced rate estimates that are conservative.

- Amounts of erosion were measured in channels on mid and lower hillslopes which are areas of maximum hillslope erosion. Data from upper hillslopes, areas in which no evidence of erosion was found, were excluded from erosion rate calculations. Since the channels are zones of maximum erosion, measurements of process magnitude made in these channels insured that rate calculations were likely to overestimate the amount of overall slope degradation and were, therefore, conservative.

- The uranium trend (U-trend) ages that were used to develop the varnish cation ratio calibration curve were minimum estimates, and only the results of multiple analyses which produced internally consistent results were used. DOE reviewed the effects of variations in U-trend ages of up to 50 percent on the varnish cation ratio calibration curve. Variations in U-trend ages produced little effect on the varnish cation ratio calibration curve.

- Bedrock incision above the potential repository and alternative incision scenarios for Fortymile Wash were examined. Extreme variations in these rates were evaluated, and these variations would not produce extreme erosion.

- At Yucca Mountain, the entire available Quaternary geologic record was examined. The record is one of the longest and best-documented records available in the southwestern United States. Maps of surficial units indicate there is no evidence of extreme erosion on Yucca Mountain or in the peripheral drainages.

- The antiquity and stability of the land surface at and around Yucca Mountain have been established by the estimated ages of the boulder deposits, presence of carbonate layers beneath some boulder deposits, thicknesses of the varnish layers on boulders, presence of an alluvial unit that is nearly 3 Ma in Fortymile Wash, preservation of relict colluvial-boulder deposits which have survived multiple climatic cycles during the Quaternary, lack of thick alluvial aprons around the base of Yucca Mountain, the distribution of the early and middle Quaternary alluvial units and geomorphic surfaces peripheral to Yucca Mountain, and the presence of readily erodible sand ramps near Yucca Mountain.

These multiple independent lines of geologic evidence corroborate the DOE conclusions regarding the antiquity and stability of the Yucca Mountain area (see Enclosure 2). The hillslope colluvial boulder deposits are the oldest known dated deposits in the southwestern United States, and their antiquity indicates that denudation has been a remarkably slow process since the boulder deposits became stabilized.

- Degradation and denudation, which are broader processes than erosion and are typically considered to include erosion, were evaluated. This insured that the process definitions did not limit evaluations of conditions. Had DOE limited its evaluation to erosion, debris flows, which are the primary transport processes at Yucca Mountain, would have been excluded from consideration.

DOE regards the information summarized above and detailed in the responses which follow, when considered in conjunction with the information in the Extreme Erosion topical report, as sufficient and adequate to resolve the NRC comments and answer the concerns about the presence of the potentially adverse condition, "evidence of extreme erosion during the Quaternary Period," at Yucca Mountain. In addition, DOE has research underway which will be used to validate the varnish cation ratio age estimates of selected boulder deposits using cosmogenic dating techniques.

This information supports the conclusion that the potentially adverse condition, "evidence of extreme erosion during the Quaternary Period," is not present at Yucca Mountain, Nevada. Preliminary comparative estimates by DOE indicate that the expected amount of erosion based on projections of the average erosion rate (DOE, 1993b, p. 48) over the period of regulatory concern, would be less than 0.02 meters. In a bounding case, the erosion rate for Boundary Ridge could be increased by two orders of magnitude (100 times), the expected amount of erosion, during the period of regulatory concern and based solely on this higher rate, would be less than 6 meters or less than three percent of the planned depth to the proposed repository of more than 200 meters. Comparison of this bounding case with the amounts of erosion expected based on projections of erosion rates for climatically and lithologically similar areas over the next 10 ka, indicates that the amount of erosion expected at Yucca Mountain would still be far less than that expected for similar areas and would not constitute extreme erosion conditions.

Responses to Concerns and Comments

Concern 1. Scope of the Topical Report

The Topical Report does not acceptably address the 10 CFR Part 60 regulatory requirements applicable to the extreme erosion topic at this time. Specifically, this Topical Report has provided information on long-term denudation rates averaged over the Quaternary Period rather than on periods of extreme erosion during the Quaternary. DOE's approach in the Topical Report is to average the effects of geomorphic processes operating on hillslopes through at least several, probably many, cycles of hillslope aggradation and degradation. As noted in SCA Comment 43 (p. 4-42):

"Regional, long-term rates of erosion averaged over time and applied to specific areas do not provide a conservative estimate of potential erosion which could occur over a short time period during a single erosive event. Failure to consider maximum conditions in predicting erosion over the next 10,000 years may result in an underestimation of the effect of potential erosion."

Therefore, as stated in its December 29, 1993, preliminary comments, the NRC staff believes that the Topical Report does not acceptably address the subject such that the staff has no questions or disagreements at this time. The basis for this finding is that DOE's assessment relies on average denudation estimates over long intervals of time (i.e., in excess of 100,000 years) rather than on periods of extreme erosion that have occurred during the Quaternary, which if they recur, could have an adverse effect on repository performance.

Response

DOE's choice of a method to estimate erosion rates required consideration of several factors including the appropriateness of the method to the geologic setting, and its ability to produce results which are easy to comprehend, consistent and comparable, and characteristic of Yucca Mountain and the surrounding area. The nature of the method, and its similarity to methods being used by other practicing geomorphologists, combine to provide rate estimates that are appropriate and defensible. DOE has described its method and articulated the basis for selecting the method in section 3.3.3 of the topical report (DOE, 1993b). DOE briefly reiterated its position on its method for calculating erosion rates in its January letter to the NRC (DOE, 1994).

DOE notes that the measurement of the magnitude of erosion requires measuring something which has been removed--something which is no longer present. The erosion rate is an estimation of the rate at which the missing material has been removed. Fortuitous circumstances are required to allow accurate measurement of the amount of missing material combined with the occurrence of datable surfaces. Both of these elements are required to calculate estimates of erosion rates. Based on the evidence in the geologic record, the average rate of erosion during the Quaternary Period is low. Estimates of the average and maximum rates are provided in the topical report (DOE, 1993b, p. 48).

As described below, the time periods DOE has used are compatible with the qualitative guidance on the meaning of the term "extreme erosion" provided by the NRC staff in NUREG 0804 (December, 1983) and with the Commission position on the definition of short-term periods of time (49 FR 9650, March, 1984). The staff guidance was issued in response to a request for clarification of the term "extreme erosion" and stated:

> "The staff has used the term 'extreme erosion' to refer to the occurrence of substantial changes in land forms (as a result of erosion) over relatively short intervals of time."

and the Commission position was provided during the preliminary concurrence on DOE's siting guidelines (49 FR 9650).

DOE's evaluations followed the guidance of the staff (NUREG-0804) and the Commission position on "short-term periods" (49 FR 9650) and focused on identifying significant changes in land forms that occurred during the Quaternary. The averaging method DOE used to estimate rates is inherently consistent with the common meaning of the word "during" which is generally defined as "throughout the duration of" (for example, see Mish, 1993, p. 360), but avoids the pitfall of estimating rates that are not characteristic of the geologic setting because they are estimated over inappropriately short periods of time.

The topical report (DOE, 1993b) presents calculated average degradation rate estimates for various portions of the Quaternary Period. The portions of the Quaternary were discriminated based on evidence preserved in the geologic record. These rates were compared to average degradation rates worldwide and elsewhere in the United States This comparison showed that Yucca Mountain rates are below rates for lithologically and climatically similar areas of the southwestern United States and are among the lowest rates documented anywhere. Since the rates are consistently below average, DOE determined that the rates are not extreme and concluded that extreme erosion is neither present within, nor characteristic of, the controlled area. Furthermore, multiple lines of independent evidence preserved in the geologic record support the relative antiquity (Whitney and Harrington, 1993, p. 1014) and geomorphic stability of Yucca Mountain and the surrounding area during the Quaternary Period (Coe and others, 1995). This information is discussed in detail in the response to Comments 1 and 4.

DOE selected the process of denudation because it is a more inclusive process than erosion. This imparted an inherent conservatism to the evaluation. A definition of the term was provided in the topical report (Appendix B), and additional discussion of the term, and its selection and use, are found in the response to Comment 1.

Recent mapping (DOE, 1995) in the vicinity of Midway Valley has provided the data for a preliminary estimate for denudation rates for the about last 20 ka. This rate is approximately 5 mm/ka (0.5 cm/ka) and is similar to the rate at Boundary Ridge. This similarity indicates that average erosion rates may have been relatively constant for the last 170 ka or more.

DOE estimated the amount of erosion that might be expected within the controlled area during the performance period and also attempted to analyze the sensitivity of the amount of expected erosion to the magnitude of the erosion rate estimate. Preliminary estimates indicate that the expected amount of erosion based on projections of the average erosion rate (DOE, 1993b, p. 48) over the performance period, would be less than 0.02 meters. Furthermore, if the maximum rate (Boundary Ridge = 0.571 cm/ka; DOE, 1993b, p. 48) were projected over the performance period, the expected amount of erosion would be less than 0.06 meters[1].

DOE notes that it is possible to develop a qualitative appreciation of the significance of the Quaternary erosion processes by comparing the maximum amount of hillslope degradation that has occurred during all of the Quaternary Period to the minimum required depth for the proposed repository. Such comparisons would consider multiple cycles of climatic change which have occurred during the Quaternary. Based on the information in Table 5 of the topical report (DOE, 1993b, p. 48), the amount of degradation at Yucca Mountain throughout the Quaternary is less than 3 meters. Projecting the maximum amount of erosion that occurred throughout the Quaternary over the next 10 ka would provide a conservative estimate of the amount of erosion that would be expected during the performance period. Even if all of the hillslope degradation observed were assumed to be the result of a single period of climatic change, over 100 such changes would be required in the next 10 ka to produce an amount of erosion equal to the required minimum depth of the proposed repository. Based on evidence in the geologic record, this frequency of climatic change during the 10 ka performance period is not sufficiently credible to warrant further consideration.

[1]For perspective, if the maximum rate were increased two orders of magnitude, and the resulting expected erosion over the performance period would be less than 6 meters. DOE notes that the planned depth to the proposed repository is more than 200 meters.

Concern 2. Adequacy of the Dating Method not Demonstrated

DOE's position on the absence of the extreme erosion potentially adverse condition is based on the varnish cation ratio (varnish cation ratio) dating technique. Based on its review of the information provided, the staff has concluded that DOE has not provided sufficient justification on the acceptability of using this particular technique. Specifically, the justification in the Topical Report does not resolve the NRC staff concerns that this technique may not provide reasonable assurance about the exposure ages of boulder deposits. These concerns stem from uncertainties with regard to the formation of desert varnish and the time-dependence of changes in the varnish cation ratio. The staff believes that these uncertainties must be acceptably addressed in the report in order to demonstrate that the varnish cation ratio dating technique is an acceptable dating method suitable for use in the Yucca Mountain, Nevada site. In addition to the concerns with the Topical Report's failure to demonstrate the acceptability of the varnish cation ratio dating method, the staff has also identified a lack of justification in the information provided that the technique has been accurately calibrated.

Response

Various concerns with the varnish cation ratio dating method have been identified by the staff in the above Concern and in Comments 4 and 5. The varnish cation ratio dating method is described in the topical report, and additional information is provided in the detailed responses to Comments 4 and 5. DOE regards the information in the topical report and these responses as sufficient to support the use and adequacy of the method. DOE has additional work in progress, as parts of other studies, which will provide cosmogenic ages for selected boulder deposits and soils. DOE expects to provide the information to the NRC by the end of fiscal year 1995 (FY 95). DOE expects that this information will corroborate the varnish cation ratio ages.

DOE has relied on varnish cation ratio dating to establish quantitative age estimates for several boulder deposits on and around Yucca Mountain. DOE demonstrates and documents, in these responses, that its understanding of the process of varnish development and limitations of the method are adequate. As reported in the topical report (DOE, 1993b, p. 36), DOE has tested the method in at least two areas with well-established ages and found that the results of varnish cation ratio dating are geologically consistent with field relationships and reasonable.

Dating information available at the time was used to calibrate the varnish cation ratio dating curve (Harrington and Whitney, 1987). Curves were constructed for Española Basin, New Mexico prior to development of the Yucca Mountain curve. Ages of features obtained by the use of each curve were evaluated within the geologic context of each area and compared to features that were independently dated. For example, as reported in the topical report (DOE, 1993b, p. 36) in the Española Basin, surface ages were compared to ages obtained for the Lava Creek B tephra and to deposits below the surface dated by amino acid racemization (Dethier and others, 1988; and Dethier and McCoy, 1993). These evaluations confirmed that the rock varnish ages are geologically reasonable. Similar comparisons in Las Vegas Wash indicate that the rock varnish ages are geologically reasonable. This method of evaluating age determinations from calibrated techniques is the standard method of justifying such Quaternary ages by practicing geomorphologists and Quaternary geologists.

In addition, a Los Alamos (LANL) Peer Review (Hawley and others, 1989) of the method resulted in the endorsement of the method as appropriate for age determinations in each of the studies for which the method had been selected.

A key issue for determination of the ages of the boulder deposits is the development of the calibration curve which shows how the varnish cation ratios of independently dated materials vary. As described in the topical report (DOE, 1993b, p. 35-37), DOE used a calibration curve developed for various materials and locations on and near Yucca Mountain. The results of this calibration indicate the following:

1. The varnish cation ratios plot as points along a straight line when plotted against the log of the age of the deposit. This result was documented in the LANL Peer Review Report (Hawley and others, 1989, p. 3 and 4).

2. The age estimates appear to be valid, reasonable, and consistent with estimates based on geologic evidence; for example, the presence of carbonate layers beneath some deposits (Whitney and Harrington, 1993, p. 1012).

3. As reported in the LANL Peer Review Report (Hawley and others, 1989, p. 4), the shape of the Yucca Mountain curve is similar to other published curves.

4. The age estimates are based on interpolation, rather than extrapolation, of data as shown in Figure 9 of the topical report and explained in section 3.3.2.1.6 Calculation of Uncertainties for Cation Ratios (DOE, 1993b, p. 37 and 42, respectively).

5. The validity of the method used to construct the calibration curve has been established by testing at other locations with well-established ages. Test locations were in the Española Basin, New Mexico (Harrington and others, 1988, p. 1051) and Las Vegas Wash in southern Nevada (Whitney and others, 1988). Both locations feature surfaces with varnished boulders which overlie deposits containing Lava Creek B tephra (620 ka). In both tests, the varnish cation ratio dating method gave results which were (1) consistent

with independent age estimates determined by other means, and (2) geologically reasonable (DOE, 1993b, p. 36).

DOE's investigations have identified no sites with geologic constraints that demonstrate the age estimates to be in error. DOE has shown that this corroborative activity provides the reasonable assurance that the NRC staff requires about the calibration of the method and the ages of the boulder deposits.

Concern 3. Deficiencies in the Qualification Process

The qualification process for the varnish cation ratio dating technique (and, consequently, the data acquired through employment of the technique) has not been demonstrated to be acceptable. The qualification process provides a formal process through which the suitability of a dating technique can be demonstrated to be suitable for its intended use. Two ways to demonstrate this are the use of independent confirmation (through the use of a second dating technique) and peer review.

In its review of the Topical Report, the staff determined that DOE had failed to demonstrate the technical adequacy of the varnish cation ratio dating technique, primarily due to a lack of calibration. A review of the varnish cation ratio dating technique by a 1989 Los Alamos National Laboratory Peer-Review Group for DOE made recommendations on how to better calibrate this age-dating technique. The Los Alamos Peer-Review Group noted deficiencies in data calibration and confirmatory benchmarking, and included in its recommendations: (1) the acquisition of more calibration points; and (2) the use of additional confirmatory dating methods. In its review of the Topical Report, the NRC staff was unable to identify any evidence that the Los Alamos Peer-Review Group recommendations had been acknowledged and/or implemented. In addition to the calibration issues raised by the Los Alamos Peer-Review Group, the staff identified concerns regarding the viability of the uranium-trend-method used to calibrate, in part, the varnish cation ratio dating technique. Given both sets of concerns, the staff has concluded that DOE has not demonstrated the acceptability of its qualification process of the varnish cation ratio dating technique.

Response

DOE determined that it has qualified the varnish cation ratio data and documented this determination in a letter to the NRC staff (DOE, 1994a, p. 2). The assessment of the suitability, for qualification, of the data for erosion rates at Yucca Mountain is described in the "Technical Assessment Report for the Qualification of Data for the Erosion Rates at Yucca Mountain" (DOE, 1992). This document is significant because it describes both the process used to assess the quality of the data collected prior to the NRC's acceptance of DOE's and Los Alamos' Quality Assurance Programs and the results of the assessment. Additional details may be found in the response to Comment 9.

The QA acceptability of the erosion data was discussed during a DOE-NRC Technical Exchange on May 27, 1992. Subsequently, a Technical Assessment of that data was performed to evaluate the QA acceptability of the data (DOE, 1992). The Technical Assessment was completed in accordance with Yucca Mountain Project Office (YMPO) Quality Management Procedure (QMP) 02-08, Rev. 1 and YMPO Administrative Procedure (AP) 5.9Q, Rev. 1, and was also consistent with Rev. 2. (Note: YMPO AP 5.9Q, Rev. 2

was being developed while the Technical Assessment was in progress.) The technical merits of the data were established according to YMPO QMP 02-08, Rev. 1.

The Technical Assessment was completed in two phases. The first phase reviewed the Technical and QA Procedures of the United States Geological Survey (USGS) and Los Alamos National Laboratory (LANL) that guided sample collection and analysis, and field measurements. These procedures were compared to current USGS and LANL procedures which control field and laboratory work at the time the assessment was made. The second phase verified that the scientific notebooks showed field work and laboratory work conformed to, and followed, the relevant procedures in-place at the time the notebooks were developed.

The assessment (DOE, 1992) was completed in August, 1992, and established that:

1. Equivalent QA procedures existed during the data gathering and evaluation.

2. The varnish cation ratio dating results obtained are not significantly different than those that would have been obtained if the work had been done under the current, approved QA program.

3. Corroborative data exists to substantiate the erosion data. The Technical Assessment Report identifies several types of corroborating age dates and notes that "... the overall argument on erosion rates does not hinge on the cation-ratio dating technique. U-series, U-trend, Cl-36, and tephrachronology studies were also carried out on early samples collected by the USGS and are in general agreement with the cation-ratio data" (DOE, 1992, p. 7).

The Technical Assessment report (DOE, 1992, p. iv) concluded:

> It is unanimously agreed by all five Technical Assessment Team Members that data collection and evaluation completed prior to NRC acceptance of the YMPO Quality Assurance Program can be qualified under current YMPO QARD requirements.

and recommended:

> The Technical Assessment Team <u>does recommend</u> to DOE YMPO that the technical data on Erosion be formally accepted as **<u>qualified</u>** under current YMPO QARD, Rev. 4 guidelines.

DOE therefore determined the data supporting the Extreme Erosion Topical Report is qualified (DOE, 1994a, p. 2) and adequate to support the topical report conclusion that the potentially adverse condition "evidence of extreme erosion during the Quaternary Period," is not present at Yucca Mountain, Nevada.

The following items relevant to the Peer Review are noteworthy:

1. The Peer Review was requested by LANL Principal Investigator, not YMSCO, and pre-dates the approval and implementation of the LANL Quality Assurance procedure. The Peer Review Report (Hawley and others, 1989) was not revised to reflect the provisions of the LANL QA procedure.

2. Although the Technical Assessment (DOE, 1992) reviewed the LANL Peer Review Report, the Technical Assessment did not include the peer review and report as elements of the process to evaluate the suitability of the data for qualification.

3. The Peer Review supported the results of the Technical Assessment. (See the Technical Assessment Report, DOE, 1992, p. 15.)

4. The Peer Review Report conclusion, that the varnish cation ratio method was technically suitable for use in seven studies (Hawley and others, 1989, p. 7), was not contingent on acceptance or implementation of the Peer Review suggestions.

5. The suggestions contained in the Peer Review Report (Hawley and others, 1989, p. 7) were provided as guidance for additional work and not to cure deficiencies in work already completed. Therefore, while DOE believes that the Peer Review Report reflected favorably on the varnish cation ratio age dating that was done by LANL, DOE did not respond to or implement, the suggestions contained in the Peer Review Report.

6. The LANL Peer Review Report endorsed the varnish cation ratio dating method as the best technique available at the time and suitable for its intended use. The report also endorsed the varnish cation ratio dating method for use in all of the studies for which it had been designated. Further, the Peer Review Panel concluded "... the varnish cation ratio age determinations by Dr. Harrington and collaborators are the best presently being done." (Hawley and others, 1989, p. 8)

DOE has established the validity of the varnish cation ratio technique by evaluating the results of varnish cation ratio dating in the context of regional and local geology and by the ability of the dating method to produce age estimates that are within the constraints of independently established age estimates. The results of varnish cation ratio dating have been tested at least two locations: Española Basin, New Mexico (Harrington and others, 1988, p. 1051), and Las Vegas Wash in southern Nevada. The varnish cation ratio results are consistent with known geologic constraints at the test locations and at Yucca Mountain. This indicates that the varnish cation ratio age estimates are geologically reasonable, and the technique provides valid age estimates.

DOE does not agree with the staff's comment that "...DOE had failed to demonstrate the technical adequacy of the varnish cation ratio dating technique, primarily due to a lack of calibration." The varnish cation ratio dating method is a calibrated technique. Estimation of ages using the varnish cation ratio method requires the development of a calibration curve from independently dated materials. Curve calibration is a location-specific process. Data from various locations cannot be grouped to generate a generic calibration curve. Furthermore, a calibration curve from one location cannot be correlated with a similar curve from a different location; nor can a curve from one location be used to estimate the ages of deposits in another area. This feature of the method was described in the LANL Peer Review Report (Hawley and others, 1989, p. 4).

The LANL Peer Review Group noted that the shape of the calibration curve, generated by Dr. Harrington, is consistent with the shapes of other published curves and depicts a linear relationship between the cation ratio and the logarithm of the age (Hawley and others, 1989, p. 4). The Peer Review Report suggested possible ways to corroborate some of the ages used to develop the calibration curve. This subject was discussed in the topical report (DOE, 1993b, p. 42) as follows:

> Although more data points might reduce the curve uncertainty to a minor degree, the concentration of data points is adequate to establish a calibration curve. Most age estimates for the boulder deposits in this report are derived from within the calibrated interval of the dating curve (11 of 12 deposits). The remaining point lies in immediate proximity to the calibrated interval. Any additional reduction in the uncertainty of the curve that could be obtained with the addition of a greater number of calibration points would not affect any of the technical conclusions in this report that are based on the dating curve.

This subject was also discussed in the Technical Assessment Report (DOE, 1992, Attachment 4, Birkeland's evaluation, p. 3):

> The main difference [between the procedures in effect when the data was collected and those in effect at the time of the Technical Assessment] is that the new procedures are much more detailed in the calibration aspects of the research, but these also are addressed in the LANL document. I [Birkeland] am not convinced that these slight differences would effect the technical results.

Based on the above information and the fact that the calibration curve was established using a least-squares fitting method, it is unlikely that including additional points, as suggested in the staff comment, would change the slope of the calibration curve used to derive the age estimates. The corroboration suggested would probably not affect any of the technical conclusions based on the dating curve in the topical report, nor would it significantly strengthen the support for DOE's conclusions about erosion rates or the absence of the potentially adverse condition. Hence, no clear technical need for the additional work exists. However, as noted previously, DOE has work in progress for other studies to date selected boulder deposits using cosmogenic beryllium 10 (^{10}Be) methods. DOE intends to provide the data to the NRC by the end of FY 95. DOE expects the results of these studies will corroborate the results of the varnish cation ratio dating technique.

Finally, DOE does not agree that "The Los Alamos Peer-Review Group noted deficiencies in data calibration and confirmatory benchmarking...." The Peer Review Report identified no deficiencies, nor was the calibration described as "deficient." Suggestions, not recommendations, for refinements in future work were offered, and the Peer Review Report endorsed Dr. Harrington's work without qualification or reservation (Hawley and others, 1989).

Comment 1

By relying on long-term denudation rates to define the absence of the potentially adverse condition, the Topical Report does not address the regulatory requirement for the potentially adverse condition, set forth in 10 CFR 60.122(c)(16), concerning evidence of extreme erosion during the Quaternary Period.

Response

The Glossary of Geology, (Bates and Jackson, 1987), published by the American Geological Institute, defines **erosion** as

> The general process or group of processes whereby the materials of the Earth's crust are loosened, dissolved, or worn away, and simultaneously moved from one place to another, by natural agencies which include weathering, solution, corrosion, and transport, but usually exclude mass wasting; specifically the mechanical destruction of the land and the removal of material (such as soil) by running water (including rainfall), waves and currents, moving ice, or wind. The term is sometimes restricted to exclude transportation (in which case denudation is the general term) or weathering (thus making erosion a dynamic or active process only).

Similarly, **denudation** is defined as

> The sum of the processes that result in the wearing away or the progressive lowering of the Earth's surface by various natural agencies, which include weathering, erosion, mass wasting and transportation; also the combined destructive effects of such processes.

The term denudation (or extreme denudation) appears to better address the intent of the potentially adverse condition than does the term erosion (or extreme erosion) because the most rapid removal of hillslope colluvium in an arid or semi-arid environment is usually by mass wasting. The form of the mass wasting is typically that of a debris flow. (For additional information on definitions, see Fairbridge, 1968 and Bull, 1991. For additional information on debris flows on and near Yucca Mountain, see DOE, 1988; Coe and others, 1992; and Whitney and Harrington, 1993, p. 1016; Coe and others, 1995).

Extreme erosion is a potentially adverse condition in physical terms only to the extent that sufficient rock and unconsolidated material overlying the proposed repository could be stripped away. This stripping can be viewed as resulting from either a single catastrophic event or from multiple less severe events. In either case, an average rate method provides an adequate means of assessing the existence of the potentially adverse condition. If the low average rate determined for Yucca Mountain is controlled by widely-separated, catastrophic events, events of this magnitude are widely separated in space and time to be of consequence, and the potentially adverse condition does not exist. If the potentially adverse condition were assumed to exist and the low average rate were due to a more-or-less continuous process or a few, large-magnitude, episodic events, the average rate when applied over the performance period, would produce an amount of erosion that is a very small fraction of the planned depth of the proposed repository. But the averaging method, as opposed to methods that rely on shorter term estimates or estimates based on single events, provides a reliable method to estimate the amount of erosion that would be expected during the performance period.

In addition, DOE's method can accommodate differences in ages of boulders from each deposit. For example, individual samples from various parts of the Skull Mountain boulder deposit show measurably different ages. This data indicates that boulders comprising toes of deposits were emplaced earlier than clasts that now form upper parts of the deposit (DOE, 1993b, p. 43 and Whitney and Harrington 1993, p. 1015). If boulders from different parts of deposits show systematic differences in varnish cation ratio ages, a consistent method to estimate the age of each deposit is required. Calculation of an average age, using the method described in the topical report (DOE, 1993b, p. 42), provides a consistent method to estimate ages of boulder deposits.

The purpose of the erosion studies and the use of the data from these studies are described in the topical report (DOE, 1993b, p. 12) as follows:

> The purpose of the erosion studies at Yucca Mountain was to determine the average long-term erosion rates on hillslopes within the Yucca mountain area and to determine average incision rates by streams in the Fortymile Wash and its tributaries overlying the repository block. Using the data gathered under these studies, a comparison is made to Quaternary erosion rates for other areas of the United States , including those with both similar rock types and with similar climatic conditions. This comparison demonstrates that erosion rates at Yucca Mountain are comparable to or lower than other published United States erosion rates. These low erosion rates result from a combination of the erosionally resistant welded tuffs that form the foundation of Yucca Mountain and the dry arid to semi-arid climate that has existed in this region throughout much of the middle and late Quaternary. Furthermore, the Quaternary geologic record for the Yucca Mountain area yields no evidence of extreme erosion during the Quaternary Period.

DOE has looked at erosion over periods of varying lengths from single events to periods that are reasonable when considered in the context of geologic time and adequacy for determining whether or not the potentially adverse condition, "evidence of extreme erosion during the Quaternary Period," is present at Yucca Mountain. DOE notes that the use of the words "long-term Quaternary erosion rates" (DOE, 1993b, p. 46) seems to have drawn attention away from the method DOE used to calculate erosion rate estimates and the fact that the time frames DOE considered are all "...during the Quaternary Period." However, DOE believes that the method is consistent with NRC staff qualitative guidance on the definition of the term "extreme erosion" in NUREG-0804 and with Commission position on the definition of "short-term" periods (49 FR 9650). DOE presented the basis for calculating erosion rates in the topical report (DOE, 1993b, p. 8) as follows:

> An unseen factor in erosion rates is time. Both climates and rates of tectonism change over time, which, in turn, results in variations in erosion rates over time. Thus, any erosion rate must be examined in light of the time period over which erosion has taken place. Long-term erosion rates average a range of erosion rates that took place during several cycles of climate change and perhaps even through changes in rates of tectonic activity. Short-term erosion rates measure the present rate of an erosion process that can be related to the present climate and tectonic environment. Short-term rates may be lesser or greater than the long-term rate of a region, depending upon how great are the climate fluctuations in a given region over time. On Yucca Mountain, for example, a short-term hillslope erosion rate on one slope may be high due to measurements after a single storm. However, if similar measurements are made on a different slope unaffected by the same storm, the short-term erosion rates will be lower than the longer-term average. For this reason, published erosion rates based on short periods, or individual events, are not included ....

The erosion rates are estimated for various portions of the Quaternary which is the regulatory period at issue and which is a short-term period from the perspective of geologic time. The rates of erosion in the topical report were calculated over time intervals varying from 170 to 1380 ka (DOE, 1993b, p. 48). Recent mapping in the vicinity of Midway Valley (DOE, 1995) has provided data for a preliminary hillslope denudation rate estimate of about 0.5 cm/ka for about the last 20 ka. The similarity of the Midway Valley rate to the Boundary Ridge rate indicates that average rates may have been relatively constant at about 0.5 to 0.6 cm/ka for the last 170 ka.

The siting criteria in 10 CFR 60.122(c) define 24 conditions as potentially adverse if they are "characteristic of the controlled area...." DOE understands "characteristic of the controlled area" to refer to an attribute or feature that is common in the controlled area or an event that happens on a regular, periodic, or frequent basis. An attribute or feature that is present at only one or two localities, or an event that occurs only once or twice during a sufficient period of time is not considered to be characteristic of the controlled area.

This definition is consistent with the concept of "characteristic" as "expected." In the context of erosion during the Quaternary at Yucca Mountain, the expected erosion rate is the mean (average) rate. DOE maintains that an average rate is characteristic of Yucca Mountain and the surrounding area throughout the Quaternary or during definable subdivisions of the Quaternary which are based on the evidence in the local geologic record. However, DOE notes that its evaluation methods allow consideration of alternative rates such as the rate estimated at Boundary Ridge (DOE, 1993b, p. 48) or the preliminary rate estimated from mapping in Midway Valley (DOE, 1995).

DOE has concluded that extreme erosion during the Quaternary is not characteristic of the controlled area because

- Degradation rates for the period 170 to 1,380 ka are less than average rates reported for climatically and lithologically similar areas of the southwestern United States and are among the lowest rates described anywhere (DOE, 1993b, p. 9-11 and 48-49). Hence, given the common meaning of the word "extreme" (DOE, 1993b, p. 2-3) the rates at and near Yucca Mountain cannot be extreme because they are less than average rates for similar areas of the southwestern United States (DOE, 1993b, p. 10-11).

- The preliminary estimate of the denudation rate for about the last 20 ka in Midway Valley is similar to the rate estimated for Boundary Ridge based on the 170 ka boulder deposits. This indicates that the erosion rate for about the last 170 ka may have been about 0.5 to 0.6 cm/ka. Compared to rates for lithologically and climatically similar areas of the southwestern U.S., this rate is again below average, and hence, it cannot be extreme.

- The 1984 Jake Ridge event (Coe and others, 1995, and Coe and others, 1992) which might be considered about as severe an event as could be expected in the area, produced no significant changes in landforms. Hence, while storm events such as that which occurred at Jake Ridge may be characteristic of the area, these storms apparently do not produce extreme erosion.

DOE has also concluded that its erosion rate estimate methods are conservative. The bases for this conclusion are as follows: (1) Degradation rates determined for weathered, unconsolidated material, colluvium, are greater than, and hence must overestimate, erosion rates for bedrock surfaces. (2) DOE investigated a broader, or more inclusive, range of land wearing phenomena by considering degradation and denudation, rather than strictly erosion. (3) DOE determined maximum process magnitudes, minimum durations, and did not include data from areas of no erosion (areas with process magnitudes of zero; DOE, 1993b, p. 46) in the erosion rate calculations. This insured that calculated rates fell within the highest part of the range of possible rates. Combined, these three elements of DOE's method for calculating erosion rates attach an inherent conservatism to erosion rate estimates.

Comment 1a

It is essential to determine whether the time periods which are used to calculate the erosion rates during the Quaternary are appropriate for evaluation of possible evidence of extreme erosion. NUREG-0804 (NRC, 1983, p. 382) defines extreme erosion as the "...occurrence of substantial changes in landforms (as a result of erosion) over relatively short periods of time..." [emphasis deleted]. Hence, estimates of erosion rates based on net erosion over hundreds of thousands or even millions of years may be inappropriate. It is feasible that much of the incision of a surface which is 500,000 year[s] old could have occurred over perhaps 10,000 year[s] or less. If this is the case, the shorter time interval could constitute a period of extreme erosion. However, averaged over a 500,000 year interval, estimated erosion rates would be 50 times less than the actual rates during the erosional episode. It is inappropriate to assume that the mean conditions which have prevailed over the past million years or so (perhaps 12 million year[s] in the case of estimated canyon incision rates) will be replicated over the next 10,000 to 100,000 years. The intent of 10 CFR 60.122(c)(16) must be carefully considered.

Response

Based on measurements of the amount of erosion during the Quaternary Period and multiple independent lines of evidence identified and described during geologic field mapping, there is no evidence in the geologic record of significant incision or "substantial changes in landforms (as a result of erosion)" (NRC, 1983a) at Yucca Mountain during the Quaternary. In fact, the geologic record indicates that the area has been remarkably stable by comparison to other areas in the southwestern United States and other areas (DOE, 1993b, p. 9-11). Maximum bedrock incision rates, averaged over the last 12.7 Ma, are about 0.8 cm/ka over the proposed repository site (DOE, 1993b, p. 54). This rate leads to an estimated 8 cm of bedrock incision over the 10 ka period of intended performance. (It should be noted that this rate includes the period of Miocene canyon formation which occurred between 12.7 and 11.6 Ma.)

Table 5 of the Topical Report (DOE, 1993b, p. 48) shows the estimated ages of various hillslope boulder deposits, the amount of channel incision adjacent to these deposits, and the average degradation rate for each location. If one considers only the deposits in Table 5 that are more than 1 Ma, the average amount of degradation adjacent to these deposits is only about 1.5 m, or the degradation rate for the million year period is about 0.15 cm/ka.

Recent field mapping (DOE, 1995) has provided data from which to calculate a preliminary estimate of the denudation rate in Midway Valley. This rate estimate is about 0.5 cm/ka for the about last 20 ka. The estimate is based on the thickness of alluvial material covering a buried soil horizon and a preliminary estimate of the surface area of the drainage that provided the alluvium. The rate is similar to the estimated rate for Boundary Ridge based on the 170 ka-old boulder deposits exposed on the ridge. The similarity indicates the erosion rate of about 0.5 to 0.6 cm/ka may have persisted for the last 170 ka.

Based on the results of field mapping, including recent work in Midway Valley, no evidence has been found in the geologic record of periods of extreme erosion at Yucca Mountain and the surrounding area. Degradation rates at Yucca Mountain and the surrounding area are below average for climatically and lithologically similar areas in the southwestern United States and are among the lowest rates described anywhere (DOE, 1993b, p. 9-11 and 48-49). For extreme erosion to exist, rates would certainly have to be above average, and no evidence for such above average rates has been found. To put the Yucca Mountain erosion rates in perspective, the expected amount of erosion based on projections of the average erosion rate (DOE, 1993b, p. 48) over the performance period, would be less than 0.02 meters. Furthermore, if the maximum rate (Boundary Ridge) were projected over the performance period, the expected amount of erosion over the performance period would be less than 0.06 meters. If the amount of expected erosion, based on the Boundary Ridge rate, were increased by 50 times, as suggested in the comment, the amount of erosion would still be less than 3 meters. Yet the planned depth for the proposed repository is more than 200 meters. Hence, the staff's concern about a potential underestimate of the erosion rate of 50 times appears to be unfounded.

DOE does not agree that "much of the incision of a surface which is 500,000 years old could have occurred over perhaps 10,000 years or less." In fact, given the geologic and climatic conditions which have prevailed at Yucca Mountain since the last glacial maximum, including the assumption of a fairly constant rate of erosion of about 0.5 to 0.6 cm/ka for probably the last 170 ka, and the time required for climatic changes, it is unlikely that conditions could develop that would be capable of producing 500,000 years worth of erosion in 10,000 years. For significant amounts of erosion to occur, multiple erosion cycles would be required, and each of these cycles would take thousands to tens of thousands of years to occur. There is simply not sufficient time in the performance period to accommodate multiple cycles of climatic change required to produce several cycles of erosion. This process of climate change is described below.

The climate model proposed in Whitney and Harrington (1993), proposes the following conditions for a hillslope erosion cycle to occur:

1. A wet climate (wetter than the present climate at Yucca Mountain) is needed to weather the material that will be eroded.

2. Time is required for the weathering processes to occur.

3. Climatic change to drier conditions is required to strip the weathered material from hillslopes.

With respect to the view that it is inappropriate to assume that conditions which have persisted over the last million years or more will be replicated over the next 10,000 to 100,000 years, the geologic evidence at the site strongly supports the position that the climatic and tectonic conditions and resultant average degradation rates that have persisted will continue during the performance period (see Harrington and Whitney, 1993, p. 1017).

Comment 1b

The role of the PAC is stated in The Statement of Considerations (NRC, 1983b, p. 28201) where the Commission stated "Thus, its interest in specifying that the geologic setting shall have exhibited "stability" since the start of the Quaternary Period was to assure only that the processes be such as to enable the recent history to be interpreted and to permit near-term geologic changes to be projected over the relevant time period with relatively high confidence. The concept is best applied by identifying, as potentially adverse conditions, those factors which stand in the way of such interpretations and projections.

Response

DOE's approach is consistent with the NRC's statement of the role of PAC. The results of various investigations that provided the data for the Extreme Erosion topical report indicate that the area has low average rates of erosion and has been geomorphically stable during the Quaternary, including the area's recent history. Evidence supporting these conclusions includes, for example:

- Hillslope boulder deposits are stable. At least part of the great stability of the boulder deposits on the steep slopes is due to underlying carbonate layers which effectively cement the deposits to the side of the mountain (Harrington and Whitney, 1993, p. 1012). Carbonate layers, many of which are generally acknowledged as requiring relatively long periods of time (possibly hundreds of thousands of years) to develop (Machette, 1985), occur beneath at least some boulder deposits (for example on Little Skull Mountain).

- Drainages in Midway Valley on the east side of Yucca Mountain, near the base of the west slope of Yucca Mountain, and near the bases of sand ramps at Busted Butte are aggrading because these drainages are all within the aggrading Fortymile Wash drainage system (DOE, 1993b, p. 29). For downcutting in Fortymile Wash to begin, the elevation of the base level in the Amargosa Valley would have to decrease, and optimal conditions, favoring downcutting, would have to develop.

- No evidence of extensive stripping of the land surface has been found even though maximum stripping occurs during arid climate cycles. In fact, as noted by Coe and others (1995) "the presence of relict colluvial-boulder deposits indicates a condition of slope stability throughout multiple climatic cycles during the Quaternary."

- Incision rates in unconsolidated colluvium on and near Yucca Mountain are low (DOE, 1993b, p. 48). Comparison of these rates with rates elsewhere (DOE, 1993b, p. 9-11) shows that the Yucca Mountain rates are below average and certainly not extreme. Yet these rates are assuredly greater than bedrock incision rates. Hence, the bedrock incision rates cannot be extreme.

- No evidence of transport of materials away from base of Yucca Mountain has been found during detailed field mapping activities. During the Jake Ridge event, about 5 percent of the available hillslope debris was eroded (Coe and others, 1995), and no significant changes to landforms were identified. Therefore, the Jake Ridge event is an excellent example of the absence of extreme erosion near Yucca Mountain during the Quaternary.

- Wells and others (1990) document that the Lathrop Wells cinder cone has undergone little erosional modification. They state "the Lathrop Wells cone has the maximum cone slope, apparently no apron development and shows no erosional modification of the cone flanks and crater." The age of the Lathrop Wells cone has been dated between 20,000 and 130,000 years and is still the subject of study. (See response to Comment 5.) However, whether the cone is 20,000 years or 130,000 years old is irrelevant; the absence of erosional modification demonstrates that erosion rates have been low during the late Quaternary and Holocene in the Yucca Mountain area.

- Surficial geological mapping around Yucca Mountain (Swadley and others, 1984) reveals extensive lower and middle Quaternary deposits. Over 85 percent of the surficial deposits and geomorphic surfaces exposed adjacent to the tilted blocks comprising Yucca Mountain were formed during the early to middle Quaternary. Exposed upper Quaternary deposits are confined to small areas on hillslopes and are probably buried below a thin veneer of Holocene alluvium in

Fortymile Wash and its tributaries, as well as the unnamed streambeds that cross Crater Flat (DOE, 1993b, p. 24). Thus there is no evidence of significant deposition, and hence no hillslope erosion on a regional scale in the vicinity of Yucca Mountain since the middle Quaternary. Also, no morphologic features that indicate localized extreme erosion during that period of time have been identified.

- Deposits of late Quaternary age are chiefly confined to present stream valleys. The lack of late Pleistocene and Holocene deposits at the base of Yucca Mountain hillslopes indicates that erosion rates from these slopes have been low during the past 100,000 years. Confinement of late Quaternary deposits to valleys and channels indicates the volume of material eroded off hillslopes has been smaller than during the early and middle Quaternary (DOE, 1993b, p. 24).

The remarkable stability of the area during the entire Quaternary, and especially during the Holocene, provides a basis for projections of erosion rates over the performance period. No evidence of the potentially adverse condition, "evidence of extreme erosion during the Quaternary Period," which would impact such projections has been identified in the Quaternary geologic record.

Comment 1c

The purpose of the extreme erosion potentially adverse condition is to assure a program of exploration and analysis which will ensure sufficient site characterization information to allow a projection of the erosion rates that could be expected during the period of the intended repository performance -- presently 10,000 years.

Response

DOE's program of evaluation for extreme erosion has drawn on the results of detailed field mapping and geochronological studies. From these studies, DOE has learned and documented the following:

1. The area features very low denudation rates (Whitney and Harrington, 1993, p. 1008) and has been geomorphically stable during middle and late Quaternary.

2. Erosion rates on and near Yucca Mountain are lower than average for climatically and lithologically similar regions in the southwestern United States and other parts of the world (DOE, 1993b, Tables 2 and 3).

3. Individual maximum erosion events, like that at Jake Ridge, do occur in the Yucca Mountain area (Coe and others,1995, and Coe and others, 1992). But these events do not produce significant changes to landforms and do not constitute

potentially adverse conditions.

4. Based on projections of the average erosion rate (DOE, 1993b, p. 48) over the performance period the expected amount of erosion is less than 0.02 meters. Similarly, if the maximum rate (determined at Boundary Ridge) were projected over the performance period, the expected amount of erosion would be less than 0.06 meters[1].

5. Recent mapping in Midway Valley (DOE, 1995), has provided data for a preliminary estimate of the denudation rate in alluvium over about the last 20 ka. The estimate is about 0.5 cm/ka and is similar to the Boundary Ridge rate. This similarity indicates that the erosion rate may have been fairly constant at 0.5-0.6 cm/ka for the last 170 ka.

6. Based on characteristic (average) hillslope denudation and stream incision rates during the Quaternary, the following amounts of erosion are predicted at Yucca Mountain over the next 10,000 years:

   < 0.02 m of slope retreat (denudation).
   < 1.0 m of downcutting in canyons above the potential repository block.
   < 15 m of downcutting in Fortymile Wash near well J-13. However, for this downcutting to occur, the elevation of the base level in the Amargosa Valley would have to decrease, and optimal conditions, favoring downcutting, would have to exist. Note that well J-13 is about 6 km southeast of the projected surface outline of the proposed repository.

This information is sufficient to demonstrate that the potentially adverse condition, "evidence of extreme erosion during the Quaternary Period," is not present at Yucca Mountain. The information is sufficient to support the conclusion because the information demonstrates the existence of multiple, independent lines of geologic evidence which, singly and in combination, show the antiquity and stability of the geomorphic features, and indicate that the condition is not present.

Furthermore, if the potentially adverse condition were assumed to be present for the purpose of discussion, the above information would provide the basis to define the range of erosion rates which might be expected at Yucca Mountain. These rates could be projected over the relevant time frame which is the performance period. Some such projections have been made (see items 4 and 6 above) and provide estimates of the amounts of erosion that might be expected under different conditions if the potentially adverse condition were assumed to exist.

Comment 1d

The staff sees nothing in the Topical Report which provides information which can be used to project erosion rates over the relevant time frame, the period of intended repository performance, or which addresses directly the question of extreme erosion.

Response

DOE provided estimates of both the average degradation rate and a maximum rate for Yucca Mountain in the topical report (DOE, 1993b, p. 48). Since these rates are far below similar rates for other areas, DOE determined that the Yucca Mountain rates cannot be extreme. In addition, DOE has shown that either the average or the maximum rate can be projected over the performance period. If such projections were made, the resulting estimates of the amount of erosion are so small that they would not be significant when compared to the planned depth of the proposed repository.

Furthermore, DOE has found no evidence of extreme erosion in the Quaternary geologic record, and DOE's evaluations considered processes that are broader in scope than erosion. These broader processes were selected to insure that debris flows, which are the primary colluvial processes on present-day hillslopes (Whitney and Harrington, 1993, p. 1016), would be evaluated rather than excluded because of the definitional limits of the term "erosion." For additional details, see the response to Comment 1.

If the Jake Ridge erosion event is taken as an example of maximum erosion during infrequent, cloudbursts in the arid to semi-arid climatic regime now existing at Yucca Mountain, and allowing for a uniform distribution of precipitation over the controlled area, this process-response model, projected over the next 10,000 to 100,000 years, should result in bare hillslopes, stripped of colluvial cover (Coe and others, 1995). As described in Whitney and Harrington (1993, p. 1010), debris flows would remove existing colluvium from the hillslopes, but little, if any, erosion of the hillslope bedrock would be expected (Harrington and Whitney, 1993, p. 1017). This would be the projection of hillslope evolution at Yucca Mountain over 10 ka in the face of unchanging climatic and tectonic influences.

If the climate changed, for example, to a cooler/wetter regime during that period, Whitney and Harrington's (1993, p. 1015-1016) climatic model requires tens of thousands of years for these changes to occur. Their process-response model over the next 100 ka would predict the re-mantling of the hillslopes with a cover of vegetation and colluvium and an overall decrease in the amount of debris flow activity on the stabilized hillslopes.

DOE's program of exploration and analysis has collected sufficient site characterization information to allow a projection of the erosion rates that could be expected during the period of the intended repository performance. Furthermore, this information plus consideration of Staff guidance (NUREG-0804) and Commission position (49 FR 9650) has led DOE to conclude the following:

1. Degradation rates are below average for climatically and lithologically similar areas in the southwestern United States. Hillslope degradation rates for study locations on and near Yucca Mountain are presented in Table 5 of the topical report (DOE, 1993b, p. 48). These rates can be compared with degradation rates for various areas within the United States (DOE, 1993b, p. 10-11) and the world (DOE, 1993b, p. 9). Comparisons of the data in these tables demonstrate that the maximum rate for Yucca Mountain is about a fourth, or less, of the rate for the Española Basin, New Mexico and the Cima Volcanic Field, California which are climatically and lithologically similar areas.

2. Maximum erosion, in the form of mass wasting (debris flows), occurs at Yucca Mountain as individual events triggered by infrequent storms (Coe and others, 1992; and Whitney and Harrington, 1993, p. 1016). However, such maximum erosion, where it occurs, is not extreme because it produces no significant changes in landforms and appears unlikely to present no adverse impact on the performance of the potential repository. Furthermore, the Commission has said that such single storm events are not of regulatory concern (49 FR 9650).

3. An adequate basis exists to make projections of the erosion rates and the amount of erosion that may be expected to occur at Yucca Mountain over the performance period. The erosion rates calculated for Yucca Mountain represent a range of climates and a number of climate cycles, and there is little basis for believing that future climates will differ sufficiently from the past climates to produce major changes in the rates of erosion (Whitney and Harrington, 1993, p. 1017). Furthermore, DOE has examined world-wide erosion rates, attained under a variety of climatic and tectonic conditions. Most of these rates are low (DOE, 1993b, p. 9-11 and 48-49), and if they were applied to Yucca Mountain and projected over the performance period, the resulting amount of erosion would be a very small fraction of the planned depth of the proposed repository.

4. Based on the results of recent mapping (DOE, 1995), preliminary estimates of the denudation rate for about the last 20 ka in Midway Valley are about 0.5 cm/ka. This rate is similar to the rate estimated at Boundary Ridge and indicates the erosion rate may have been fairly constant at about 0.5 - 0.6 cm/ka for the last 170 ka. If this rate were projected over the performance period, the expected amount of erosion would be about 0.05 to 0.06 meters compared to the planned depth of the proposed repository of

more than 200 meters.

5. DOE's investigations have provided multiple lines of independent evidence that demonstrate the geomorphic stability of the area during the Quaternary. Evidence for stability includes the following:

   - The ages of the dated boulder deposits (range of ages is 140 to 1,510 ka, (DOE, 1993b, p. 44 and Whitney and Harrington, 1993, p. 1014) indicate the antiquity of the hillslope surface. As noted by Coe and others (1995), the presence of relict boulder deposits indicates that stable slopes existed during multiple climatic cycles during the Quaternary.

   - The morphologies of the boulders comprising the deposits show no signs of differential movement of individual boulders or mechanical degrading of the varnish coatings which are considered to develop *in situ* (Whitney and Harrington, 1993, p. 1011). Hence, the boulders have been stable since the onset of the development of the varnish.

   - The boulder deposits themselves have not been incised, dissected, removed, or buried.

   - Carbonate layers, many of which require several hundred thousand years of relatively stable geomorphic conditions to develop (Machette, 1985), have been found beneath some boulder deposits (Whitney and Harrington, 1993, p. 1012). The shallow depths of burial of carbonate layers, beneath relatively thin layers of colluvium, indicates a general paucity of hillslope material that during the late Quaternary available to bury the carbonate layers.

   - The existence of thick sand (readily erodible material) ramps at Busted Butte and other locations near Yucca Mountain indicates that the magnitude and/or frequency of various erosion processes are not capable of removing even these unconsolidated materials.

   - The model of hillslope evolution (Whitney and Harrington, 1993, p. 1015-1016) precludes bedrock erosion in 10 ka because multiple episodes of climate change are necessary to create and subsequently strip colluvial material from hillslopes.

   - Wells and others (1990) document that the Lathrop Wells cinder cone has undergone little erosional modification. They state "the Lathrop Wells cone has the maximum cone slope, apparently no apron development and shows no erosional modification of the cone flanks and crater." The age of the Lathrop Wells cone has been dated between 20,000 and 130,000 (Crowe and others, 1992) years and is still the subject of further study. However, whether the cone is 20,000 years or 130,000 years old, the absence of erosional modification further demonstrates how low erosion rates have been since the late Pleistocene in the Yucca Mountain area.

- Extensive lower and middle Quaternary deposits and limited late Quaternary and Holocene deposits indicate most erosion of hillslopes occurred in the early and middle Quaternary. Little erosion has occurred since middle Quaternary time (Whitney and Harrington, 1993, p. 1017).

- Deposits of late Quaternary age are chiefly confined to present stream valleys. The lack of late Pleistocene and Holocene deposits at the base of Yucca Mountain hillslopes indicates that erosion rates from these slopes have been low during the past 100,000 years. Confinement of late Quaternary deposits to valleys and channels indicates the volume of material eroded off hillslopes has decreased since the early and middle Quaternary (DOE, 1993b, p. 24).

- Recently completed mapping in Midway Valley (DOE, 1995) has identified buried soil horizons in some alluvial units. This work has provided data for a preliminary estimate of the denudation rate in alluvium for about the last 20 ka of about 0.5 cm/ka. This rate is similar to the Boundary Ridge rate (0.571 cm/ka, DOE, 1993b, p. 48) and indicates that the rate of erosion may have been relatively uniform for the last 170 ka.

- An alluvial unit exposed along Fortymile Wash (Lundstrom and Warren, 1994) contains a unique clast population which indicates that the unit has been in place for nearly 3 Ma. This indicates that wholesale removal of this unit has not occurred, and the channel incision envisioned in the maximum incision scenario is unlikely.

DOE's investigations have provided sufficient information to describe the low rates of erosion that characterize the area and demonstrate the stability of the area during the Quaternary. The stability of the area precludes the existence of the potentially adverse condition, "evidence of extreme erosion during the Quaternary Period." This stability throughout the Quaternary, including the Holocene, also provides the basis necessary to project erosion rates over the period of intended performance.

Comment 1e

On pages 2 and 3, DOE agrees with the NRC characterization of "extreme erosion" as the occurrence of substantial changes in landforms (as a result of erosion) over relatively short intervals of time.

Response

This is a description of information in the topical report. No response required.

Comment 1f

On page 31, it is stated that "The erosion rates calculated in this study are long term erosion rates that average the effects of processes operating on these hillslopes through at least several, probably many, cycles of hillslope aggradation and degradation." Therefore, while the report agrees with the basic concept behind extreme erosion, the investigations documented in this report are not aimed at gathering the information necessary to resolve the question of extreme erosion.

Response

The information necessary to resolve whether or not the potentially adverse condition exists are estimates of the amount of erosion that has occurred at Yucca Mountain during the Quaternary and the results of comparing that information with other areas. DOE has provided this information in the topical report (DOE, 1993b, p. 48 and p. 9-11). In its estimates and comparisons, DOE used degradation rather than erosion to ensure that hillslope processes, such as debris flows, which are the principal hillslope erosional processes at Yucca Mountain (Harrington and Whitney, 1993, p. 1016) were not considered because of definitional limits.

The method DOE used to calculate erosion rates is appropriate to estimate erosion over relatively short periods of geologic time because of several considerations including:

1. Events like the Jake Ridge (Coe and others, 1992 and Coe and others, 1995) storm are maximum erosion events that are capable of moving alluvium and colluvium in an arid to semi-arid environment. The Jake Ridge storm is an excellent example of the absence of extreme erosion because it produced no significant changes in landforms. If such maximum events are not capable of producing extreme erosion, it is unlikely that the potentially adverse condition could exist under conditions which are, on average, less severe.

2. DOE determined, and the Commission agreed, that erosion rates of interest for determining the existence of the

potentially adverse condition are rates that occur over relatively short periods of geologic time (tens of thousands of years) but do not include individual, brief, episodic events (49 FR 9650). Even though individual events are inappropriate for consideration as potentially adverse conditions, DOE's method, nevertheless, provides a mechanism for including the cumulative effects of such events.

3. DOE understands "characteristic of the controlled area" to refer to an attribute or feature that is common in the controlled area or an event that happens on a regular, periodic, or frequent basis. DOE considers average magnitudes of processes and events to be characteristic as explained below.

4. The process of erosion must be considered in the context of the climatic cycles, especially the time necessary to develop or change climates, as necessary, to sustain erosion. Hence, rates calculated over time periods defined on the basis of evidence in the Quaternary geologic record are appropriate.

The estimation method that DOE (1993b) used calculates mean rates of erosion for periods of time which can be discriminated based on evidence in the local Quaternary geologic record. In the response to Comment 1, DOE explained why short-term hillslope erosion rates cannot be reliably extrapolated over the performance period. Erosion of a hillslope involves the removal of either bedrock or colluvium. DOE (1993b) has demonstrated that the down-cutting of bedrock is extremely slow in an arid to semi-arid environment and is not a short-term event except when the term "short-term" is considered in the context of geologic time. For significant amounts of hillslope erosion of colluvium to occur, barren slopes must be subjected to an episode of physical weathering to create debris that could wash off the slope. Thus, bedrock slopes must experience a cycle of climate change to create the colluvial debris necessary to support rare debris flows which strip the hillslopes (Coe and others, 1992). Climatic cycles require several thousand years to develop, and this is not consistent with the use of short-term rates except where "short-term" is defined in the context of geologic time.

DOE considers the estimation of average rates to be consistent with the regulatory definition of conditions as potentially adverse (10 CFR 60.122(c)) if they are "characteristic of the controlled area ...." Comparison of the Yucca Mountain average degradation rates with rates for climatically and lithologically similar areas in the southwestern United States indicates that the Yucca Mountain rates are below average (DOE, 1993b, p. 9-11 and 48-49). Even under the most conservative and restrictive definition, rates of extreme erosion must be above average. Therefore, the Yucca Mountain erosion rates, which are below average, cannot be extreme. Based on this consideration, DOE (1993b) concluded that the Yucca Mountain rates are not extreme, and the potentially adverse condition of "evidence of extreme erosion during the Quaternary Period" is not present at Yucca Mountain.

Comment 1g

From examination of information found in Tables 4 (p. 44) and 5 (p. 48) it is apparent that not only were several cycles of both deposition and erosion used to calculate the values quoted, but the time periods used are, in some instances over two orders of magnitude greater than the present regulatory period of performance (i.e., 10,000 years).

Response

Based on evidence preserved in the geologic record, there is no clear scientific basis to subdivide the cycles of erosion and deposition as suggested by the comment. (Note: Discussions of paleoclimatic conditions at Yucca Mountain are provided in DOE, 1993b and Harrington and Whitney, 1993.) Therefore, investigations, and subsequent rate estimates, must consider full cycles of erosion and deposition, and the time required for these cycles to be completed. The time periods used for erosion rate calculations are based on estimated ages of geomorphic surfaces. These surfaces include the effects of all of the erosion and deposition cycles necessary to form them. DOE's method of calculating average degradation rates contains two inherent advantages: (1) all of the information on the amount of degradation and the recurrence rate is included, and (2) the degradation rate estimates are "characteristic" of the area.

DOE's approach is consistent with evidence preserved in the geologic record. The ages of several different deposits have been determined. The study of these different-aged deposits has included examination of different erosional cycles. Had any one of these been particularly severe, the observed consistency in long-term erosion rates would be unlikely. Also, recent mapping by the USGS (DOE, 1995) in Midway Valley has provided the data for a preliminary estimate of denudation rates for about the last 20 ka. This rate is approximately 5 mm/ka (0.5 cm/ka) and is similar to the rate for Boundary Ridge. This similarity indicates that erosion rates may have been fairly uniform over the last 170 ka. If this Midway Valley Holocene rate were projected over the performance period, the expected amount of erosion would be about 0.05 meters. Yet the planned depth for the proposed repository is more than 200 meters.

Comment 1h

The major portion of the Topical Report deals with dating of hillslope deposits presumed to be geomorphically stable. Estimates of rates of incision of channels adjacent to the stable boulder deposits are provided but there is little discussion of rates of incision along the canyons and washes, or of scarp retreat and other backwearing phenomena that are fundamentally *distinct from regional lowering of the land surface. Although the terms denudation and erosion are often used interchangeably (for example, see Kearey, 1993), for the purposes of this study, they should be clearly defined and differentiated.*

Response

Rates of incision along canyons and washes have been discussed in the topical report (DOE, 1993b, p. 45-46). DOE hopes that the results of the cosmogenic beryllium 10 dating will provide information from which scarp retreat rates for the Yucca Mountain area may be determined. DOE expects to provide the ^{10}Be data to the NRC by the end of fiscal year 1995.

An unusually long Quaternary record is preserved on the Yucca Mountain landscape. Early and middle Quaternary hillslope and basin alluvial deposits are common, while late Quaternary deposits are generally confined to the present washes (DOE, 1993b, p. 24). Degradation on hillslopes with dated deposits ranges from <0.1 to <0.6 cm/ka (DOE, 1993b, p. 48). Based on long-term average hillslope denudation and stream channel incision rates, the following amounts of erosion are predicted at Yucca Mountain over the next 10,000 years:

< 0.02 m of slope retreat (denudation).
< 1.0 m of downcutting in canyons above the potential repository block.
< 15 m of downcutting in Fortymile Wash near well J-13. (Note that well J-13 is about 6 km southeast of the projected surface outline of the proposed repository.)

The antiquity and geomorphic stability of the area throughout the Quaternary has been well documented (for example see Whitney and Harrington, 1993, p. 1014). Specific evidence for the geomorphic stability of the area was provided in the response to Comment 1d.

DOE has found no evidence of significant amounts of scarp retreat or other backwearing processes. In fact, scarp retreat seems to be a low rate process at Yucca Mountain. The absence of significant relief between channels on slopes indicates that a process of parallel slope retreat is operative, but again the rate is slow. Evidence for the slow rate includes the preservation of precariously balanced boulders near the crest of Yucca Mountain, and ridge crest outcrops and preserved boulders featuring thick coats of varnish.

With respect to the comment that "Although the terms **denudation** and **erosion** are often used interchangeably ... for the purposes of this study, they should be clearly defined and differentiated," DOE provided definitions of these terms in the topical report in Appendix B (DOE, 1993b, p. 59). DOE considers that (1) the uses of the terms in question are in concert with definitions of the American Geological Institute and experts in the field, and (2) additional definition of the terms is unnecessary. Finally, as noted in the response to Comment 1, DOE evaluated denudation and degradation in the topical report. These processes are more inclusive than "erosion." Had DOE limited its evaluation to "erosion," debris flows, which are the primary mass wasting process operating in arid to semi-arid environments (Harrington and Whitney, 1993, p. 1016), would have been excluded. To insure that these processes were included, DOE evaluated the processes included in the broader terms denudation and degradation. Hence, DOE's evaluation incorporated an inherent element of conservatism because of the inclusive nature of the processes evaluated.

Comment 1i

The foregoing observation calls into question the concept underlying the approach to this study. By dating stable geomorphic surfaces, the study is more likely to provide an impression of landscape stability than if its focus was the dating of erosional landforms and events. It would be valuable to estimate the likely range in erosion rates by comparing, for example, 1,000 or 10,000 year of an interpluvial episode (such as the Holocene) with a period of similar length during a pluvial cycle (such as that from about 25 to 15 ka).

Response

DOE has examined the available Quaternary geologic record. Fortunately, the available record is a long one and comprises approximately three-fourths of the period of the Quaternary as defined by the NRC for regulatory purposes. All available lines of evidence indicate the Quaternary was a period of geomorphic stability in the region. Specific evidence of this stability has been provided in the response to Comment 1d.

The methods DOE used to estimate erosion rates and the rationale supporting the method have been described. These methods have shown that no significant amounts of erosion occurred over periods of time that can be discriminated based on evidence in the geologic record. Much of the information in the record supports qualitative estimates of erosion rates for the periods suggested and the contention that hillslope deposits are old. The data supporting the antiquity of the hillslope deposits has been described in the Executive Summary (Enclosure 1) and the response to Comment 1a.

Furthermore, DOE adhered to the Commission's position (49 FR 9650) on the definition of "short-term" and believes that this position indicated that the periods of time that are of interest for determining whether the potentially adverse condition exists are "short-term periods taken from the perspective of geologic time (i.e., the Quaternary Period) [which] could last tens of thousands of years." DOE believes that the Commission's position obviates the need to evaluate short periods or discreet episodic events as suggested by the staff.

Finally, the results of recent mapping in Midway Valley (DOE, 1995) have provided data from which a preliminary estimate of the denudation rate in alluvium can be calculated. This rate is about 0.5 cm/ka over about the last 20 ka. This rate is similar to the rate estimated at Boundary Ridge and indicates that an erosion rate of about 0.5 cm/ka has may have persisted near Yucca Mountain for the last 170 ka. In addition Whitney and Harrington (1993, p. 1017) estimated an overall degradation rate of 0.008 m/ka, but they did not attempt to differentiate rates that might be likely during pluvial and interpluvial periods. The results of their work showed that pluvial periods are net aggradational and would show a stabilization of hillslopes associated with lower erosion rates when compared with arid to semi-arid periods. The stabilization of hillslopes would result from the development of a thicker soil mantle and additional vegetation. Additionally, more frequent but less intense precipitation is less capable of stripping colluvium from hillslopes than are individual, cloudburst-type storms.

Recommendation

DOE should use a methodology that provides information on the "extreme erosion rates"; those erosion rates which may have been experienced in the general Yucca Mountain area during relatively short periods of time, on the order of those periods of time equal to the regulatory period of performance (i.e., 10,000 to 100,000 years).

Response

DOE has examined both maximum erosion events, like that at Jake Ridge in 1984 (Coe and others, 1992 and Coe and others, 1995), and average erosion rates that are characteristic of the area (DOE, 1993b, p. viii). DOE considers the Jake Ridge event to be an excellent example of the absence of the potentially adverse condition because the event did not produce any significant changes in landforms (COE and others, 1995).

The results of recently-completed mapping in Midway Valley (DOE, 1995) have provided data for a preliminary estimate of the denudation rate in Midway Valley for about the last 20 ka. This period is within the range indicated in the comment. The rate is about 0.5 cm/ka and is similar to the Boundary Ridge rate. The similarity indicates that erosion rates may have been fairly uniform for the last 170 ka. Based on detailed investigations, DOE has found no evidence to support the existence of the potentially adverse condition, "evidence of extreme erosion during the Quaternary Period," at or near Yucca Mountain. Therefore, DOE has concluded that the potentially adverse condition is not present.

DOE evaluated a group of hillslope processes that are more inclusive than "erosion" and that were selected to insure that debris flows, which are the primary hillslope colluvial processes active in arid to semi-arid environments (Harrington and Whitney, 1993, p. 1016) such as that at Yucca Mountain, were evaluated. Had DOE evaluated only *erosion*, as strictly defined, debris flows would have been excluded from the evaluation. DOE determined that, by basing its investigations on a more inclusive term, the evaluation is more inclusive, conservative and robust than an evaluation based on the strict definition of the term "erosion."

In NRC's December 30, 1993 letter to DOE (NRC, 1993), the staff stated that the definition in NUREG-0804 for "relatively short intervals of time" referred to periods "which approximate the regulatory period of performance (i.e., 10,000 to 100,000 years)". DOE is concerned that the NRC (References 2 and 4) appears to have established expectations for evaluations that may be different than, or in addition to, requirements explicit in 10 CFR 60.122(c)(16).

DOE provided the staff with a list of the methods that could be used to date Quaternary deposits in Study Plan 8.3.1.5.1.4 (Analysis of the Paleoenvironmental History of Yucca Mountain Region). DOE is concerned that the staff's expectations may reflect unresolved questions about the capabilities of these Quaternary dating methods to provide resolutions in the 10 to 100 Ka range with accuracy and precision. These expectations for resolution of short-term events could impact other aspects of site characterization, such as the study programs for seismicity and volcanism. However, with regard to Extreme Erosion, DOE's investigations have provided ample information from several independent lines of geologic evidence to support (1) the determinations about the antiquity and geomorphic stability of Yucca Mountain and the surrounding area, and (2) the conclusion that the potentially adverse condition, "evidence of extreme erosion during the Quaternary Period," is not present at Yucca Mountain or in the surrounding area.

Comment 2

The rate of canyon cutting (quoted on page 55) appears to underestimate an estimated erosion rate in the Yucca Mountain region.

Response

The comment appears to be the result of a comparison of the estimated rate of canyon cutting above the repository (0.8 cm/ka) with stream incision rates for Fortymile Wash. If the canyon cutting rate is compared with the average erosion rate for Yucca Mountain (0.19 cm/ka, DOE, 1993b, p. 54), the rate of canyon cutting is shown to be more than four times the average erosion rate. However, the geologic evidence indicates that most of this incision occurred in Miocene time. Hence, in terms of the time frame being considered for regulatory purposes, the rate of bedrock incision is minimal.

Comment 2a

The topical report indicates that the rate of canyon cutting has been calculated at 0.8 cm/ka or less based on the fact that 60- to 100-meters canyons are cut into 12.7 million year old volcanic tuff.

Response

This observation is correct. However, based on the distribution of tuffs overlying the Tiva Canyon Tuff (that is, Pre-Tuff X, Tuff X, and Rainier Mesa Tuff units (Carr, 1992)), most of this incision is probably mid-Miocene and occurred between 12.7 and 11.6 Ma. This was the period of most active down cutting in the region and is beyond the period of regulatory interest.

Comment 2b

If the effect of tectonism is ignored, from the crest of Yucca Mountain to either Jackass Flat or to Crater Flat, over 300 meters of material has been eroded in the last 12.7 million years, not 60 to 100 meters.

Response

That more than 300 meters of material has been eroded assumes a geometry of the Tiva Canyon tuff and younger tuff units which is not supported by evidence in the geologic record. The preserved maximum thickness of the Tiva Canyon tuff is between 100 and 150 meters (Geslin and Moyer, 1995), and field evidence indicates that the deposition of non-welded tuff units above the Tiva

Canyon was restricted to canyons (*scoured surfaces* in Carr, 1992) cut into the fault-tilted blocks that comprise Yucca Mountain. Detailed stratigraphic investigations (Geslin and Moyer, 1995), and mapping (Maldonado, 1985 and Frizzell and Shulters, 1990) indicate that the only places the Rainier Mesa tuff, Tuff X, and Pre-Tuff X, are preserved are in canyons cut into the Tiva Canyon between 12.7 and 11.6 Ma or at the bases of fault scarps in the Tiva Canyon. There are no indications that the thicknesses of these units, which would be required to support the assumed geometry, were deposited on the upland portions of Yucca Mountain. Based on drill hole information (Geslin and Moyer, 1995), DOE estimates that the maximum amount of Tiva Canyon tuff that has been removed from northern Yucca Mountain is probably less than 15 meters. On the southern part of the mountain, the maximum amount of material that has been removed is probably less than 25 meters.

The interpretation that 60-100 meters of localized incision of the Tiva Canyon (but not degradation of the Tiva Canyon surface) have occurred during the last 12.7 Ma is consistent with evidence preserved in the geologic record. This evidence supports the calculated bedrock incision rate of 0.8 cm/ka described in the topical report (DOE, 1993b, p. 54). This incision rate is not represented in the topical report as a Quaternary rate. In fact, most of this erosion is pre-Quaternary and hence, is beyond the regulatory period of interest.

Comment 2c

In addition to those formations present on the crest of Yucca Mountain, the Rainier Mesa Member of the Timber Mountain Tuff is found on both sides of Yucca Mountain, and an unknown ash fall/ash flow unit is present in the subsurface in the area of the proposed repository. This unit is thought to be equivalent to units between the Tiva Canyon Member of the Paintbrush Tuff and the Rainier Mesa Member of the Timber Mountain Tuff. Therefore, the thickness of the Tiva Canyon remaining represents an underestimate of the amount of material which was originally present at Yucca Mountain. A conservative estimate would suggest that the canyon cutting rate quoted in the report could be low by a factor of 3 to 4 or more.

Response

This comment is an elaboration of the previous comment, and it indicates a possible lack of clarity in the description of the geology and geologic history of the area. The description of the stratigraphic relationships in the comment contradicts the mapped relationships (Maldonado, 1985; Frizzell and Shulters, 1990, and Geslin and Moyer, 1995). Specifically, the Pre-Tuff X, Tuff X, and Rainier Mesa tuffs were ash flows that were deposited in canyons and valleys (Carr, 1992) on and adjacent to Yucca Mountain. DOE has found no data to indicate that significant thicknesses of these non-welded, post Tiva Canyon tuffs were deposited on the upland portions of Yucca Mountain.

Data from detailed mapping of the surface geology (Maldonado, 1985) and core from drill holes (Geslin and Moyer, 1995) (including core from holes which penetrate buried sections containing apparently fairly complete thicknesses of Tiva Canyon tuff, indicate that (1) the thicknesses of Tiva Canyon underlying the hillslopes that form the eastern flank of Yucca Mountain are generally fairly uniform, and (2) most of the thickness of the unit has been preserved. DOE has found no evidence in the geologic record that "the thickness of the Tiva Canyon remaining represents an underestimate of the amount of material which was originally present at Yucca Mountain."

Based on the results of its investigations, DOE does not agree with the staff's concern that the canyon cutting rate that "could be low by a factor of 3 to 4 or more." The estimated rate of canyon cutting is 0.8 cm/ka which is more than four times the average erosion rate. Yet even if the canyon cutting rate were projected over the 10 ka performance period, the resulting amount of erosion would be only 8 cm versus the planned depth to the proposed repository of more than 200 meters. Furthermore, as explained in the response to Concern 1, projection of the maximum erosion rate (Boundary Ridge) over the performance period would result in an expected amount of erosion of less than 0.06 meters. A brief description of the effect increasing the maximum erosion rate by two orders of magnitude on the expected amount of erosion has been provided in the response to Concern 1 (see footnote 1). This description addresses the staff's concern with increases in the canyon cutting rate of 3 or 4 times and indicates that increases of two orders of magnitude in the rate are unlikely to produce significant erosion during the performance period.

Comment 2d

During the past 12.7 million years, the "erosion potential" of the Yucca Mountain area varied considerably during different climatic regimes -- there were periods of primary erosion and periods of primary deposition. Even if the average rate of canyon cutting for the last 12.7 million years can be calculated, it is unclear how this rate would be related to the rate which could be expected to occur during the period of performance. The rate quoted in the report could underestimate the expected rate of canyon cutting during the period of performance.

Response

The geological record indicates that most of the erosion that has occurred since the deposition of the Tiva Canyon tuff occurred in the mid-Miocene during the period 12.7 to 11.6 Ma. This erosion produced the canyons, lateral to Yucca Mountain, in which the post-Tiva Canyon tuffs, mentioned above, were deposited. DOE realizes that the potentially adverse condition concerns only evidence of extreme erosion that occurred during the Quaternary Period. The period 12.7 to 11.6 Ma is well beyond this period of regulatory concern. This information can be used to show that canyon cutting rates since 11.6 Ma, while they cannot be quantitatively estimated, have been low, and certainly lower than the 0.8 cm/ka rate estimated for the last 12.7 Ma.

As a consequence, DOE determined that the expected rate of canyon cutting during the performance period has not been underestimated and can be used as an upper bound for estimating the amount of canyon incision that would be expected during the performance period.

Recommendation

DOE should provide a methodology for determining the rate of canyon cutting which is representative of conditions that have occurred in the Yucca Mountain region during the Quaternary.

Response

The method described in the topical report (DOE, 1993b, p. 51) for calculating the rate of canyon cutting is representative of Quaternary conditions in the Yucca Mountain region because it uses deposits or surfaces to infer climates, and this same information is used as the basis for calculating canyon cutting rates. DOE provided bounding estimates of the amount of incision of unconsolidated deposits and bedrock that might be expected on and around Yucca Mountain. For incision in unconsolidated deposits, DOE proposed two incision scenarios to bound the problem (DOE, 1993b, p. 51-54). Based on information from recent mapping in Fortymile Wash (Lundstrom and Warren, 1994) and Midway Valley (DOE, 1995), the upper bounding (maximum incision) scenario appears unlikely and not sufficiently credible to warrant further consideration. From its investigations, DOE has determined that the minimum incision scenario is probably representative of conditions and processes that occurred at Yucca Mountain. Estimates of bedrock incision based on the minimum scenario are conservative because the scenario is based on rates in unconsolidated materials rather than on estimated rates for bedrock. The rate for unconsolidated materials is certainly higher than the rate for bedrock. Hence, estimates of the amount of canyon cutting during the Quaternary, based on the rate in unconsolidated materials, would be conservative.

Comment 3

The hillslope degradation rates, quoted in Table 5 (p. 48), appear to underestimate the rates of erosion which have occurred in the Yucca Mountain region during individual periods of erosion.

Response

DOE has estimated erosion rates through unconsolidated materials found at various locations on and around Yucca Mountain. The rates, cited in Table 5 (DOE, 1993b, p. 48), are for portions of the Quaternary which can be discriminated based on information contained in the geologic record. Since unconsolidated materials are more easily eroded than bedrock, one would expect that these rate estimates are higher than, and certainly provide conservative estimates of, bedrock incision rates which are the rates of principal regulatory interest.

Comment 3a

The purpose of the potentially adverse conditions (PAC -- 10 CFR 60.122(c)) is to identify those characteristics of the site that might have an unfavorable effect on 10 CFR Part 60 performance objectives. The rule requires that these conditions be described and analyzed a particular way (10 CFR 60.21 (c)(1)(ii)) in order to demonstrate that the performance objectives will be met (10 CFR 60.122(a)). One of the criteria that must be demonstrated is that "...the effects [of the potentially adverse condition on the performance objectives] have not been underestimated" (60.122(a)(2)(ii)).

Response

DOE believes that the regulations require that "'...the effects [of the potentially adverse condition on the performance objectives] have not been underestimated' (60.122(a)(2)(ii))" only "if any of the potentially adverse conditions specified in paragraph (c) of this section is present...." (10 CFR 60.122(a)(2)). DOE's comprehensive investigations have provided ample evidence to indicate that the condition is not present. DOE maintains, therefore, that it is not necessary to further evaluate the effects of the non-existent condition.

DOE has estimated erosion rates through unconsolidated materials found at various locations on and around Yucca Mountain. The erosion rate estimates are from lower hillslopes where colluvial wedges have accumulated, and the erosion rates calculated are for incision into these lower slope deposits and do not include areas where no erosion occurred (DOE, 1993b, p. 46). The comparison of the erosion rates estimated for Yucca Mountain (DOE, 1993b, p.

48) and the surrounding area with rates for climatically and lithologically similar areas (DOE, 1993b, p. 10) shows that the Yucca Mountain rates are far below average and certainly not extreme. The Yucca Mountain area average hillslope degradation rates are for unconsolidated materials. These rates are higher than rates calculated for the entire hillslope (which would include areas of no erosion that have excluded from estimates; see DOE, 1993b, p. 46) and would be expected to be higher than bedrock incision rates, which are the rates of primary regulatory concern. The use of these higher rates in the evaluation of the existence of the potentially adverse condition imparts an inherent conservatism to the evaluation.

To put the Yucca Mountain erosion rates in perspective, the expected amount of erosion based on projections of the average erosion rate (DOE, 1993b, p. 48) over the performance period, would be less than 0.02 meters. Furthermore, if the highest degradation rate, 0.571 cm/ka at Boundary Ridge, were taken as the rate for Yucca Mountain, and that rate were projected over the period of intended performance, the expected amount of erosion would be less than 0.06 meters. For perspective, the planned depth to the proposed repository is more than 200 meters.

DOE maintains that the potentially adverse condition is not present at Yucca Mountain, and the assessments specified in 10 CFR 60.122(a) are unnecessary. However, for the sake of discussion and allowing that NRC rejects DOE's conclusion that the potentially adverse condition is not present on the basis of the evidence currently available to them, DOE can address the aspects of 10 CFR Part 60.122(a)(2)(i) and (ii) that seek to determine the extent to which the "condition may be present and still undetected", and that DOE avoid "assumptions which are not likely to underestimate its effect," respectively[2].

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[2]In the response to Concern 1, DOE described the amount of erosion that would be expected during the performance period if the erosion rate were increased by 100 times[1]. Assuming that, (1) DOE has overestimated the age of the hillslope deposits by using the varnish cation ratio technique and has therefore underestimated the process rate calculated from it, and (2) the corresponding erosion rates were actually 10 times, or 100 times, greater than the average bedrock rate (0.19 cm/ka), or the maximum rate calculated at Boundary Ridge (0.57 cm/ka), what would be the effect?

The effect would be to increase the degradation of the landscape over the next 10,000 years by an *additional* 19 cm and 1.9 m based, respectively, on 10 times and 100 times the average rate, and 57 cm and 5.7 m based respectively on 10 times and 100 times the maximum estimated rate. Furthermore, taking 10 times and 100 times the estimated canyon cutting rate of about 0.8 cm/ka would produce an additional 80 cm and 8.0 m of erosion, respectively, in the bedrock canyons overlying the repository block.

Perhaps the most important focus for NRC's concerns about DOE's conclusions regarding the PAC is the accuracy of the varnish cation ratio technique, and the consequences of its accuracy on calculating erosion rates. The effect of uncertainty in the accuracy of the varnish cation ratio technique for dating these deposits

Comment 3b

On page 27 [of the topical report], it is stated that during pluvial periods colluvium aggradation occurs on the hillslopes, while during more arid conditions (such as the present) hillslope stripping occurs.

Response

The paucity of late Pleistocene deposits on and around Yucca Mountain has climatic significance. A marked contrast exists between the geomorphic processes that operate under the present semiarid-to-arid climate and those that prevailed during cooler and wetter climates during the Quaternary. A significant number of the surficial deposits on and around Yucca Mountain were apparently formed during the early and middle Quaternary by processes related to cool pluvial climates or during the transition from warmer to colder climates.

The primary colluvial process on the present hillslopes, on and near Yucca Mountain, is debris-flow activity (DOE, 1988 and Coe and others, 1992). Isolated debris flows occur during infrequent, high intensity, short duration thunderstorms on the sparsely vegetated hillslopes. Modern debris-flow activity does not appear to be effective in eroding or removing well-varnished, stabilized colluvial boulder deposits because debris flows are commonly confined to present hillslope channels between the topographically inverted boulder deposits. Measurements of debris eroded off Jake Ridge, located 5 km northeast of Yucca Mountain, during an intense two-day storm in 1984 are discussed

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has little consequence on the erosion rate estimates and is therefore not important to the conclusion that the PAC is not present. Even if NRC assumes that the varnish cation ratio age estimates contain larger uncertainties than those described in the topical report (DOE, 1993b, p. 44) the resulting erosion rate estimates are still valid for evaluating the potentially adverse condition, if it is assumed to exist, because erosion rates that are one, or even two, orders of magnitude greater, when projected over the performance period, would produce only modest amounts of erosion relative to the planned depth of the proposed repository.

Thus, a bounded problem is presented. Any effect on erosion rates over the performance period contributed by (1) uncertainty in the accuracy of the varnish cation ratio dating technique, overestimating the ages of hillslope colluvial deposits, and thereby underestimating the process effect, (2) uncertainty in having detected tectonic or climatic effects that would increase average erosion rates, and (3) uncertainty in being able to resolve short-term episodes of temporally clustered periods of increased erosion based on the geologic record, can be assessed.

Based on the above analysis, DOE believes that it is unlikely that the practical effects of either (1) cumulative uncertainties in the existing data, or (2) the condition is present but undetected, have not been adequately evaluated. The analysis has shown that increases of two orders of magnitude in the estimated erosion rate produce only modest amounts of erosion relative to the planned depth of the proposed repository. It is unlikely that the cumulative uncertainties in the data or the erosion rate estimates themselves could be sufficiently underestimated to alter this conclusion.

briefly in the topical report (DOE, 1993b, p. 22). Additionally, the Commission's position (49 FR 9650) precludes the need to consider such events as of potentially adverse conditions.

During dry, interglacial conditions which existed for most of the Holocene, small tributaries of Fortymile Wash became choked with debris flows (for example, see Coe and others, 1992) that originated on adjacent hillslopes. Runoff has been insufficient, however, to transport much of the coarse debris through Fortymile Wash to the basin floor of the Amargosa desert. Thus, the entire drainage system appears to be slowly aggrading with sediment eroded during infrequent summer convective storms.

In contrast, cycles of intense weathering on ridge crests and hillslopes during glacial (pluvial) episodes have produced relatively thin mantles of bouldery colluvium, that have been only partly removed by interpluvial erosion. The preservation of relatively large volumes of early and middle Quaternary deposits on and around Yucca Mountain indicates that both weathering and erosional processes have not been as effective, and climates have not been as extreme during the late Quaternary as they were during the early and middle Quaternary. As evidenced by the distribution of these ancient hillslope deposits and the large volumes of middle Quaternary alluvium in Crater Flat, Midway Valley, and Jackass Flats, significantly less debris has been produced during the late Quaternary. This indicates that the overall climate has become increasingly arid in the southern Great Basin from the middle Pleistocene to the present. This climatic interpretation is supported by the hydrologic behavior of several nearby basins that contained large lakes in the middle Pleistocene, such as Lake Tecopa and Searles Lake but have been mostly dry since the late Pleistocene.

As explained in Whitney and Harrington (1993, p. 1016)

> ... full glacial climates were times of sediment storage on hillslopes in southern Nevada with relatively little material being delivered to the basin floor. In contrast, interglacial episodes of debris flow activity resulted in hillslope stripping, active fan aggradation, and rapid delivery of these sediments to the basin floors. Similar models of hillslope development have been proposed for the arid Negev Desert... and for southern California....

The results of studies at Yucca Mountain indicate that boulder production, talus mantle creep, and boulder flow activity occurred during colder, wetter, glacial climates and were stabilized during transitions to drier interglacial climates. The rock varnish ages of the older hillslope deposits indicate that these climatic conditions existed in southern Nevada at several times during the early and middle Pleistocene.

Comment 3c

On page 43 [of the topical report], it is suggested that five periods of boulder deposition can be documented to have occurred in the Pleistocene in the Yucca Mountain area.

Response

This comment is a description of information in the topical report. Additional information is available in Harrington and Whitney, 1993, p. 1014-1015)

Comment 3d

On page 46 [of the topical report], it is stated that these deposits were "... deposited in and filled topographic lows and hollows, and spilled over [o]nto adjacent slopes ...."

Response

This is a quotation from the topical report. No response required.

Comment 3e

On page 42 [of the topical report], it is stated that the cation ratio age is the estimated surface exposure age of the boulder deposit.

Response

The complete text of the paragraph is found on page 42 of the topical report and is as follows:

> The rock-varnish dating curve for Yucca Mountain (Harrington and Whitney, 1987) was calibrated using cation ratios calculated from the data derived using the SSQ program. Thus, the age estimates for these colluvial boulder deposits are obtained by plotting SSQ-generated cation ratios on this dating curve, and no additional uncertainties arising from mixing analytical procedures are introduced. The ratio of [K+Ca)/(Ti+~1/3Ba)] is calculated for six overlapping sites on a disk (each about 25 mm^2 in area) and averaged, effectively producing an integrated analysis of the varnish surface. A varnish cation ratio (varnish cation ratio) is the average of all the varnish analyses on each sample boulder. A varnish

cation ratio for a colluvial boulder deposit is determined by averaging the varnish cation ratios for all the sample boulders from the deposit. The time over which surface clasts have been stable in a colluvial boulder deposit is estimated by plotting the varnish cation ratio for the deposit on the calibrated cation ratio curve. This is the estimated surface exposure age for the boulder deposit.

The surface exposure age of a deposit or surface represents the time of surface stabilization as discussed in Dethier and others (1988). This is not the time of deposition, but the time that material is no longer being transported on or over the surface. Once stabilization has occurred, rock varnish can accrete on the boulder surface without being removed by material in transport on the surface, and incision of the surface can begin. Therefore, the rock varnish age closely represents the time of the first period of surface erosion, and does not lead to underestimating the erosion rate.

Comment 3f

On page 38 [of the topical report], it is stated that the oldest deposits were those selected.

Response

The sampling protocol reported in the topical report was designed to select the boulders thought, for the reasons articulated in section 3.3.2.1.3 (DOE, 1993b) to be parts of the oldest exposed surfaces and therefore most representative of the age of initial incision following stabilization of the boulder deposit.

Rock varnish provides the means by which the exposure age of boulder deposits on these hillslopes can be estimated. Rock varnish begins to form on the surface of boulders after they have been stabilized on the upper surfaces of hillslope debris. To obtain a varnish age that most closely approximates the age of the deposit, the oldest varnish on the boulder deposit would have to be sampled and analyzed. There is a time lag of uncertain duration between the deposition of the boulders and the beginning of varnish accumulation on the surface of the boulder. Thus, rock varnish dating provides only a minimum age for the boulder deposit. Using the age of the rock varnish as a proxy for the age of the boulder deposit, therefore, could result in underestimating the value (T), the time over which the process (development of the boulder deposit) has been operative. Additionally, if the varnish sampled from the boulder deposit is not the oldest formed on the deposit, or if some event on the hillslope occurs after the deposition of the boulders and results in either the stripping of varnish from the clasts or in the overturning of the clasts on the deposit, then sampling of any younger varnish formed on the clast surface would yield an erroneously young varnish age. Thus, the use of any varnish, other than the oldest occurring on the deposit, to calculate the deposit age results in the value (T), in the rate equation, being erroneously underestimated and the process rate calculated being overestimated. The erosion rates calculated in this report, because they are based on rock varnish ages of the boulder deposits, are likely somewhat overestimated and are, therefore, conservative.

Comment 3g

On page 45 [of the topical report], it is stated that the process rate equals the magnitude of the process divided by the time the process operated. Therefore, if the magnitude of the process is underestimated or if the time of the process is overestimated the resultant process rate will be an underestimate.

Response

Process rate calculations are discussed in section 3.3.3.1 of the topical report (DOE, 1993b). The methods for determining process magnitude and time of the process, and subsequent calculation of erosion rate estimates incorporate multiple conservatisms (for example see Executive Summary, Enclosure 1) and provide reliable and reasonable estimates of the erosion rate at Yucca Mountain.

DOE has incorporated conservatism into the calculation of erosion rates as described in the topical report (DOE, 1993b, p. 43):

> A conservative approach has been incorporated in the use of age estimates and in calculation of erosion rates because the minimum age of the age range (last column, in brackets, Table 4) is used in the calculation of erosion rates.

and page 46:

> For deposits on mid to lower hillslopes, long-term Quaternary erosion rates have been calculated for the hillslopes on which the colluvial boulder deposits occur. The surface of the oldest dated boulder deposit on a hillslope was used to define the topography that existed when the boulders were deposited and rock varnish began forming. The erosion that has occurred on the hillslope since that time was measured as the perpendicular distance between the modern hillslope and the top of relict hillslope deposits (Figure 12). The level of the paleohillslope was assumed to be

represented by the surface of the relict boulder deposit and incision or degradation was measured below this surface. Because colluvial boulder deposits commonly possess a lenticular cross-section shape, it is believed that these colluvial deposits were deposited in and filled topographic lows and hollows, and spilled over onto adjacent slopes; this assumption maximizes the erosion rate. At present, these boulder deposits form slight topographic highs, commonly 0.5 to 1 m above bedrock (or thinly mantled) hillslopes.

The relief on paleohillslopes as depicted in Figure 12 of the topical report (DOE, 1993b) is discussed in the response to Comment 3k.

Average erosion rates for various parts of the Quaternary have been calculated, and these rates are consistent with the common meaning of the term "characteristic of the controlled area." Further, the method used to calculate these rates is widely accepted by practicing geomorphologists, and it appears consistent with the Commission position (49 FR 9650) on the consideration of short-term periods of time, the Staff's definition of extreme erosion, and the plain meaning of the term.

The Yucca Mountain area has been generally characterized by geomorphic stability during the Quaternary. Evidence of this stability includes the following:

- Carbonate layers, many of which are generally acknowledged as requiring hundreds of thousands of years to develop (Machette, 1985), occur beneath at least some boulder deposits (Whitney and Harrington, 1993, p. 1012). At least part of the great stability of the boulder deposits on the steep slopes is due to underlying carbonate which effectively cements the deposits to the side of the mountain.

- Drainage systems in Fortymile Wash, Midway Valley, near the base of the west slope of Yucca Mountain, and near the bases of sand ramps at Busted Butte are aggrading. For downcutting to begin, the elevation of the base level in the Amargosa Valley would have to decrease or uplift of Yucca Mountain would have to occur, and optimal conditions, favoring downcutting, would have to exist.

- No evidence of extensive stripping of the land surface has been found even though maximum stripping occurs during arid climate cycles (Whitney and Harrington, 1993, p. 1017).

- Stream incision rates are low in unconsolidated alluvium and colluvium. Yet these rates are assuredly greater than bedrock incision rates,

- No evidence of extensive transport of materials away from the base of Yucca Mountain has been found. For example, during the Jake Ridge event, about 5 percent of the available hillslope colluvium was stripped (Coe and others, 1995); only about 15 percent of the material removed from hillslopes reached the adjacent main drainage (DOE, 1993b, p. 22), and none of that material was transported down stream.

- Wells and others (1990) document that the Lathrop Wells cinder cone has undergone little erosional modification. The age of the Lathrop Wells cone is still the subject of study. (See response to Comment 5.) Regardless of the age of the cone, the absence of degradation demonstrates that erosion rates have been low during the late Quaternary and Holocene in the Yucca Mountain area (Whitney and Harrington, 1993, p. 1008).

- Surficial geological mapping around Yucca Mountain (Swadley and others, 1984) reveals extensive lower and middle Quaternary deposits, but exposed upper Quaternary deposits are confined to small areas on hillslopes and are probably buried below a thin veneer of Holocene alluvium in Fortymile Wash and its tributaries, as well as the unnamed streambeds that cross Crater Flat (DOE, 1993b, p. 24). Thus there is no evidence of significant erosion on a regional scale in the vicinity of Yucca Mountain since the middle Quaternary, and there are no morphologic features that indicate localized extreme erosion during that period of time.

- Deposits of late Quaternary age are chiefly confined to present stream valleys. The lack of late Pleistocene and Holocene deposits at the base of Yucca Mountain hillslopes indicates that erosion rates from these slopes have been low during the past 100,000 years. Confinement of late Quaternary deposits to valleys and channels indicates the volume of material eroded off hillslopes has been smaller than during the early and middle Quaternary. (DOE, 1993b, p. 24).

Detailed investigations of the Quaternary geologic record have found no relationships to indicate that the magnitude, or amount, of erosion has been underestimated or that the time of operation of the process has been overestimated. Hillslope denudation rates, canyon incision rates, and hillslope degradation rates are all much below average rates for climatically and lithologically similar areas in the southwestern US. Hence, DOE has concluded that the rate of erosion at Yucca Mountain cannot be extreme.

Comment 3h

As it is suggested that several periods of aggradation and intervening degradation are reflected in the erosional record of the Yucca Mountain area, the rates calculated reflect not an erosion rate but a summation of landscape changes by erosion and deposition through the period analyzed.

Response

The rates presented in the topical report (DOE, 1993b, p. 8) are comprehensive estimates of the rate of material removal from middle and lower hillslopes on Yucca Mountain and the surrounding area during geologically recognizable portions of the Quaternary Period. DOE has identified, measured, and described the amount of colluvial material that has been removed from these selected hillslopes since the colluvial boulder deposits were stabilized and available for stripping. The presence of mature varnish on the exposed boulder surfaces precludes significant amounts of aggradation during the periods in question and at the sites selected for sampling. If aggradation were active, one would not expect to find boulders with well-developed varnish exposed at the surface.

Even if the Quaternary erosional record contains several periods of aggradation and degradation as suggested in the comment, it is still true that the total amount of Quaternary hillslope degradation is less than 3 meters (DOE, 1993b, p. 48; Harrington and Whitney, 1993, p. 1017). DOE notes that the planned depth for the proposed repository is more than 200 meters. Furthermore, if for the sake of discussion, one were to invoke erosional episodes that could produce even ten meters of erosion during the performance period, one would have to call on phenomena which would be beyond any processes known to have occurred during at least the last half million years, if not during the entire Quaternary. Based on the evidence in the geologic record and that presented in the topical report, such event magnitudes could be categorized as not sufficiently credible to warrant further consideration. DOE believes that it should not be required to speculate about such events.

Comment 3i

From Topical Report Table 5 (p. 48), a comparison of the calculated rates for Boundary Ridge (the youngest deposit sampled) with those rates which include several periods of erosion/degradation strongly suggest that the average rate quoted is an underestimate since the rate for Boundary Ridge is approximately a factor of three greater than any other deposit.

Response

If the average rate were used to estimate the rate for Boundary Ridge, the average rate would indeed be an underestimate. To address this problem, DOE compared the average rate and the Boundary Ridge rate to rates for other areas of the southwestern United States . This information is presented in the topical report (DOE, 1993b, p. 9-11 and 56). This comparison showed that degradation at Yucca Mountain is less than rates for other areas of the southwestern United States and some 40 times less than the average for the entire United States (DOE, 1993b, p. 56).

The Boundary Ridge rate is higher than the overall average rate; hence, the average rate does underestimate the Boundary Ridge rate. But the Boundary Ridge rate should not be used in isolation. As explained in the footnotes to Table 5 (of the topical report; DOE, 1993b, p. 48), the Boundary Ridge rate is based on deposits in a poorly-defined or non-existent channel. To be conservative, the rate estimate calculations used the youngest estimated ages for the boulder deposits. In addition, the results of recent mapping in Midway Valley (DOE, 1995) indicate that the denudation rate in alluvium of about 0.5 cm/ka has persisted for about the last 20 ka. The Boundary Ridge data plus the Midway Valley data indicate that an erosion rate of about 0.5-0.6 cm/ka may have persisted for the last 170 ka. This information is described in the response to the staff recommendation for Comment 1.

Even if the assertion were accepted for the purpose of conservative analysis, and the Boundary Ridge rate were taken as the bounding rate for Yucca Mountain:

1. The Boundary Ridge rate is significantly less than rates for climatically and lithologically similar areas elsewhere in the southwestern United States (See DOE, 1993b, p. 49). Hence, the Boundary Ridge rate is not extreme.

2. The Boundary Ridge rate could be projected over the performance period, and the amount of erosion would be less than 0.06 meters. The effects of other hypothetical increases in erosion rates and the resulting expected amounts of erosion have been described in the responses to Concern 1 and Comment 3a (see footnotes 1 and 2, respectively).

Comment 3j

If the age quoted in Table 4 (p. 44 [of the topical report]) represents the surface exposure age of the deposit, this age reflects the time at which the material was deposited, and therefore represents a period of aggradation, not degradation.

The period of time between the age cited on Table 4 and the onset of erosion is unknown. As the oldest date for the deposit was purposely selected and analyzed the methodology has served to maximize the possible degree of overestimation. Therefore, based only on age relationships, the rates appear to underestimate the rate of erosion.

Response

The age of the surface fixes the youngest time at which the surface was available for erosion. This age is established by the age of the varnish. The age of the underlying deposit is irrelevant to the calculation of erosion rates.

While it is true that the maximum age of the surface is approximately equal to the minimum age of the underlying deposit, the assertion that the age of the surface in Table 4 (page 44 of the topical report) reflects the time at which the material was deposited is not correct. In fact, the age of a surface developed on a deposit must be younger than the underlying deposit. From information in the geologic record it is usually possible to determine whether the surface in question was developed under conditions of aggradation or degradation. However, if the age of the surface is determined, the conditions under which it developed are irrelevant. By dating the oldest boulders on the surface, but using the youngest of the determined ages, and measuring the amount of incision from the tops of those boulders into the underlying deposit, it is possible to estimate a maximum erosion rate because:

(1) The average age estimate is based on data which includes information from early USGS sampling. Typically, varnish cation ratio age dates on the USGS samples are younger than ages determined on later samples. This effect was reported in Attachment V of the Technical Assessment Report (DOE, 1992). Inclusion of these younger ages insures that the overall age estimates are minimums and, hence, conservative.

(2) The measurements from the tops of the boulders represent the maximum amount of downcutting into the deposit, which again provides a conservative estimate of the parameter.

This method provides for calculation of a maximum erosion rate estimate by using the maximum amount of downcutting divided by the shortest time for the downcutting to have occurred. Furthermore, even if the maximum rate (Boundary Ridge) were taken as the rate for Yucca Mountain and projected over the performance period, the expected amount of erosion would be less than 0.06 meters while the planned depth of the proposed repository is more than 200 meters.

Comment 3k

As can be seen from Figure 12 (p. 47), the methodology assumes that the present top of the deposit represents the original land surface. If, as the report states, these deposits were believed to have been deposited in lows, there had to be some topographic "highs" present. The former slope surface had to be at a higher elevation than that shown on this figure. Thus the process of magnitude calculations appears to have been selected such that the erosion rate has been underestimated.

Response

The process to estimate magnitude or amount of erosion is discussed in the response to Comment 3g, and the process to estimate maximum erosion rates is discussed in response to Comment 3j. The topical report describes the process of accumulation of colluvial boulder deposits "... in hillslope hollows" (DOE, 1993b, p. 30).

The model of hillslope evolution (DOE, 1993b, p. 29-31; and Whitney and Harrington, 1993, p. 1010-1012) describes the origin and development of boulder deposits. The deposits form from frost cracking of resistant volcanic units during pluvial episodes. At Yucca Mountain, the bedrock outcrops are somewhat patchy and irregular. This outcrop pattern, coupled with a slow rate of production of boulders, tends to produce elongated, lens-like deposits in gullies cut into the middle and upper hillslopes. With time, the deposits fill the gullies and spread laterally to cover adjacent areas. Since the deposits spread laterally over the adjacent lands, the tops of the channelized boulder deposits provide estimates of the heights of the adjacent land surfaces.

As climatic conditions become drier, the boulder deposits cease to accumulate and become stranded on slopes because debris flow activity ceases to transport material to the deposits and instead begins to incise marginal channels that elevate, isolate and stabilize the deposits. The general, cross-sectional shape of the deposits is described on page 46 of the topical report (DOE, 1993b), and the development of the deposits is described on pages 25 through 31 of the topical report (DOE, 1993b). However, it is important to note that since the boulder deposits do spread laterally, it is reasonable to use the tops of the channel deposits as estimates of the heights of the divides between the gullies.

Documentation of generally low relief on hillslopes is provided in the topical report (DOE, 1993b, p. 30 and 31) as follows:

> The assumption of low relief is related to the fact that boulder deposit formation occurs during the wetter

> parts of the climatic cycle when weathering of the bedrock takes place and when the hillslopes are being aggraded with colluvium.... The deposition of these colluvial materials would result in a reduction of the relief on these hillslopes, creating a rather smooth low relief profile along the slope.

Figure 12 (DOE, 1993b, p. 47) was developed based on the field relationships of various surface units at Yucca Mountain. Examination of modern hillslopes shows that channels incised into hillslopes average less than 2 meters deep, and are separated from adjacent channels by low, broad ridges. The absence of uniform talus mantles and presence of channelized boulder deposits indicate that the paleosurface was not uniform. The paleotopography of the hillslope depicted in Figure 12 was reconstructed based on hillslope channel morphology. As shown in the reconstruction in Figure 12, the surface was one of relatively low relief but was sufficiently non-uniform to cause the development of channelized boulder deposits which spread laterally to cover the adjacent surfaces. Whitney and Harrington (1993, p. 1010) describe the slopes as having "smooth topographic contours with gentle relief both along slope and downslope." The morphology of the boulder deposits shown in Figure 12 is consistent with this slope description. Divides between adjacent channels are broad and low, give the gentle relief to the slope surfaces, and provide the smooth topographic surface described above. These slope surfaces do not suggest the former presence of "highs" that might have a morphology different from the broad, low ridges now present. Hence, there is no basis to assume that (1) the paleosurface was at an elevation that was significantly higher than the surface depicted in the figure; (2) erosion has removed amounts of material greater than the relatively modest amounts described; or (3) process magnitudes, and resultant erosion rates, have been underestimated.

The dashed line labeled "Former Slope Surface" in Figure 12 was drawn with a concave-upward orientation by the graphics preparer. DOE should have noted the error and directed a change to be made to the graphic. Despite the configuration, this line does not suggest the former presence of "highs" on a paleosurface that might have a morphology different than the broad, low ridges between the channelized boulder deposits.

The topical report provides a description of the evaluation of alternative hillslope erosion rates which assume greater relief on the hillslope (DOE, 1993b, p. 50). However, the topical report clearly states that there is no field geomorphic evidence to support any hypothesis of increased hillslope relief. In fact, since boulder deposits accumulate only during periods of hillslope aggradation, the conditions necessary for boulder deposit development would operate to reduce, not increase, relief on the hillslopes. The topical report describes the process and results as follows:

> In fact, because boulder deposits formed during periods of hillslope aggradation would result in reduction of general hillslope relief by filling in the drainage channels on the hillslope, boulder-mantled hillslopes probably possessed less relief than that on the modern hillslope. (DOE, 1993b, p. 50)

The topical report then explores the effects of assuming higher relief on the hillslope as follows:

> Assumptions of higher relief will yield higher erosion rates than the measured rates; however, these rates clearly demonstrate that degradation under the most severe conditions imaginable will lower hillslope surfaces less than 1 meter over the next 10,000 years. If it is assumed that the ancient land surface had 2-3 times greater relief than the modern hillslope, then the hillslope degradation rates would still increase to no more than 0.6 cm/ka (three times the average degradation rate of 0.19 cm/ka calculated for Yucca Mountain hillslopes - Table 5) and this still constitutes a very low erosion rate. (DOE, 1993b, p. 50)

Other information supporting the slope surface configuration depicted in Figure 12 includes the following:

1. The slope profiles indicate development through a parallel slope retreat mechanism. Under this mechanism, it is not possible to erode a hillslope without eroding the ridge crest. At Yucca Mountain, the ridge crest is stable. Among the lines of evidence indicating this stability are the precariously balanced boulders, thin colluvial deposits averaging about 0.4 m thick (DOE, 1993b, p. 21), and the thick varnish which coats outcrops and boulders that occupy the ridge. Rock varnish development is described in the topical report (DOE, 1993b, p. 45) as follows:

    > Rock varnish development is commonly found on bedrock outcrops on the top of Yucca and Skull Mountains as well as on other ridges in the area. Dark rock varnish has accumulated on these surfaces over at least several tens of thousands of years and at some outcrops probably over more than 100,000 years indicating little, if any, rock material has been broken from these outcrops, by freeze and thaw processes, since mid Quaternary time (<128 ka).

In addition, DOE has ^{10}Be dating work in progress to provide data from which it may be possible to estimate the bedrock degradation rate on the crest of Yucca Mountain. DOE intends to provide this data to the NRC by the end of fiscal year 1995.

2. Excavations at Solitario Canyon Trench 2 exposed bedrock at a very shallow depth beneath a thin pediment cover. Selection of the site for the trench was made on the results of mapping which indicated the site was expected to be located on a thick section of fan gravels and colluvium. Excavation of the trench showed that the surface was a pediment not a fan. The pediment was underlain by a thin gravel veneer on a bedrock surface. The presence of the preserved pediment coupled with the lack of fan gravels and colluvium indicates that, near Yucca Mountain, the late Quaternary was a period of hillslope stability.

From the evidence preserved in the geologic record, there is no basis to assume that the amount of relief on the surfaces was greater in the past than it is now. In fact, if parallel slope retreat process operated to form the slopes, relief of the kind suggested in the comment is virtually impossible. Conversely, if parallel slope retreat were not operative, one would expect to see sinusoidal hillslope surfaces, and no such surfaces have been identified at Yucca Mountain. Hence, DOE does not agree with the comment that ". . . the process of magnitude calculations appears to have been selected such that the erosion rate has been underestimated" is correct. Rather, DOE's method for estimating the erosion rate is consistent with the evidence preserved in the geologic record.

Finally, Osterkamp and Toy (1994) described rill formation in artificial exposures (road-cuts) by the gully gravure process which is a small-scale hillslope process. Based on the descriptions in Harrington and Whitney (1993), Osterkamp and Toy speculated about gully gravure as a permissible process for the formation of the colluvial boulder deposits at Yucca Mountain. However, this small-scale process is not analogous to the process of formation for the large-scale hillslope colluvial boulder deposits at Yucca Mountain. The colluvial boulder deposits were formed in a colder paleoclimate regime by freeze/thaw wedging of boulders that gradually accumulated into hillslope channels (DOE, 1993b, p. 30). Speculation about development of hillslope channels by gully gravure processes is not supported by evidence contained in the geologic record, and the requisite geologic conditions described by Osterkamp and Toy did not occur at Yucca Mountain.

Comment 31

If the boulder deposits represent the remains of a semi-uniform mantle of boulders that covered the surface and that the top of the boulder deposit is a good approximation of the former land surface, the process that is being measured is the average rate of degradation of an armored surface -- a surface that was covered with natural riprap. As this does not represent the normal condition for the hillslopes in the Yucca Mountain area, the values reported are not relevant in projecting erosion rates over the period of performance.

Response

The comment appears to reflect a lack of clarity in the description of the hillslope evolution model for Yucca Mountain and the general assumptions that DOE used to make its erosion rate estimates (DOE, 1993b). The preservation of the boulder deposits is described in the topical report (DOE, 1993b, p. 45). As described in the response to Comment 3k, while DOE agrees that the tops of the boulder deposits provide a good approximation of the former land surface, DOE does not agree that the boulder deposits represent the remains of a semi-uniform mantle of boulders.

DOE also does not agree that "... the process that is being measured is the average rate of degradation of an armored surface ...." DOE would expect little or no erosion of such armored surfaces, and in fact, DOE has excluded, from the erosion rate calculations, data from areas where no erosion has occurred (DOE, 1993b, p. 46). The erosion measured is the amount of channel incision that occurred lateral to the elongated boulder deposits that accumulated in channels on the hillslopes. That is, the incision occurs peripheral to, not through, the boulder deposits that have been localized in hillslope channels. The mechanisms of isolation of the boulder deposits followed by marginal incision are described in the topical report (DOE, 1993b, p. 30 and Whitney and Harrington (1993). The method DOE used to measure this incision is described in detail on page 46 of the topical report (DOE, 1993b).

Nothing in Figure 12 (DOE, 1993b, p. 47) or in the description of Yucca Mountain indicates that the boulder deposits are remnants of a semi-uniform talus mantle. DOE described its model for the development of the hillslope boulder deposits on pages 29 - 31 of the topical report (DOE, 1993b). The model relies on what is known about actively forming boulder deposits today; that is, these deposits develop during pluvial climatic conditions and accumulate (at Yucca Mountain) by filling existing channels on hillslopes. As climatic conditions change to more arid conditions and hillslope stripping begins, the boulder deposits mantle, and thereby protect, former channels, and the focus of erosion shifts to the areas between the mantled channels. Thus, the rate of degradation of the inter-channel areas, then, becomes the measure of erosion.

Recommendation

DOE should provide a methodology for the calculation of erosion rates which does not underestimate the effects.

Response

DOE has provided such a method, and it is described in section 3.3.3.1 of the topical report (DOE, 1993b, p. 45-48). The method calculates erosion rates based on the maximum amount of incision divided by the shortest amount of time that the incision could have occurred and does not include data from parts of hillslopes where no erosion has occurred (DOE, 1993b, p. 46). Thus, the rates are conservative. By calculating average rates, the method has determined erosion rates which are characteristic for Yucca Mountain and the surrounding region. The method integrates the effects of climatic cycles which occur over time, and is consistent with NRC staff guidance on, and the plain meaning of, the term "extreme erosion," as well as with the Commission position on the meaning of "short-term" periods of time (49 FR 9650).

Comment 4

Reliance on the varnish cation ratio (varnish cation ratio) dating method alone to establish the age of geomorphic surfaces is inadequate for demonstrating the absence of extreme erosion.

Response

DOE has relied on the varnish cation ratio dating method to provide quantitative estimates of the ages of boulder deposits. These age estimates were needed to calculate erosion rates for Yucca Mountain and the surrounding area. However, as noted in the response to Comment 3, the antiquities of the boulder deposits have been corroborated by several lines of independent evidence, thus adding confidence to the varnish cation ratio age estimates.

Selection of the varnish cation ratio dating technique was predicated on the need to obtain quantitative ages to calculate erosion rate estimates. DOE wishes to point out that, at the time the surfaces were being dated, the varnish cation ratio method was the only method available to date boulders on geomorphic surfaces. Cosmogenic dating techniques were not readily available until the early 1990s, and these techniques possessed significant uncertainties. Rock and surficial deposit dating techniques, including K/Ar, Ar/Ar, U-trend, U-series, thermoluminescence, amino acid racemization, and others, while suitable for dating various types of rocks or unconsolidated deposits, are not well-suited for dating surfaces which developed on those rocks or deposits. And it was the ages of the boulder deposits and their associated surfaces which were required for determining erosion rates on Yucca Mountain and in the surrounding area. The Criteria for Selection of a Dating Methodology are described in Section 3.3.2.1.1 of the topical report (DOE, 1993b, p. 32 - 35).

The LANL Peer Review of the varnish cation ratio method endorsed the application of the method as "appropriate for age estimation of deposits as outlined in the seven studies of the study plan" (Hawley and others, 1989, p. 7). The report was requested by the Principal Investigator, Dr. Charles Harrington, not by DOE/YMSCO(YMPO), to provide an independent review of his work and suggestions for additional work. The report was completed before the LANL procedure for peer reviews was approved and implemented. Key points of the Review Report include the following:

(1) Endorsed the work being done at LANL as the best varnish cation ratio dating that was being done.

(2) Commented favorably on the investigators' careful attention to sample collection, preparation, and analysis techniques.

(3) Commented favorably on the investigators' knowledge of, and appreciation for, the limitations of the method.

The Peer Review offered several suggestions for additional research that would strengthen the case for the age estimates of the boulder deposits, but no deficiencies that required correction were identified; nor was the endorsement by the Peer Review Group contingent on correction of any deficiencies or completion of any of the suggested work.

DOE has tested the reasonableness of the varnish cation ratio ages by comparing the ages with several pieces of qualitative information, which by themselves, were insufficient for calculating erosion rate estimates. The varnish cation ratio ages determine the surface exposure ages of the deposits and indicate the lengths of time various boulder deposits have been in place.

Field observations that provided qualitative data to support the relative antiquity of hillslopes at Yucca Mountain and in the surrounding area include:

1. Modest amounts of hillslope degradation and canyon incision since the middle Quaternary. Most of the Quaternary degradation and incision occurred during the early and middle Quaternary. Slopes were subsequently stabilized during the development of drier climates (Whitney and Harrington, 1993, p. 1017).

2. Existence of pedogenic carbonate and silica-rich soil horizons, which require several hundreds of thousands of years to develop, beneath some dated boulder deposits (Whitney and Harrington, 1993, p. 1012).

3. Thick layers of varnish, which require long periods of time to develop, on boulders (Whitney and Harrington, 1993, p. 1014).

4. Presence of very thin and areally limited late Quaternary and Holocene deposits around Yucca Mountain (DOE, 1993b, p. 24).

5. Indicated ages of the boulder deposits (DOE, 1993b, p. 44 and Whitney and Harrington, 1993, p. 1014).

In addition, the varnish cation ratio technique testing that was done in the Española Basin (Harrington and others, 1988) and Las Vegas Wash (Whitney and others, 1988) strongly indicates that the varnish cation ratio technique provided geologically reasonable age estimates for coarse-grained clastic deposits. The comparison to other dated surfaces and deposits in the Yucca Mountain area provided supporting dating information that indicated the rock varnish ages were reasonable. Even if one assumed, for discussion purposes, that the varnish ages of the boulder deposits overestimated their true ages by factors of 3 to 4 times (even though such overestimations are not geologically reasonable given the various lines of independent evidence which corroborate the antiquity of the hillslopes and the boulder deposits; for example see Whitney and Harrington, 1993, p. 1014), the resulting average erosion rate would still not be extreme by comparison to similar rates for other areas of the southwestern United States (DOE, 1993b, p. 10-11).

Whitney and Harrington (1993, p. 1014) sampled three darkly varnished boulders at Buckboard Mesa for surface exposure dating using cosmogenic ^{36}Cl. The estimated ages range from about 600 (actual range 671-549) ka to about 310 (actual range 336-288) ka for the samples. However, the ^{36}Cl accumulation in rocks is calibrated in radiocarbon years which, when adjusted, will increase calculated ages by about 10 percent. Additionally, the oldest sample has a measured ^{36}Cl content of greater than 92 percent of the saturation value. Because this sample is close to the theoretical saturation, the sample may represent the maximum ^{36}Cl concentration effectively measurable. The age estimate may represent the practical upper limit of this dating technique and not closely limit the age of the deposit (Whitney and Harrington, 1993, p. 1014). It should be noted, however, that even if the youngest, 310 ka, age estimate were accurate for the Buckboard Mesa deposits and were used with the measured channel incision of 0.3 meters (DOE, 1993b, p. 48), to estimate channel incision rates, that rate estimate would be about 0.1 cm/ka.

The ^{36}Cl dating at Buckboard Mesa was carried out under the quality conditions of the existing state of the practice, but not under a quality assurance program. DOE therefore did not cite or rely on the ^{36}Cl data in the topical report. To presume that this data does not exist, however, fails to bring all available information to bear upon the extreme erosion issue. DOE cites it now because it is relevant to the conclusions in the topical report.

DOE has ^{10}Be dating work under a quality assurance program in progress to provide data from which it may be possible to corroborate the age estimates for colluvial boulder deposits in both tuff and basalt substrates. DOE expects to provide this data to the NRC by the end of fiscal year 1995.

Comment 4a

The varnish cation ratio dating technique has received considerable attention since it was first proposed and developed by Dorn (1983). Despite a considerable amount of work on the physical and chemical properties of desert varnish (Perry and

Adams, 1978; Potter and Rossman, 1979, Krumbein and Jens, 1981; Dorn and Oberlander, 1982; Dorn, 1984), the exact reasons for apparent variations in the ratio of potassium and calcium to titanium (K + Ca)/Ti or (KCT) are obscure.

Response

The key issue for determination of the ages of the boulder deposits is the development of calibration curves which show how the varnish cation ratios of independently dated materials vary. DOE completed such calibrations for various materials and locations on and near Yucca Mountain and reported the results in the topical report (DOE, 1993b, Figure 9 and p. 35-36). The results of the calibrations indicate the following:

1. The varnish cation ratios plot as points along a straight line when plotted against the log of the age of the deposit. This result was documented in the LANL Peer Review Report (Hawley and others, 1989, p. 3 and 4).

2. The age estimates are reasonable and consistent with qualitative estimates based on geologic evidence; for example, the presence of carbonate layers beneath some deposits (Whitney and Harrington, 1993, p. 1012).

3. As reported in the LANL Peer Review Report (Hawley and others, 1989, p. 4), the shape of the Yucca Mountain curve is similar to other published curves.

4. The age estimates are based on interpolation rather than extrapolation of data as shown in Figure 9 of the topical report (DOE, 1993b, p. 37) and explained in Section 3.3.2.1.6 Calculation of Uncertainties for Cation Ratios (p. 42).

5. The validity of the calibration method has been established by testing at other locations with well-established ages, the Española Basin, New Mexico (Harrington and others, 1988), and Las Vegas Wash (Whitney and others, 1988).

Rock varnish age estimates have been evaluated within the geologic context and constraints of other study areas (DOE, 1993b, p. 36). In the Española Basin, New Mexico (Dethier and others, 1988; Dethier and McCoy, 1993) the rock varnish age estimates were compared to amino acid racemization ages of deposits underlying the rock varnish covered surfaces and were found to be consistent with the geological relationships. Additionally, a rock varnish age estimate of 550 ka (Dethier and others, 1988) was obtained for a surface overlying deposits containing the Lava Creek B tephra (620 ka); this result supports the contention that the rock varnish age estimates are geologically reasonable.

In southern Nevada similar geologic comparisons were made, and it was noted that (1) varnish thickness is greatest on the deposits that yield the oldest age estimates, and (2) the thickest carbonate soil horizons are likewise noted in the deposits with the oldest estimated ages (Harrington and Whitney, 1991). Finally, rock varnish on a surface in Las Vegas Wash yields a 600-ka age estimate and is underlain by deposits that contain the Lava Creek B tephra (620 ka) at a depth of two meters (Whitney and others, 1988). Thus, the Yucca Mountain rock varnish age estimates appear reasonable when placed within the geologic constraints of the area. In none of these areas have geologic constraints been found that would demonstrate the age estimates are in error, and DOE has concluded that the age estimates are valid.

Comment 4b

There are three primary models to account for variations in minor element abundances in rock varnish with time. A widely held model is that relatively mobile K and Ca are preferentially leached from accreting varnish while Ti remains immobile, resulting in lower KCT with time (e.g. Dorn, 1983; Dorn and Krinsley, 1991). However, Reneau et al., (1992) concluded that variations in the composition of detrital mineral grains and authigenic mineralization strongly influence the composition of rock varnish, and that these variations in composition invalidate the basic premises of the varnish cation ratio dating technique. In addition, Reneau and Raymond (1991) and Bierman and Gillespie (1994) have observed that minor element variations in rock varnish were inconsistent with a leaching hypothesis. Instead, they postulated that observed KCT relationships reflect the preferential incorporation of host-rock fragments, which have high KCT ratios, into thin, young varnish deposits. Older, thicker deposits contained relatively fewer host-rock fragments and thus have lower KCT ratios. However, the results of these studies indicate that the amount of substrate incorporation does not vary linearly with time.

Response

In addition to the three models identified in the comment, Harrington and Whitney (1995)[3] and Whitney and Harrington (1993, p. 1014) support a fourth model which features the role of barium in producing the decreasing cation ratios with varnish age.

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[3]Harrington, C.D. and J.W. Whitney, 1995. "Comment on 'Evidence suggesting that methods of rock-varnish cation ratio dating are neither comparable nor consistently reliable,'" by P.R. Bierman and A.R. Gillespie. Quaternary Research, January, 1994. Accepted and scheduled for publication in March, 1995 issue of Quaternary Research.

Although different models for variations in minor element abundances in rock varnish with time exist, DOE's research has demonstrated temporal variations control in the concentrations of various cations in varnish are (1) related to variations in the eolian materials which provide the constituents for varnish development, (2) apparently are related to the presence of barium, and (3) show an approximately linear relationship between the cation ratio and the log of age. DOE agrees that the "observed minor element variations in rock varnish are inconsistent with a leaching process." However, DOE notes that the description of "... preferential incorporation of host-rock fragments ..." attributed in the comment to Reneau and Raymond (1991), and Bierman and Gillespie (1994), is a misquotation of the referenced articles. If this process were operative, one would expect to find evidence of the incorporation of fragments in the varnish. However, scanning electron microscope cross-sections of varnish (DOE, 1993b, Figure 10) show no fragments of substrate incorporated into the varnish. Furthermore, Harrington and Whitney (1995[3] and 1987) describe how their analytical methods preclude incorporation of substrate material and support their conclusion that "... substrate inclusion is not a major determinant of calculated cation ratios."

The comment further notes that "... variations in composition invalidate the basic premises of the varnish cation ratio dating technique." DOE wishes to point out that its varnish cation ratio analytical techniques uses the scanning electron microscope which analyzes only the upper few microns of the varnish. DOE has identified no "variations in composition" which might be attributed to processes outlined in the comment.

Comment 4c

If the host rocks for the dated varnish deposits have similar lithologies (i.e. composition, mineralogy, texture), then the KCT ratios may [emphasis deleted] vary uniformly with time for these deposits (i.e, Dorn, 1983). However, if different host lithologies are present, then different KCT ratios could be incorporated into the analyzed varnish deposits. This observation is especially significant for the Yucca Mountain region because different host lithologies are used in both calibration standards and dated samples.

Response

The results reported in the topical report (DOE, 1993b) are consistent with the results of other published studies and show that KCT ratios do vary uniformly with time as described on page 31 of the topical report. Harrington and Whitney (1995) describe the requirement to demonstrate that for any rock type used for varnish cation ratio dating, cation ratios change with time.

The results of various published varnish cation ratio dating studies indicate a linear relationship between varnish cation ratios and log age (DOE, 1992, p. 4). Harrington and Whitney (1995) provide information that the varnish composition and development is independent of the substrate composition but partially dependent on the physical characteristics of the substrate surface. They note that varnish development is minimal on smooth non-porous substrates, like chert or the surfaces of mineral grains in coarse grained igneous or metamorphic rocks. Conversely, varnish is well developed on porous surfaces, like those of tuff and basalt, which are characterized by microscopic indentations which can trap dust-sized particles and provide a suitable environment for the microorganisms which are thought to produce the varnish (for example, see Hawley and others, 1989, p. 2).

The point of the second sentence of the comment: "... if different host lithologies are present, then different KCT ratios could be incorporated into the analyzed varnish deposits" is not clear. The cation ratio is the result of various processes which develop the varnish. This ratio varies systematically with time as the development of the varnish proceeds (See DOE, 1993b, page 31).

Comment 4d

Basaltic rocks in the Yucca Mountain region have KCT ratios that are between about 10 to 13. These basalts are the primary host for dated varnish deposits at Skull Mountain, Little Skull Mountain, Buckboard Mesa, and Crater Flat. However, talus deposits at Yucca Mountain consist of fragments of welded rhyolitic ignimbrite, which are primarily from the Tiva Canyon member of the Paintbrush Tuff (see Chapter 1.2 ("Site Geology") in DOE, 1988). KCT ratios for Tiva Canyon Rhyolite are about 60 but decrease to about 30 for less abundant quartz latite members (Broxton et al., 1989). These ignimbrites also are the dominant lithologies in the alluvial deposits used to construct part of the cation-ratio calibration curve for Yucca Mountain (Harrington and Whitney, 1987; and Whitney and Harrington, 1993). Thus two distinct lithologies (basaltic lava and welded rhyolitic ignimbrite) are used to construct the cation-ratio calibration curve for Yucca Mountain.

Response

Based on the results of its research, DOE determined that the role of the substrate is limited to providing the host site for the development of the varnish (Harrington and Whitney, 1995[3] and 1987). That is, the substrate provides a surface characterized by micro-indentations which receive and retain dust-sized particles, and provide an environment for the microorganisms which produce the varnish. DOE determined the varnish is (1) produced by the action of the microorganisms (for example, see Hawley and others, 1989, p. 2). on the chemical constituents of the dust particles, and (2) influenced by the barium content of the varnish (Harrington and Whitney, 1995[3]). DOE is aware of no firm evidence to support the hypothesis that the substrate either provides material for varnish development or exerts any control on varnish development beyond providing a site with characteristics as described above (Harrington and Whitney, 1987, p. 967-968). This process was also described by Dr. Harrington during the site visit on February 1-3, 1994.

In addition, the cosmogenic ^{10}Be dating of boulder deposits at Buckboard Mesa, the crest of Yucca Mountain, will provide information to assess the significance of using different lithologies to construct the cation-ratio calibration curve for Yucca Mountain. DOE intends to provide this data to the NRC by the end of FY 1995.

Comment 4e

If the hypothesis of Reneau and Raymond (1991) and Bierman and Gillespie (1994) is accepted, then a linear relationship may not exist between the 40-225 ka ignimbrite hosts and the 1.1 Ma basaltic hosts on the Yucca Mountain cation-ratio calibration curve. The KCT ratios of these two lithologies could represent two different cation-ratio trends that originate at different initial KCT ratios that reflect the different host lithologies. In addition, measured KCT ratio variations on samples of unknown age may reflect variations in the amount of substrate fragments incorporated into the varnish and not accurately represent the age of the deposit.

Response

Although the relationships described may be possible, DOE has found no reason to accept the hypothesis of Reneau and Raymond (1991) or that of Bierman and Gillespie (1994). In fact, DOE's research (Harrington and Whitney, 1995[3]) indicates temporal control of the concentration of cations in varnish, and DOE determined that the development of varnish is independent of the substrate composition. The only role played by the substrate in varnish formation is providing a surface with physical characteristics that provide an environment which favors the development of varnish. Details describing the role of the substrate and temporal control of varnish development are available in the responses to comments 4b and 4c and in Harrington and Whitney, 1987 (p. 967-968).

Comment 4f

Furthermore, varnish deposition is thought to be controlled by the microtopography of the substrate (Dorn and Oberlander, 1982; Dorn and Krinsley, 1991; Reneau et al., 1992). Local microtopographic lows trap detrital mineral grains more readily and collect water for authigenic mineral formation, resulting in relatively thick varnish layers (e.g., Reneau et al., 1992). Basaltic lavas and rhyolitic ignimbrites have obvious differences in macroscopic and microscopic textural features, including the presences of vesicles, groundmass porosity, and permeability, amounts of groundmass glass and crystals, abundances and sizes of primary minerals, and the morphologies and abundances of fissures and joints (e.g., Vaniman et al., 1982 Bish and Chipera, 1989). Each of these textural features could influence the development of rock varnish, and textural differences between the lava and ignimbrite thus could result in variations in rock varnish thickness and composition.

Response

DOE wishes to emphasize that the substrate apparently plays no active role in varnish formation; the substrate provides only a surface on which the varnish develops and accumulates (Harrington and Whitney, 1987, p. 968). Although the possibilities described could perhaps exist, no basis to support the postulation of a causal relationship between variations in textural features and variations in varnish characteristics has been provided. In fact, DOE's research (Harrington and Whitney, 1995[3]) indicates that varnish development, except as described in the response to Comment 4d, is independent of the substrate's physical and chemical characteristics; the ingredients in varnish are provided by eolian material which accumulates on exposed surfaces of boulders and outcrops. The role of the microtopography is limited to providing a suitable surface for varnish development and accumulation, DOE has no information to support the hypothesis that gross textural features (fissures and joints) or microscopic textural features of the substrate control variations in rock varnish development. In fact, the sampling and analytical protocols developed by DOE insure that gross textural features of the substrate would not influence the analytical results (Harrington and Whitney, 1987, p. 967).

Comment 4g

In addition to the possible effects of substrate, rock varnish on a single surface may be texturally inhomogeneous and include sites where varnish chemistry may have been influenced by cracking, proximity to soil, organic matter accumulation, *biogenic activity, or ponding of water (Dorn, 1989; Krinsley et al., 1990). These disturbed sites are not suitable for cation-ratio dating studies because they may represent cation ratio variations that developed independent of time (e.g., Dorn and Krinsley, 1991).*

Response

DOE recognized the potential for variations in cation ratios that could be independent of time or the results of processes or features as described in the staff comment. DOE required participants to develop sample collection and sample preparation procedures to insure that such adverse conditions were eliminated before the varnish samples were analyzed. Similar concerns were identified and discussed in detail in the Technical Assessment Report on the Qualification of Data (DOE, 1992). The conclusions of TA Team Members was that the procedures, in place at the time the sample collection and analyses were done, were adequate and would have produced results similar to those that would be obtained under the subsequently approved QA procedures. Furthermore, the technical data, on which the topical report is based, have been found to be suitable, and was recommended, for qualification under DOE's QA Program (DOE, 1992).

In addition, DOE's investigations have demonstrated the role of the substrate material in the development of varnish. As reported in Harrington and Whitney (1995[3] and 1987, p. 967), this work precludes the hypothesis of variations in varnish cation ratios being controlled by incorporation of substrate material. For details, see responses to comments 4b and 4c.

Comment 4h

Dorn and Krinsley (1991) measured KCT ratios at the Little Cone volcano, which is part of the Quaternary volcanic alignment that includes Black Cone and Red Cone (e.g., Vaniman et al., 1982). KCT ratios for Little Cone layered-texture varnish are 2.7 ±0.1 (1 sigma), which is comparable to reported values of 2.2 ±0.3 and 2.3 ±0.1 for Black Cone and Red Cone, respectively (Harrington and Whitney, 1987). However, porous-texture varnish at Little Cone has a KCT ratio of 1.9 ±0.4. Although the Dorn and Krinsley (1991) values are each within the range of 1 sigma error reported for Black and Red Cones, the Little Cone data suggests that Black and Red Cone KCT ratios could be mixtures of layered-texture and porous texture varnish. Similar textural variations likely effect KCT ratios in other deposits. Thus, textural variations in varnish may produce some of the KCT variations attributed solely to age.

Response

DOE determined cation ratios using a scanning electron microscope (Harrington and Whitney, 1987, p. 967-969; DOE, 1993b, p. 40) which penetrates only about the upper 15 microns of the varnish, and this makes the issue of the existence of layered- versus porous-textured varnishes irrelevant. Furthermore, the DOE protocols used for sample collection, preparation, and analysis (DOE, 1993b, p. 38-42; Harrington and Whitney, 1987, p. 967-969) would preclude mixing of porous-texture and layered-texture varnish such that textural variations described in the comment are unlikely.

Recommendation

In the field of Quaternary geochronology, where new techniques are being developed and old techniques are being refined, it is recommended that additional methods to determine the age of exposure of surfaces be used to provide reasonable assurance with regard to the findings of the study on extreme erosion. Before the varnish cation ratio dating technique can be used to establish ages of geomorphic surfaces, it is recommended that the hypothesis that cation-ratio variations may represent different degrees of substrate contamination, amount of composition of the underlying substrate, composition of deuteric minerals, or textural variations need to be tested.

Response

DOE's research (for example, Harrington and Whitney, 1995; and Harrington and Whitney, 1987) has provided no evidence that any of the processes described in the Recommendation operate to control or influence the composition of varnish. In fact, DOE's research indicates that such processes are not operative in the development of varnish. In addition, DOE has developed independent lines of evidence from the geological record which corroborate the antiquity (for example see Whitney and Harrington, 1993, p. 1014) and stability of Yucca Mountain and the surrounding area. This information has been described in detail in the supplemental responses to Comments 1, 2, and 3.

The varnish cation ratio dating method is a calibrated method which provides estimates of the ages of the materials dated. DOE regards the varnish cation ratio data as correctly calibrated to independent age estimates, and hence considers the age estimates of boulder deposits are reliable.

DOE also has limited data which corroborates the varnish cation ratio age dates. Whitney and Harrington (1993) sampled three darkly varnished boulders at Buckboard Mesa for surface exposure dating using cosmogenic chlorine 36 (^{36}Cl). The estimated ages range from about 600 (actual range 671-549) ka to about 310 (actual range 336-288) ka for the samples. However, the ^{36}Cl

accumulation in rocks is calibrated in radiocarbon years which, when adjusted, will increase calculated ages by about 10 percent. Additionally, the oldest sample has a measured ^{36}Cl content of greater than 92 percent of the saturation value. Because this sample is close to the theoretical saturation, the sample may represent the maximum ^{36}Cl concentration effectively measurable. The age estimate may represent the practical upper limit of this dating technique and not closely limit the age of the deposit (Whitney and Harrington, 1993). It should be noted, however, that even if the 310 ka age estimate were to be accurate for the Buckboard Mesa deposits and were used with the measured channel incision of 0.3 meters (DOE, 1993b, p. 48), to estimate channel incision rates, that rate estimate would be about 0.1 cm/ka.

In addition, DOE has studies under way to determine cosmogenic ages for selected boulder deposits. DOE intends to provide the results to the NRC by the end of FY 1995. DOE believes that the results of this work will corroborate the results of the varnish cation ratio dating.

Finally, the issues of the potential for contamination of varnish by substrate material and for textural differences in varnish to influence cation ratios in varnish has been discussed in Harrington and Whitney (1995[3] and 1987). Based on the results described in these references, DOE has determined that substrate material and/or textural differences do not exert significant controls on varnish composition.

Comment 5

The calibration curve for the varnish cation ratio dating method which illustrates the relationship between the KCT of the varnish and the age of the geomorphic surface uses material dated by the uranium-trend (U-trend) method to determine the age of coarse-grained alluvial deposits and the potassium-argon (K-Ar) method to determine the age of basalts. Application of U-trend and K-Ar dates to establish the ages of the stable geomorphic surface is uncertain.

Response

The K-Ar age dating method and its limitations have been extensively studied, widely documented, and are well understood. The K-Ar method is generally accepted as a reliable age dating method for unaltered rocks whose ages are greater than 500 ka. Ages determined using this method were selected as calibration points for part of the calibration curve. The age of the basalts was used as an upper bound on the age of the surface on the basalt. Cosmogenic beryllium 10 dating is in progress to provide information on the amount time required for geomorphic surfaces to develop on the basalt flows. DOE expects to provide the results of this work by the end of FY 1995.

Uranium-trend ages were used for calibration only where the deposits had been dated more than once with resultant comparable ages being obtained. Rosholt and others (1985, p. 13), in their description of the results of 30 U-trend age determinations from alluvial units at the Nevada Test Site, note the following:

> A histogram showing 30 U-trend age determinations from alluvial units at NTS [Nevada Test Site] are shown in Figure 35 [of Rosholt's open-file report]. Results of the first sampling of Frenchman Flat alluvium (S1) are excluded from the histogram. Median ages for these deposits indicate the following times of widespread depositions: About 40 ± 15 Ka for Q2a sediments, 170 ± 40 Ka for Q2b sediments, 270 ± 60 and 440 ± 60 Ka for younger and older Q2c deposits. These results are reasonably consistent with other age determinations, stratigraphic constraints, and with estimates based on geomorphic evidence. In this area, most of the late to middle Pleistocene sediments appear to have been deposited in these time frames.

The uranium-trend age dates for the coarse-grained alluvial deposits were estimated from the results of multiple analyses of samples from differentiable layers or units comprising the deposits (Rosholt and others, 1985, p. 2 and Rosholt, 1985, p. 1). Ages were estimated only in those instances where: (1) the analytical results were internally consistent, and (2) the results showed small dispersion about a least squares linear regression line fitted to the data (Rosholt and others, 1985). Analyses that did not result in internal consistency were not used.

Because of the consistency of the U-trend age determinations with other age determinations, stratigraphic constraints, and with estimates based on geomorphic evidence, DOE determined that the U trend ages used were reasonably reliable and suitable for use in construction of the of the varnish cation ratio calibration curve.

The U-trend method is a calibrated dating technique that was developed specifically to date open systems and is a variant of more widely used U-series age dating techniques. When dating soil caliche deposits, it is likely that both the U-trend method and the more widely accepted U-series methods provide estimates of minimal ages of the deposits in question. DOE notes that the strength of calibrated techniques, and particularly the U trend method, is that successful use requires only that the technique be correctly calibrated; it is not necessary to have a complete understanding of chemical and physical processes that determine the behavior of the individual radionuclides to utilize the method. Furthermore, to use the method, the developers (Rosholt and others, 1985) required that the data be both internally consistent and show a small dispersion about the regression line fitted to the data.

In a literature review of uranium and thorium decay series dating methods, Ku (1988) reported that U-trend data from coarse-grained alluvial deposits on the Nevada Test Site could be divided into three qualitative categories based on the ability of the data to support linear regressions in the $(^{234}U-^{238}U)/^{238}U$ vs. $(^{238}U-^{230}Th)/^{238}U$ plots. Category A included data whose plots provided sufficiently well-defined slopes and x-intercepts that their ages would have 10-20 percent errors. Category B included data likely to produce errors of about 50 percent, and Category C could have uncertainties of greater than 100 percent.

All of the Yucca Mountain data Ku reviewed fell in Category A or B. If we assume that the data were all Category B and indeed contained a 50 percent error such that the ages were over-estimated by 50 percent, and applied a 50 percent correction to the calibration curve (DOE, 1993b, Figure 9), it appears that the result of the correction would have little effect on the conclusions about estimated erosion rates. In an extreme case, the rate might double. If the maximum erosion rate calculated at Boundary Ridge were doubled, the expected erosion over the 10 ka performance period would be about 0.11 meters compared to the planned depth of the proposed repository of more than 200 meters.

Rock varnish age estimates have been evaluated within the geologic context and constraints of other study areas (DOE, 1993b, p. 36). In the Española Basin, New Mexico (Dethier et al., 1988 and Harrington and others, 1988) the rock varnish age estimates were compared to amino acid racemization ages of deposits underlying the rock varnish covered surfaces and were found to be reasonable. Additionally, a rock varnish age estimate of 550 ka (Dethier et al., 1988) was obtained for a surface overlying deposits containing the Lava Creek B tephra (620 ka); this result supports the contention that the rock varnish age estimates are geologically reasonable because they are consistent with geologic constraints at the site.

In Las Vegas Wash in southern Nevada similar geologic comparisons were made, and it was noted that (1) varnish thickness is greatest on the deposits that yield the oldest age estimates, and (2) the thickest carbonate soil horizons are likewise noted in the deposits with the oldest estimated ages (Harrington and Whitney, 1991). Finally, rock varnish on a surface in Las Vegas Wash yields a 600 ka age estimate and is underlain by deposits that contain the Lava Creek B tephra (620 ka) at a depth of two meters (DOE, 1993b, p. 36). Thus, the Yucca Mountain rock varnish age estimates appear reasonable when placed within the geologic constraints of the area. In none of these areas have geologic constraints been found that would demonstrate the age estimates are in error, and DOE has concluded that the age estimates are valid.

In addition, sample collection is now in progress to provide material for cosmogenic dating of some deposits previously dated by other methods. DOE believes that this additional dating will provide corroborative age estimates which will support the calibration of the varnish cation ratio curve. DOE intends to provide the data to the NRC by the end of FY 1995.

Comment 5a

In the Topical Report, three of the five calibration points are dated using U-trend methods. Swadley et al., (1984) used these same dates to estimate the ages of Quaternary soils and alluvial deposits in the vicinity of Yucca Mountain. They noted that the dating method was experimental and "that accuracy of the absolute ages derived by this method is not known ..." (Swadley et al., 1984, p. 6). Geyh and Schleicher (1990; p. 226) also question whether U-trend dates actually represent the age of the deposit. No data have been presented in the Topical Report to demonstrate that the U-trend dates used in the calibration curve either precisely or accurately represent the age of the varnish associated with these deposits. Although Harrington et al., (1988; p. 1052) stated that the "analytical uncertainty in the K-Ar and U-series SIC dates is minimal," the Los Alamos peer-review group felt that "additional calibration points should *use all suitable methods" (Birkeland et al., 1989; p. 6). The varnish cation ratio calibration curve used for this study apparently has not been modified or tested in any since it was originally published by Harrington and Whitney (1987).*

Response

The U-trend method has provided age estimates that are adequate for calibration of part of the varnish cation ratio dating curve. DOE's investigations have produced several independent lines of evidence supporting the antiquity and stability of the land surface (for example, see Coe and others, 1995) and associated landforms, and supporting the reasonableness of the numeric age and erosion rate estimates (See responses to Comments 1b and 2d). The numeric age estimates appear to be internally consistent with one another, and consistent with both qualitative evidence and with age estimates derived from evidence preserved in the geologic record.

The citation (Swadley and others, 1984) is incomplete and presents a possibly inaccurate view of what the authors actually said about the U-trend method. The complete text of the citation is as follows:

> Stratigraphic units and post-fault carbonate and silica deposits were sampled in six trenches for isotopic age determinations. Sample locations are shown on trench diagrams in the appendix. Surficial deposits were dated by the uranium-trend method (Rosholt, 1980). This method is experimental but was used because materials needed for more conventional radiometric dating methods are sparse in the Yucca Mountain area. Dates determined by the uranium-trend method theoretically indicate the minimum age for deposition of surficial deposits .... The technique is considered to be applicable for deposits that range in age from 5,000 to 900,000 years and has a potential estimated accuracy of about ±10 percent. Uranium-trend dates have been used in an attempt to determine minimum ages for deposits that structurally and stratigraphically bracket the age of fault related features in trenches [sic] 2, 13, 14, and CF3. Approximate limits on the absolute age of faulting are inferred on the basis of these dates. The accuracy of the absolute ages derived by this method is not known, but ages determined for some stratigraphic units are reasonably consistent over the study area and are consistent with the broad limits on the ages of stratigraphic units in the study area inferred on the basis of correlations with better dated sequences from the surrounding area.

Swadley and others (1984) acknowledged the limitations of the method but still embraced its ability provide consistent and usable results.

The nature of the staff's concern reflected as " ... Harrington et al., (1988, p. 1052) stated that the 'analytical uncertainty in the K-Ar and U-series SIC dates is minimal,'...." is not clear. DOE believes that the "SIC" in the comment may be an unconventional form of the term "[sic]" which is used to identify portions of quotations which, while incorrect, have been intentionally so written to maintain the integrity of the quotation. If this were the case, then it would appear that the staff is taking exception to the term "U-series" in the quotation in question. However, the nature of the exception is not clear because the complete text of the quotation is as follows:

> Analytical uncertainty in the K-Ar and U-series [emphasis added] dates is minimal, however, and probably small in comparison to the geologic uncertainty in surface ages, as suggested above.

The portion of the staff comment which states "... the Los Alamos peer-review group felt that 'additional calibration points should use all suitable methods' (Birkeland and others, 1989, p. 6)" cites a suggestion that calibration of the method and development of additional calibration curves should be done for other "points" which DOE interprets to mean other "sites" or "locations." However, except for additional testing and confidence building in the method, it is not clear that this suggestion would have any direct application to varnish cation ratio dating efforts at Yucca Mountain. Calibration of a varnish cation ratio curve is a site specific process, and it is difficult to envision how the curves for different locations might be correlated. The results from completed studies indicate that curves calibrated for one site cannot be used for determination of ages at other sites. Furthermore, the calibration curve was established using least-squares curve fitting methods. The fact that r=-0.992 (Harrington and Whitney, 1987, p. 968) indicates a strong negative linear correlation between varnish cation ratio and log of years before the present. Given this strong relationship, it is doubtful that additional points would significantly improve the shape of the curve.

Comment 5b

It is not possible to directly correlate the samples dated by the uranium-trend method (Rosholt et al., 1985) with calibration units Q2c, Q2b, and CF, using the limited data presented in the Topical Report or associated publications. Although unpublished U-trend dates by D.R. Muhs are used in Table 1 of Harrington and Whitney (1987), these dates are not presented in the Topical Report and cannot be evaluated for precision or accuracy.

Numerous sites for units Q2c, Q2b, and CF are however, presented in Rosholt et al. (1985), but there is no discussion of the range in apparent ages of these units in Harrington and Whitney (1987). The 40 ±10 ka "Crater Flat surface" reported in Harrington and Whitney (1987) apparently corresponds to unit Q2a in Rosholt et al. (1985), which has an apparent age 30 ±10 to 55 ±20 ka in the Yucca Mountain area. Unit Q2b, which has a reported age of 160 ±20 ka in Harrington and Whitney, ranges in age from 160 ±25 to 200 ±80 ka in Rosholt et al. (1985). Unit Q2c, which has a reported age of 255 ±15 ka in Harrington and Whitney, ranges in age from 240 ±50 to 310 ±40 ka for the upper member reported in Rosholt et al. (1985). The precision and accuracy of the dates associated with units Q2c, Q2b, and CF is significantly lower than reported in Harrington and Whitney (1987).

Response

The purpose of the topical report was to present evidence supporting DOE's position that the potentially adverse condition, "evidence of extreme erosion during the Quaternary Period," is not present at Yucca Mountain. The varnish cation ratio calibration curve was adopted from Harrington and Whitney, 1987, but DOE provided a detailed reference list and included relevant sources of information on various age dating techniques, the surficial and bedrock geology of Yucca Mountain and the surrounding area, surficial processes and associated landforms, and data on other areas of the United States and the world. DOE considered that the information it provided to be adequate documentation to support evaluation of the varnish cation ratio calibration curve.

As noted in the quotation from Swadley and others (1984) in the response to Comment 5a, the U-trend method produces minimum age estimates. To insure consistent conservatism in the calibration of the varnish cation ratio curve, DOE used ages that are minimums within the range of ages determined for the respective units. This convention insured that the varnish cation ratio curve was calibrated at the lower end of the age estimates, and this added an inherent conservatism to the varnish cation ratio curve because the young end of the curve was calibrated to minimum ages. This provided a reduced slope for the calibration line and insured that varnish cation ratio age estimates were in the lower part of the range of possible ages. Subsequent erosion rate estimates were then maximum rates because the maximum process magnitudes and youngest ages were used in the calculations.

In addition, sample collection is now in progress to provide material for cosmogenic dating of some deposits previously dated by other methods. DOE intends to provide the data to the NRC by the end of FY 1995. DOE believes that this additional dating will provide corroborative age estimates which will support the calibration of the varnish cation ratio curve and plans to review this issue at that time.

Comment 5c

Rosholt et al. (1985) report the gravels in the upper member of unit Q2c "locally overlie and contain reworked cinders from the Big Dune basalt center 11 kilometers northwest of Lathrop Wells," Nevada. Although earlier K-Ar dates for this volcano (Vaniman et al., 1982) are between 200 and 300 ka, these dates are generally regarded as erroneously old (e.g., Crowe et al., 1992). Relatively high-precision Ar-Ar (Turrin et al., 1991) and cosmic-ray exposure dates (e.g., Crowe et al., 1992; Zreda et al., 1993) indicate that the age of the "Big Dune" volcano is likely 100 ±50 ka. Thus, unit Q2c should be significantly younger than the 255 ±15 ka age used in the varnish cation ratio calibration curve for the Topical Report. Likewise, the ages of overlying units Q2b and CF may also be significantly younger than represented by the U-trend dates.

Response

Wells and others (1990) document that the Lathrop Wells cinder cone has undergone little erosional modification. They state "the Lathrop Wells cone has the maximum cone slope, apparently no apron development and shows no erosional modification of the cone flanks and crater." The age of the Lathrop Wells cone has been dated between 20 and 130 ka (Crowe and others, 1992). The most recent dates on the lavas are in the range of 60 to 120 ka (Crowe and others, 1995). In spite of the apparent quality of the recent dates, the Lathrop Wells cone continues to be the subject of study. Based on available information, it appears that the cone has a complex history and was the product of multiple extrusive events which spanned a significant portion of the late Quaternary Period. However, regardless of the age of the cone, the absence of erosional modification demonstrates that erosion rates have been low during the late Quaternary in the Yucca Mountain area.

Comment 5d

The ages of Black Cone and Red Cone have been established by use of the K-Ar dating method. This method assumes that the K-Ar system is closed upon the quenching of the extruded magma. In order to use these materials in the KCT ratio versus age of stable surface calibration, it must be assumed that the varnish began to form as soon as the extruded magma was quenched. No information supporting this assumption is provided and the *assumption may be incorrect.*

Response

Available information indicates that varnish begins to develop on appropriate surfaces in arid and semi-arid environments relatively soon (about a hundred years according to Dorn, 1984) after the surfaces become exposed and stabilized. The uncertainty in assumptions about when varnish began to form is much less than the uncertainty in K-Ar dates which provide the basis for determining the age of the two cones in question.

In a general sense, the assumption about quenching is correct as stated. Strictly, however, one can relax the assumption somewhat because of the uncertainty in the K-Ar dates. For the calibration to be valid, one must assume that the varnish began to form after the lava was quenched and sometime within the period of uncertainty calculated for the K-Ar age. Recently determined Ar/Ar dates on the Crater Flat volcanic centers indicates that the ages cluster around 1.0 Ma ± 110 ka (Crowe and others, 1995). If Dorn's estimate of the time required for varnish to begin forming is within an order of magnitude of being correct, varnish would certainly have begun to form within the period of uncertainty associated with the estimated age for the Crater Flat centers. In any case, the varnish cation ratio calibration curve, which plots cation ratio against the logarithm of age (expressed as years before present), is less sensitive to variations in age estimates than to variations in the cation ratios. Therefore, it is unlikely that refining assumptions about the onset of varnish development will have any significant effect on the overall shape of the calibration curve or on the age estimates that result from the use of the calibration curve.

In addition, DOE has work in progress to cosmogenically date some outcrops and colluvial boulder deposits. Some of this work may provide data to determine the surface exposure age and the amount of time necessary to degrade the surfaces of the Black Cone and Red Cone lavas. DOE intends to provide the data to the NRC by the end of FY 95 and plans to review this issue at that time.

Recommendation

To use the varnish cation ratio dating technique to establish the ages of stable geomorphic surfaces, it is recommended that additional methods of dating such as the cosmogenically-produced isotopes ^{3}He, ^{14}C, ^{10}Be, ^{26}Al, and ^{36}Cl (e.g., Nishimiizumi et al., 1991), be used to make the calibration curve more robust.

If uranium-trend dates of alluvial deposits are to be used in the calibration curve, then apparent ambiguities between U-trend dates used in the Topical Report and those in Rosholt et al. (1985) must be addressed.

Response

The Criteria for Selection of a Dating Methodology are described in Section 3.3.2.1.1 of the topical report (DOE, 1993b). DOE wishes to point out that cosmogenic dating now in progress is expected to provide the corroboration necessary to establish robustness. DOE intends to provide the results of this work to the NRC by the end of fiscal year 1995.

Uranium-trend ages were not provided in the topical report. The topical report presented the calibration curve developed in Harrington and Whitney (1987). Harrington and Whitney (1987) cited multiple sources for the U-trend data they used to construct the calibration curve. To resolve this question, the data points in question will need to be specified.

As noted in Swadley and others (1984), the U-trend method produces minimum age estimates. DOE regards the U-trend ages that were used to construct the calibration curve as reasonably reliable. To insure consistent conservatism in the calibration of the varnish cation ratio curve, the curve was constructed using ages that are within the lower part of the range of ages determined for the respective units. This convention insured that the varnish cation ratio curve was calibrated at the lower end of the age estimates, and this added an inherent conservatism to the varnish cation ratio curve because the young end of the curve was calibrated to minimum ages. This provided a reduced slope for the calibration line and insured that varnish cation ratio age estimates were in the lower part of the range of possible ages. Subsequent erosion rate estimates were then maximum rates because the youngest ages and maximum process magnitudes were used in the calculations.

Rock varnish age estimates have been evaluated within the geologic context and constraints of other study areas (DOE, 1993b, p. 36). In the Española Basin, New Mexico (Dethier and others, 1988) the rock varnish age estimates were compared to amino acid racemization ages of deposits underlying the rock varnish covered surfaces and were found to be reasonable. Additionally, a rock varnish age estimate of 550 ka (Dethier and others, 1988) was obtained for a surface overlying deposits containing the Lava Creek B tephra (620 ka); this result supports the contention that the rock varnish age estimates are geologically reasonable.

In southern Nevada similar geologic comparisons were made, and it was noted that (1) varnish thickness is greatest on the deposits that yield the oldest age estimates (topical report, Figure 7; DOE, 1993b), and (2) the thickest carbonate soil horizons are likewise noted in the deposits with the oldest estimated ages (Whitney and others, 1988). Finally, rock varnish on a surface in Las Vegas Wash yielded a 600-ka age estimate and is underlain by deposits that contain the Lava Creek B tephra (620 ka) at a depth of two meters (DOE, 1993b, p. 36). Thus, the Yucca Mountain rock varnish age estimates appear reasonable when placed within the geologic constraints of the area. In none of these areas have geologic constraints been found that would demonstrate the age estimates are in error, and DOE has concluded that the age estimates are valid.

Section 3.3.2.1.6 of the topical report (DOE, 1993b) discusses the calculation of uncertainties for cation ratios and explains that

> Although more data points might reduce the curve uncertainty to a minor degree, the concentration of data points is adequate to establish the calibration curve. Most age estimates for the boulder deposits in this report are derived from within the calibrated interval of the dating curve (11 of 12 deposits). The remaining point lies in immediate proximity to the calibrated interval. Any additional reduction in the uncertainty of the curve that could be obtained with the addition of a greater number of calibration points would not affect any of the technical conclusions in this report that are based on the dating curve.

DOE considers that the age estimates are sufficiently reliable as calibration points and that the uncertainty in the calibration curve is sufficiently well understood that further work is unnecessary. However, DOE may review this issue in light of the results of the cosmogenic dating which are expected by the end of FY 1995.

Comment 6

The development and issuance of a geomorphic map of Yucca Mountain and adjacent areas is an important factor in the determination of the presence, or absence, of extreme erosion. However, no such map, or its equivalent (such as a surficial geology map) has been submitted with the Topical Report.

Response

Published surficial geology maps exist for areas west and south of Yucca Mountain (Map I-1826, Swadley and Parrish, 1988), Big Dune (Map I-1767, Swadley and Carr, 1987), Lathrop Wells (Map I-1361, Swadley, 1983). These maps cover almost all of the area where material eroded from Yucca Mountain might reasonably be deposited, but these maps show no anomalous Quaternary deposits nor incised channels or anomalous changes in stream gradients. that could be attributed to extreme erosion. Furthermore, additional new information, which is or soon will be available, includes:

1. Map and description of the surficial geology of Fortymile Wash (Lundstrom and Warren, 1994).

2. Maps of surficial geology of Midway Valley and parts of Fortymile Wash (DOE, 1995).

3. Data from the Jake Ridge storm in July, 1984 (Coe and others, 1995).

Comment 6a

It appears that several objectives of site characterization, related to erosion are: (1) to identify the erosional processes that have been operating in the Yucca Mountain area during the Quaternary; (2) to identify the specific locations of past erosion; and (3) to quantify the rates of the different processes and assess their relative importance. It is assumed that this information would be used in the analysis of the potentially adverse condition of extreme erosion. However, the Topical Report does not appear to have met these objectives.

Response

The purpose of the topical report was to demonstrate that the potentially adverse condition, "evidence of extreme erosion during the Quaternary Period," is not present at Yucca Mountain, present focused arguments, technical and regulatory, supporting that position, and provide selected information relevant to the focused arguments. DOE estimated Quaternary erosion rates at certain locations as part of the evaluation process, and used the erosion rate estimates to demonstrate that the potentially adverse condition is not present at Yucca Mountain.

The topical report discusses the erosional processes which operate on hillslopes and drainages in the Yucca Mountain area (DOE 1993b, p. 29-31 and 50-54). The topical report also differentiates between the rates of the processes in unconsolidated hillslope deposits and those in hillslope bedrock, and differentiates these rates from rates for erosion in drainages.

DOE's investigations focused on determining the locations of past erosion. As a result of these investigations, DOE has determined where erosion has occurred and estimated erosion rates for those locations, and identified locations where there has been no erosion (DOE, 1993b, p. 46 and 50-54). The identification of these latter locations was especially important to DOE's evaluations because DOE developed its erosion rate estimates by excluding data from areas where no evidence of erosion was found. By excluding these areas of no erosion (DOE, 1993b, p. 46), DOE insured that its rate estimates are likely to be overestimates of an inclusive rate and are, therefore, conservative.

By comparison of Quaternary degradation rates at Yucca Mountain with estimates for other similar areas in the southwestern United States (DOE, 1993b, p. 48 and p. 9-11), DOE has found that the Yucca Mountain rates are below average. Since the degradation rates are below average, DOE has determined that they cannot be extreme. Hence, DOE has concluded that the potentially adverse condition, "evidence of extreme erosion during the Quaternary Period," is not present at Yucca Mountain or in the surrounding area.

Furthermore, even if the potentially adverse condition were assumed to exist, rates of erosion would be low. To put the Yucca Mountain erosion rates in perspective, the expected amount of erosion based on projections of the average erosion rate (DOE, 1993b, p. 48) over the performance period, would be less than 0.02 meters. Furthermore, if the maximum estimated erosion rate (0.571 cm/ka at Boundary Ridge) were projected over the performance period the amount of erosion that would be expected would be less than 0.06 meters. DOE notes that the planned depth of the proposed repository is more than 200 meters.

Finally, DOE has investigated Holocene erosion in Midway Valley (DOE, 1995) and modern erosion in Fortymile Wash (Lundstrom and Warren, 1994) and at Jake Ridge (Coe and others, 1995 and 1992). The Midway Valley study provided data for a preliminary estimate of the denudation rate over about the last 20 ka of about 5 mm/ka (0.5 cm/ka). The modern examples of maximum erosion were related to infrequent but severe summer thunderstorms (Coe and others, 1995 and 1992). Details of these investigations have been supplied in the response to Comment 1. These maximum events have not produced significant changes in landforms and are, therefore, excellent examples of the absence of extreme erosion at Yucca Mountain and in the surrounding area.

Comment 6b

A geomorphic (surficial deposits) map of Yucca Mountain would allow: (1) determination of the areal distribution of active erosional areas and geomorphically stable areas; and (2) determination of the spatial distribution of the different types of geomorphic processes and associated deposits. It is not evident to the staff that the data supporting the accomplishment of the above objectives have been submitted for staff evaluation.

Response

Areas of active erosion and stability were described in the topical report (for example see DOE, 1993b, p. 22-31). The information suggested is available as published maps for areas west and south of Yucca Mountain (Map I-1826, Swadley and Parrish, 1988), Big Dune (Map I-1767, Swadley and Carr, 1987), Lathrop Wells (Map I-1361, Swadley, 1983). These maps cover almost all of the area where material eroded from Yucca Mountain might reasonably be deposited, but these maps show no anomalous Quaternary deposits that could be attributed to extreme erosion.

Surficial geological mapping around Yucca Mountain (Swadley and others, 1984) reveals extensive lower and middle Quaternary deposits. As noted in the topical report (DOE, 1993b, p. 24)

> Over 85 percent of the surficial deposits and geomorphic surfaces exposed adjacent to the Yucca Mountain tilted blocks were formed during the early to middle Quaternary. Exposed upper Quaternary deposits are confined to small areas on hillslopes and are probably buried below a thin veneer of Holocene alluvium in Fortymile Wash and its tributaries, as well as the unnamed stream beds that cross Crater Flat.
>
> Deposits of late Quaternary age are chiefly confined to present stream valleys. The lack of late Pleistocene and Holocene deposits at the base of Yucca Mountain hillslopes indicates that erosion rates from these slopes have been low during the past 100,000 years or more. Confinement of late Quaternary deposits to valleys and channels indicates the volume of material eroded off hillslopes has been smaller than during the early and middle Quaternary....

This restriction of the late Quaternary deposits indicates that the amount of material available has not been sufficient to develop extensive alluvial units in the drainages adjacent to Yucca Mountain.

There is a shortage of late Pleistocene deposits on and around Yucca Mountain. The significance of this shortage relative to inferences about the tectonic and climatic history of the area is described in the topical report (DOE, 1993b, p. 25) as follows.

> The paucity of late Pleistocene deposits on and around Yucca Mountain has climatic, as well as tectonic, significance. A marked contrast exists between the geomorphic processes that operate under the present semiarid-to-arid climate and those that prevailed during cooler and wetter climates that occurred during the Quaternary. A significant portion of the surficial deposits on and around Yucca Mountain formed during the early and middle Quaternary by processes related to cool pluvial climates or during the transition from warmer to colder climates. Two periods of alluvial deposition in Fortymile Wash, one which ceased prior to about 270 ka and one which ceased prior to about 145 ka, are likely related to the transition from drier (interpluvial) to wetter (pluvial) conditions.
>
> Shallow entrenchment (3-6 m) of streams, along the margins of Crater Flat, through older deposits suggests slow uplift of Yucca Mountain or slow subsidence in adjacent basins. This geomorphic response is consistent with the slow rates of tectonic activity measured on the major Yucca Mountain faults. Alternatively, stream incision may reflect changes in fluvial processes due to Quaternary climate changes. Such valley entrenchment likely occurred during pluvial climatic conditions. The present well-defined drainage channels indicate that future stream incision will be confined to the present valleys for at least tens of thousands of years.

In addition, the results of recent mapping in Fortymile Wash (Lundstrom and Warren, 1994) and Midway Valley (DOE, 1995) are being evaluated. The Fortymile Wash mapping has shown that the wash is a pre-Quaternary feature. The oldest dated alluvial unit is about 2.8 Ma, and the presence of this unit in the wash precludes deep incision and wholesale removal of alluvial units at any time since the 2.8 Ma unit was deposited. This information indicates that this ancient landscape has maintained a low rate of erosion and is geomorphically stable.

Comment 6c

Figure 7 [of the topical report] (map of surficial deposits around Yucca Mountain) lacks sufficient detail necessary to evaluate the presence, or absence, of extreme erosion. In addition, the figure does not provide sufficient detail to show landforms (both bedrock and surficial deposits) and to allow evaluation of the types of past and present geomorphic processes that are chiefly responsible for their formation.

Response

Figure 7 of the topical report (DOE, 1993b) was intended to show only the general distribution patterns of the consolidated Quaternary alluvial and eolian units, Quaternary volcanic units, and the pre-Quaternary units. No attempt was made to provide detailed information on any unit or suite of units, and DOE made no representations in the topical report that the figure contained information in sufficient detail to determine landforms or evaluate the geomorphic processes responsible for their development. References to reports and maps containing the detailed information of interest to the staff were provided in the topical report, and copies of relevant reports have been provided to the NRC. In addition, as noted above, much of the information described in the comment is available as published maps, at appropriate scales, for areas west and south of Yucca Mountain (Map I-1826, Swadley and Parrish, 1988), Big Dune (Map I-1767, Swadley and Carr, 1987), Lathrop Wells (Map I-1361, Swadley, 1983). Since the topical report was submitted, some mapping in Fortymile Wash (Lundstrom and Warren, 1994) and Midway Valley (DOE, 1995) has been completed. This recently completed work has been done at a larger scale than the earlier work. The results of this new mapping, in conjunction with the earlier published maps, provides the data requested by the staff in this comment.

Recommendation

Develop a geomorphic map of the Yucca Mountain area, or alternatively a surficial deposits map, and use the map as one of the elements in determining the presence, or absence, or the extreme erosion potentially adverse condition.

Response

Geomorphic maps covering the areas in which material eroded from Yucca Mountain could accumulate have been published and are identified above. As noted in the response to Comment 6c, the results of recently completed mapping have recently been compiled (DOE, 1995). All of these maps show that there are no deposits or landforms which indicate that extreme erosion has occurred at

Yucca Mountain or in the surrounding area and support DOE's contention that the potentially adverse condition, "evidence of extreme erosion during the Quaternary Period," does not exist at Yucca Mountain.

Comment 7

The technical basis for the Fortymile Wash maximum incision scenario shown in Figure 13 (see p. 53) is not provided in the Topical Report.

Response

Erosional processes have been evaluated for major canyons and valleys in the vicinity of Yucca Mountain (DOE, 1995, Lundstrom and Warren, 1994, and Glancy, 1994). Fluvial activity since the middle Quaternary in Fortymile Wash and its principal tributaries has been limited to aggradation and reintrenchment through its own alluvial fill. The figure indicates that during the past half million years, four stream terraces have formed in Fortymile Wash. Remnants of the oldest Fortymile Wash terrace are located east of Alice Ridge.

Figure 13 (of the topical report; DOE, 1993b) illustrated two possible cases for stream incision in the alluvial gravels of Fortymile Wash. One case depicted a maximum incision case; the other depicted a more likely, minimum incision scenario. Since developing the maximum incision scenario, which was presented as an extreme end member possibility that was not supported by any data, mapping in Fortymile Wash (Lundstrom and Warren, 1994) and Midway Valley (DOE, 1995) has revealed the presence of two alluvial units which preclude the catastrophic down-cutting hypothesized in this scenario:

1. Presence of pre-Quaternary (about 3 Ma) alluvium in Fortymile Wash (Lundstrom and Warren, 1994).

2. Presence of preserved soil horizons in soil pits dug into the 270 ka alluvium (unit Q2c in figure 13 of the topical report, DOE, 1993b).

The presence of the pre-Quaternary alluvium indicates that wholesale stripping of alluvial units has not occurred since before the pre-Quaternary unit identified in Lundstrom and Warren (1994) was deposited. In addition, a soil horizon preserved in the 270 ka alluvium indicates that erosion, sufficient to disrupt or remove the soil horizon, has not occurred within Fortymile Wash since the onset of the soil development. The field evidence (Lundstrom and Warren, 1994) indicates that the mean rate of incision in Fortymile Wash for the last 2.8 million years has been 36 m/Ma or about 3.6 cm/ka.

The likely scenario (labelled "minimum incision scenario in Figure 13) is based on discrimination and correlation of alluvial units in Fortymile Wash. The oldest Quaternary alluvium in Fortymile Wash is correlated with dated deposits of about 430 ka. The valley floor is situated about 28 m below the surface of the alluvium. The main, or most prominent, terrace is 3 m below the oldest terrace (25 m above the valley floor) and is dated at about 270 ka . The next younger terrace is about 10 m above the present channel and is about 150 ka old. The lowest terrace is situated just above the active flood plain and is of Holocene age. The depth of the fill across from Busted Butte, as measured in well J-13, is 108 m below the present channel. The number, thickness, and ages of fills below the valley floor are unknown. However, a maximum, long-term average downcutting rate on Fortymile Wash can be calculated by assuming that the wash cut down to the base of its present fill and aggraded to the 150 ka terrace level between the time of the main terrace at 270 ka and the formation of the lower terrace at 150 ka.

If it is further assumed that the downcutting took place during the first half of that time interval (270 ka - 150 ka) and aggradation of the lower alluvial fill occurred during the second half, then Fortymile Wash cut down about 133 m in 60,000 years, or an average incision rate of 222 cm/ka. A slightly lower incision rate can be calculated assuming the present fill was emplaced after the formation of the 150 ka terrace. In the area just below the mouth of Fortymile Canyon, where cutting and filling has been the most active, the maximum average downcutting rate can be used to predict about 22 m of incision in 10,000 years. However, for this incision to occur, the present aggradational conditions in the wash would have to change to near-optimal erosional conditions. Initiation of erosion in the wash would require a major climatic change to pluvial conditions to provide sufficient moisture to sustain fluvial activity. Nevertheless, this erosion would occur within the alluvial package, and no bedrock incision would occur. As evidenced by the Quaternary record, the period of erosion would be followed by an aggradation cycle, resulting in a net minor elevation change in the wash unless there was a major change in base level for Fortymile Wash.

Comment 7a

Figure 13 [of the topical report] suggests that a portion of the alluvium occupying the channel of Forty Mile Wash is assumed to have been incised and then essentially refilled to a depth of 108 meters within the Holocene (a time period of approximately 10,000 years).

Response

Two incision scenarios for Fortymile Wash were described in the topical report (DOE, 1993b, p. 51-54 and Figure 13). The amount of incision described in the staff comment is for the maximum incision scenario which is a worst case scenario. This scenario was presented for the sake of comparison but not as an expected case. Since the topical report was submitted, mapping in Fortymile Wash (Lundstrom and Warren (1994) has shown the presence of a pre-Quaternary gravel having a distinctive clast population. Additionally, recent mapping in Midway Valley (DOE, 1995) has identified soil horizons preserved at about a meter below the surface of the 270 ka alluvium. The existence preserved pre-Quaternary alluvium and the soil horizon preclude the amount of canyon incision and associated wholesale stripping of units implicit in the maximum incision scenario. Because of this recently obtained data described above, the DOE no longer considers this worst-case scenario to be credible.

Comment 7b

Figure 13 [of the topical report] shows that a stream once occupying ancestral Forty Mile Wash is assumed to have incised the valley fill (Q2c Alluvium) to a depth of 133 meters and then nearly refilled the incised channel with alluvium within a period of 120,000 years. Incision (downcutting) is assumed to have occurred during the first 60,000 years.

Response

Figure 13 depicts a maximum incision scenario which assumes that Fortymile Wash was incised from the 270 ka terrace to the base of the valley fill (133 m) in 60,000 years before aggrading to the 150 ka terrace level. The depth of incision and the period of time are both from the worst case scenario which DOE considers not credible and did not occur.

Lundstrom and Warren (1994) reported that Fortymile Wash contains a pre-Quaternary gravel having a distinctive clast population. Additionally, Lundstrom, (1995) identified soil horizons preserved at about a meter below the surface of the 270 ka alluvium. The existence preserved pre-Quaternary alluvium and the soil horizon preclude the amount of canyon incision and associated wholesale stripping of units implicit in the maximum incision scenario.

Comment 7c

Figure 13 [of the topical report] shows that the 430 ka terrace (QTa Alluvium) of ancestral Forty Mile Wash was incised and subsequently refilled to a depth in excess of 133 meters within a period of 150,000 years. Incision (downcutting) is assumed to have occurred within the first 80,000 years.

Response

The comment invokes the assumptions implicit in the maximum incision scenario. Based on the results of recent mapping (see above), DOE considers that this scenario is no longer credible and did not occur.

Comment 7d

The maximum incision scenario for Forty Mile Wash is considered permissible and is based upon interpretations of geologic field relations and dated terrace surfaces (DOE, 1994, p. 3).

Response

DOE has stated "The Forty Mile Wash stream incision scenarios in TR [topical report] section 3.3.3.4 (Figure 13) are interpretations permissible from geologic field relations and dated terrace surfaces" (DOE, 1994, p. 3). However, as noted on page 54 of the topical report and corroborated by the results of recent mapping (see above), DOE believes that maximum incision in Fortymile Wash has not occurred during the Quaternary.

About 15 km south of well J-13, near Highway 95, the channel of Fortymile Wash merges with the general alluvial plain of the Amargosa Desert. No canyon or record of Quaternary downcutting exist at this locality; thus, the lower reaches of Fortymile Wash appear to have been primarily in a state of aggradation during the Quaternary Period. The low rates of channel incision calculated for the wash both upstream and downstream from the Fran Ridge-Busted Butte segment of the wash support a downcutting history through the midsection of the wash that closely approximates the minimum calculable incision rate scenario.

In order for stream incision to occur in Fortymile Wash along the segment adjacent to Yucca Mountain (the Fran Ridge-Busted Butte segment), one of two basic conditions must exist: (1) the base level of lower Fortymile Wash must be lowered so as to initiate a headcut in the channel that would then migrate upstream, or (2) the slope of the channel must steepen to a gradient that would also initiate headcutting upstream along the channel. The fact that Fortymile Wash discharges onto the aggradational plains of Amargosa Valley, indicates that its base level is not lowering at present, but rising as a result of channel aggradation. A rising base level lowers the overall channel gradient and results in progressive upstream channel aggradation, which is the present condition of Fortymile Wash. Channel incision in the present arid climate is very unlikely and potentially limited to discontinuous gullies in short, locally over steepened reaches of the valley floor.

The most likely way for the modern aggradational mode of Fortymile Wash to change to an incisional mode is by a significant change in hydrologic conditions caused by a major climatic change. Under cooler and wetter climatic conditions, with well vegetated hillslopes, runoff may become great enough to transport channel sediment beyond the Amargosa Valley (Desert) floor, although no evidence exists to indicate that such hydrologic conditions occurred during the extent of full glacial (18 to 15 ka) climatic changes. If such climatic changes did occur in the southern Great Basin, then Fortymile Wash might begin to incise its valley floor. However, as stated above, incision in the site area would likely not occur until a headcut initiated downstream of the Amargosa Valley had migrated upstream. This headcut migration process could take several thousand years and would shorten the time available for incision. This shortening of the time available for incision then limits maximum incision that could occur along the wash during the next 10,000 years.

Comment 7e

If the maximum incision scenario is permissible, the three examples of incision (erosion) presented above would be considered as evidence of extreme erosion having occurred: (1) during the Quaternary Period; (2) within the conceptual controlled area boundary; and (3) within a time frame representative of the repository period of performance -- 10,000 to 100,000 years (see NRC, 1993, p. 2).

Response

Based on the results of recent detailed mapping (Lundstrom and Warren, 1994 and DOE, 1995; see above) DOE examined the maximum incision scenario and does not consider that scenario to be credible or realistic. DOE questions the staff's statement that a permissible scenario "would be considered as evidence of extreme erosion having occurred." DOE has found no evidence in the Quaternary geologic record to suggest that the extreme erosion has occurred. Cycles of incision and aggradation are common in alluvially-filled stream channels and are mechanisms of moving packets of sediment downstream. These cyclic events do not involve incision of the bedrock floor of the channel. On the contrary, the evidence in the geologic record shows that Yucca Mountain and the surrounding area have been geomorphically stable and are characterized by low rates of erosion and channel incision. DOE believes, consistent with the NRC regulatory requirements of 10 CFR Part 60, that it should not required to speculate about the existence of events or processes which, based on available data, are not sufficiently credible to warrant further consideration. DOE articulated this position in a letter (DOE, 1993a).

Finally, the results of recent field work in Midway Valley (DOE, 1995) have provided data for a preliminary estimate of the local denudation rate over about the last 20 ka. This estimate is about 0.5 cm/ka, and the rate is sufficiently similar to the Boundary Ridge rate to indicate that an erosion rate of about 0.5 to 0.6 cm/ka may have persisted for the last 170 ka.

Comment 7f

A single data point (Well J-13; see p. 51) is used as the sole subsurface basis for defining the maximum/minimum incision scenarios shown on Figure 13 (p. 53) and is inadequate, when used alone for defining the alluvium-bedrock contact underlying Forty Mile Wash in the vicinity of Busted Butte.

Response

Figure 13 (DOE, 1993b) is intended only to illustrate the two incision scenarios depicted. The maximum incision scenario, while permissible, is not realistic. Field evidence (DOE, 1995; and Lundstrom and Warren, 1994) indicates that the minimum incision scenario is more realistic and representative of conditions in the Fran Ridge - Busted Butte section of Fortymile Wash. Although a single data point was used to define the bedrock-alluvium contact for the purposes of constructing Figure 13, the basis for the staff's assertion of inadequacy of this single data point is not clear given the illustrative purpose of the figure.

Wells UE-29A#1 and UE-29A#2 are located in Fortymile Canyon about 15 km upstream from Fran Ridge. These wells were drilled to bedrock from the surface of the main, 270 ka alluvial fill. The thickness of the fill is only about 20 meters, and no younger alluvial terrace is present at this locality. If the downcutting assumption presented above (realistic scenario) is applied (incision of the 20 meters of fill occurred in half the time interval from 270 ka to present), then Fortymile Wash would have a long-term average, and DOE maintains characteristic, incision rate of about 15 cm/ka in this upstream segment of Fortymile Canyon. This incision rate is significantly lower than the maximum rate calculated for the wash near Fran Ridge, is slightly lower than the minimum rate calculated above, and indicates incision rates decrease upstream from Fran Ridge. Projecting these lower rates over 10,000 years results in only 1.5 m of anticipated incision of the alluvial gravels if conditions were optimum to promote downcutting.

About 15 km south of well J-13, near Highway 95, the channel of Fortymile Wash merges with the general alluvial plain of the Amargosa Desert. No canyon or record of Quaternary downcutting exists at this locality; thus, the lower reaches of Fortymile

Wash appear to have been primarily in a state of aggradation during the Quaternary Period. However, the low rates of channel incision calculated for the wash both upstream and downstream from the Fran Ridge-Busted Butte segment of the wash support a downcutting history through the midsection of the wash that closely approximates the minimum calculable incision rate scenario.

Comment 7g

Site characterization investigations, including drill holes and geophysical surveys, have been conducted in Forty Mile Wash (see DOE, 1992; Ponce et al., 1992) and may provide subsurface information amenable for use in support of the subsurface conditions shown on the maximum/minimum incision scenarios (see Figure 13; p. 53).

Response

See response to previous item.

Comment 7h

The three erosion/deposition cycles cited above suggest the lowering and raising of the local base level through tectonic processes not acknowledged in either the Quaternary tectonic history presented on page 24 [of the topical report] or in the SCP (see DOE, 1988, pp. 8.3.1.6-20 and 8.3.1.6-22).

Response

Fluvial activity since the middle Quaternary in Fortymile Wash and its principal tributaries has been limited to aggradation and reintrenchment through its own alluvial fill (Hoover, 1989; Taylor, 1986). The most likely way for the modern aggradational mode of Fortymile Wash to change to an incisional mode is by a significant change in hydrologic conditions caused by a major climatic change. Under cooler and wetter climatic conditions, with well vegetated hillslopes, runoff may become great enough to transport channel sediment beyond the Amargosa Valley (Desert) floor, although no evidence exists to indicate that such hydrologic conditions occurred during the extent of full glacial (18 to 15 ka) climatic changes. If such climatic changes did occur in the southern Great Basin, then Fortymile Wash may begin to incise its valley floor. A realistic scenario for the initiation of channel incision along Fortymile Wash would include at least a 3,000 to 5,000 year time period necessary for the climate to change to conditions that may induce channel incision. Within the context of the 10 ka performance period, the time required to initiate climate change would limit incision time to

5,000 to 7,000 years. This time restriction would limit incision along the wash to no more than a few meters during the next 10,000 years.

Deposits of late Quaternary age are chiefly confined to present stream valleys. The lack of late Pleistocene and Holocene deposits at the base of Yucca Mountain hillslopes indicates that erosion rates from these slopes have been low during the past 100,000 years. Confinement of late Quaternary deposits to valleys and channels indicates the volume of material eroded off hillslopes has been smaller than during the early and middle Quaternary.

The paucity of late Pleistocene deposits on and around Yucca Mountain has climatic significance. A marked contrast exists between the geomorphic processes that operate under the present semiarid-to-arid climate and those that prevailed during cooler and wetter climates during the Quaternary. A significant portion of the surficial deposits on and around Yucca Mountain was apparently formed during the early and middle Quaternary by processes related to cool pluvial climates or during the transition from warmer to colder climates. Two periods of fluvial aggradation in Fortymile Wash ceased prior to about 270 ka and 145 ka, respectively, and appear to be related to the transition from wetter (pluvial) to drier (interpluvial) conditions.

Shallow entrenchment (3-6 m) of streams in Crater Flat through older deposits indicates slow uplift of Yucca Mountain or slow subsidence in adjacent basins. This geomorphic response appears to corroborate the slow rates of tectonic activity measured on the major Yucca Mountain faults. Alternatively, stream incision may reflect changes in fluvial processes due to Quaternary climate changes. Such valley entrenchment likely occurred during pluvial climatic conditions. The present well-defined drainage channels indicate that future stream incision will be confined to the present valleys for at least tens of thousands of years.

Finally, the landforms on and around Yucca Mountain indicate that the land surface is stable (See response to Comment 1d) and has not undergone radical changes due to extreme erosion or other processes, such as tectonic uplift, which could contribute to increased erosion.

Recommendation

Although it is recognized that the incision scenarios presented on Figure 13 represent, in some cases, the "worst-case" situation, the scenarios described should be internally consistent with other sections of the topical report and with the SCP (see DOE 1988, pp. 8.3.1.6-20 and 8.3.1.6-22), unless more *recent site characterization studies have demonstrated otherwise.*

Provide a geologic history for the Fortymile Wash that is consistent with the Quaternary tectonic record.

Response

The scenarios described in Figure 13 of the topical report (DOE, 1993b) are consistent with other sections of the report and the SCP because they provide information about an upper bounding case as well as the case that DOE considers to be realistic (minimum incision scenario) based on the evidence contained in the geologic record.

The topical report provides evidence that the DOE possesses an understanding of the processes and events that have occurred within the geologic setting during the Quaternary Period. The data which have been provided in the topical report cover a period of about 0.17 to 1.38 Ma in the Yucca Mountain area, and DOE considers this information to be sufficient and adequate to characterize the magnitude of erosional processes operating during the Quaternary Period at Yucca Mountain. DOE has used its understanding to make reasonable and conservative projections about the potential processes and events that could affect a geologic repository during the performance period.

The geologic history of Fortymile Wash is consistent with the Quaternary tectonic record. Stream incision and aggradation are controlled by changes in the base level of the Amargosa Valley. The Quaternary geologic record, including landforms on and around Yucca Mountain, indicate that Quaternary tectonic processes have not been significant in producing erosion (Harrington and Whitney, 1993, p. 1017).

Additionally, DOE now has the results of mapping completed since the topical report was submitted (DOE, 1995; and Lundstrom and Warren, 1994). This mapping has provided additional information to support the minimum incision scenario depicted in Figure 13 of the topical report and preclude the maximum incision scenario.

Comment 8

Insufficient evidence has been presented in the Topical Report regarding the extent of the Quaternary Period in order to determine the presence, or absence, of the PAC on evidence of extreme erosion.

Response

The statement of the potentially adverse condition (10 CFR 60.122(c)(16) requires that "evidence of extreme erosion *during* [emphasis added] the Quaternary Period" be evaluated to determine whether or not the condition exists. This statement fits well within the regulatory framework articulated by the Commission where it addressed this issue and stated

> The references to "the start of the Quaternary Period" have been removed because of the difficulties that might be involved in dating this point with precision; for present purposes, all that is important is that processes "operating during the Quaternary Period" be identified and evaluated, and this is reflected in the revised language. (NRC, 1983b at 48 FR 28,211).

While issues surrounding the onset and extent of the Quaternary Period may be interesting subjects for study, neither is critical to evaluating the existence of the potentially adverse condition.

DOE articulated its position in the topical report (DOE, 1993b, p. 3) as follows:

> There is some disagreement in the geologic community as to the precise beginning of the Quaternary Period. DOE has chosen to use a time period of the most recent 1.6 million years to bound the Quaternary Period. This time period was chosen because it is the time period published and supported by the Geological Society of America.
>
> The exact date of onset of the Quaternary Period is not considered by DOE to be critical for evaluating extreme erosion so long as the geologic record is consistent and substantially complete for the more recent geologic time period. DOE believes that the more recent geologic past is a better indicator of possible future activity than the distant geologic past, and that in performing an evaluation of potential future activity and the effect such activity can have on a repository, a sufficient data base must be established to make the various projections. Furthermore, DOE believes that the reference to the Quaternary Period was intended to imply a concept related to the sufficiency of the

> geologic record to be used for projecting natural processes and events during the intended period of performance rather than a specified time interval. This portion fits well within the regulatory framework articulated by the NRC....
>
> Thus, the Regulatory Evaluation herein and the NRC's administrative record are consistent [in] that the only important issue is whether a given process, in this case extreme erosion, has occurred during the Quaternary Period, and that such a record is sufficient and reflective of what could be expected throughout the entire period.
>
> This topical provides evidence that the DOE possesses an understanding of the processes and events that have occurred within the more recent geologic past within the geologic setting, and uses this understanding to make reasonable and conservative projections about the potential processes and events that could affect a geologic repository. Therefore the data which have been gathered that embody a period of about 0.17 to 1.38 Ma at the Yucca Mountain area are considered to be sufficient and adequate to characterize the extent of erosional processes operating during the Quaternary Period....

As explained in the topical report (DOE, 1993b, p. 3-5), DOE has adopted the period of time endorsed by the Geological Society of America for the length of the Quaternary--about 1.6 Ma. Additional details are provided in the responses to comments 8a through 8f.

Comment 8a

DOE's regulatory evaluation of the PAC on extreme erosion during the Quaternary Period (10 CFR 60.122(c)(16)) establishes a time period of the most recent 1.6 million years as bounding the Quaternary Period (DOE, 1993, p. viii).

Response

DOE explained its choice of the length of the Quaternary Period in the topical report (DOE, 1993b, p. 3). Based on recent geological research published by the Geological Society of America in *The Decade of North American Geology* (Morrison, 1991), DOE endorsed boundary dates for the Quaternary Period as shown in Table 1 of the topical report (DOE, 1993b, p. 5). The DOE has chosen to use a time period of the most recent 1.65 Ma to bound the Quaternary Period and be consistent with the Geological Society of America (DOE, 1993b, p. 3-5). The exact date of onset is not considered by DOE to be critical for evaluating extreme erosion so long as the geologic record is consistent and complete for the more recent geologic time period. In addition, in the basis for Question 2 on Study Plan 8.3.1.8.5.1 (NRC, 1991, enclosure 1), the staff noted that "The whole Quaternary is only 1.6 Ma...." This description of the length of the Quaternary Period is the same as that described by DOE in the topical report (DOE, 1993b, p. 3), but it is not the same as the length of the Quaternary described for regulatory purposes in Comment 8b.

Comment 8b

However, for regulatory purposes, the NRC has taken the position that a time span of 2 million years is the length of the Quaternary Period.

However, the staff will consider other time periods submitted by DOE provided that DOE can demonstrate a sufficient understanding of the recent geologic past such that geologic changes can be projected over the intended period of performance with reasonably high confidence.

Response

The NRC staff has indicated the more recent geologic past is a better indicator of possible future activity than the distant geologic past. DOE agrees with this position. In the topical report (DOE, 1993b), DOE provided data which cover a period of about 0.17 to 1.38 Ma in the Yucca Mountain area. These investigations cover nearly three-fourths of the Quaternary as defined by the NRC for regulatory purposes and essentially all of the Quaternary as defined by DOE. None of the studies has found any evidence to support the occurrence of extreme erosion during the Quaternary. In addition, as described in the response to Comment 8a, DOE believes that there are some inconsistencies in the staff's specification of the length of the Quaternary.

Recently completed mapping in Fortymile Wash (Lundstrom and Warren, 1994) and Midway Valley (DOE, 1995) has provided data for a preliminary estimate of the denudation rate for about the last 20 ka. This rate is about 0.5 cm/ka and is similar to the Boundary Ridge rate estimated for the last 170 ka. This similarity indicates that erosion rates may have probably been fairly uniform at about 0.5 to 0.6 cm/ka for the last 170 ka.

DOE regards the investigations described in the topical report (DOE, 1993b) plus the additional work described above are sufficient for DOE to demonstrate that a reasonable portion of the Quaternary has been investigated and adequately evaluated for evidence of extreme erosion. DOE has also demonstrated sufficient understanding of the recent geologic past to make projections of geologic conditions over the intended period of performance with reasonably high confidence.

Comment 8c

Twelve hillslope boulder deposits, dated by varnish cation ratio dating (varnish cation ratio) technique, yield apparent ages ranging from 170 to 1,380 thousand years.

Response

This is a description of information presented in Table 5 of the topical report (DOE, 1993b, p. 48). No response required.

Comment 8d

The Topical Report fails to address the occurrence of significant, relatively instantaneous events (those events having occurred within a time frame equivalent to the period of performance) before, or during the time interval covered by the boulder deposits studied by DOE. Consideration of these events is significant in determining if the adverse condition is present but undetected.

Response

The comment does not provide a method to define the duration of a minimum period of time to be considered. However, DOE notes that the Commission has agreed with DOE that the effects of individual short-term events like storms need not be considered and that "short-term periods taken from the perspective of geologic time (i.e., the Quaternary Period) could last tens of thousands of years" (49 FR 9650). DOE believes that the Commission's position obviates the need to evaluate short periods or discreet episodic events whose durations are less than "tens of thousands of years." DOE interprets the Commission's position as requiring evaluation of periods whose durations are twenty thousand years or more in length. However, for completeness, DOE has investigated and evaluated short-term storm events such as that which occurred at Jake Ridge in July, 1984 (Coe and others, 1995 and Coe and others, 1992).

Given the level of detail in the investigations completed, if significant events of the kind specified had occurred, the geologic record would contain indications of their existence. In spite of comprehensive investigations, DOE has found no evidence in the geologic record to support the existence of such events.

For example:

1. DOE has investigated the oldest Quaternary rocks at Black Cone and Red Cone (DOE, 1993b, p. 36) (varnish age 1.3 ma). These rocks record a continuous history of erosion but do not show any evidence of erosional modification (Wells and others, 1990). In addition, DOE has cosmogenic ^{10}Be dating in progress. Some of this work may help to determine the surface exposure age and the amount of time necessary to degrade the surfaces of the Black Cone and Red Cone lavas. DOE intends to provide the data to the NRC by the end of FY 95.

2. Modern examples of maximum erosion events have been investigated at Jake Ridge (Coe and others, 1992) and Coyote Wash (Glancy, 1994). These same events are excellent examples of the absence of the potentially adverse condition because both events failed to produce any significant changes in landforms.

3. Surficial geological mapping around Yucca Mountain (Swadley and others, 1984) reveals extensive lower and middle Quaternary deposits. As noted in the topical report:

   > Over 85 percent of the surficial deposits and geomorphic surfaces exposed adjacent to the Yucca Mountain tilted blocks were formed during the early to middle Quaternary. Exposed upper Quaternary deposits are confined to small areas on hillslopes and are probably buried below a thin veneer of Holocene alluvium in Fortymile Wash and its tributaries, as well as the unnamed streambeds that cross Crater Flat. (DOE, 1993b, p. 24)

   Thus, there is no evidence of significant erosion on a regional scale in the vicinity of Yucca Mountain since the middle Quaternary, and there are no morphologic features that indicate localized extreme erosion during that period of time.

4. Recent mapping by the USGS (DOE, 1995) in the vicinity of Midway Valley has provided the data for a preliminary estimate of the local denudation rate in alluvium for about the last 20 ka. This rate is approximately 5 mm/ka (0.5 cm/ka). This rate is similar in magnitude to the rate estimated for Boundary Ridge based on an age estimate of 170 ka. The similarity in rates indicates that erosion in the area may have been fairly constant for the last 170 ka. Furthermore, all of the dated deposits represent erosion from the time of stabilization of the dated deposit to the present. Thus, erosion adjacent to each of the dated deposits includes erosion which occurred during a period of

time equivalent to the performance period which is of concern to the NRC staff.

Comment 8e

The most recent part of the Quaternary Period -- the past 170 thousand years -- has not been investigated.

Response

DOE has examined the entire preserved Quaternary record which represents the period from the present to about 1.38 Ma. These investigations have included modern examples of maximum erosion at Fortymile Wash in 1969 and Jake Ridge in 1984. Most of these investigations have been described in the topical report. Because of the relative antiquity of the boulder deposits, DOE has determined no varnish cation ratio ages less than about 170 ka (DOE, 1993b, p. 44 and Whitney and Harrington, 1993, p. 1014). In addition, DOE has examined younger deposits in natural and trench exposures in Fortymile Wash, Midway Valley, and Crater Flat. Recent mapping in Midway Valley (DOE, 1995) has provided the data for a preliminary estimate of the local denudation rate for about the last 20 ka. This rate is approximately 0.5 cm/ka, and it has been described in the responses to Comments 8c and 8d.

Comment 8f

The gaps in the age-dates assigned to the boulder deposits are so large that about one-half of the total time spanned by the DOE investigation is not represented.

Response

DOE believes the Commission anticipated dealing with both "uncertainties and gaps in knowledge" in compliance demonstrations and described how these items would be considered in 10 CFR 60.101(b).

In spite of comprehensive examinations, gaps do exist in the ages of the dated boulder deposits. The gaps, however, reflect the character of the geologic record and are not the products of incomplete investigations. The available record shows that the development of geomorphic surfaces is an intermittent process. DOE has shown that the geologic record for the area is one of the longest Quaternary records known in the southwestern U.S., and "the dated boulder deposits have provided the oldest age estimates for unconsolidated hillslope deposits in the southwestern United States " (Whitney and Harrington, 1993, p. 1008). In addition, recent mapping (DOE, 1995) in the vicinity of Midway Valley indicates that erosion in the area may have been proceeding at the same rate for the last 170 ka (See responses to Comments 8c and 8d).

Recommendation

DOE should demonstrate that a reasonable portion of the past (i.e., Quaternary Period) has been investigated and adequately evaluated for evidence of extreme erosion. If the geologic record is incomplete of resolution of time intervals not possible, then this must be factored into the consideration that the adverse condition is present, but undetected.

Response

The information provided in the topical report (DOE, 1993b, p. 4) and in these supplemental responses to the NRC staff comments on the topical report demonstrate the breadth and adequacy of DOE's investigations concerning the existence of extreme erosion at and near Yucca Mountain during the Quaternary. DOE has investigated the entire available Quaternary geologic record and has found no evidence of extreme erosion. To the contrary DOE's investigations have indicated that erosion rates are among the lowest rates found in the United States and are reasonable considering the rock type at Yucca Mountain and the climate that has existed at Yucca Mountain during the Quaternary Period.

DOE has erosion rate estimates that have been calculated over the period 170 ka to 1,380 ka (DOE 1993b, p. 48) and has presented shorter term preliminary estimates calculated for about the last 20 ka in these responses. These rate estimates include all erosional events that occurred during the periods. Furthermore, comprehensive examinations of the geologic record have found no indications of extreme erosion at any time during the Quaternary Period. Because of the comprehensiveness of DOE's investigations and the methods used to calculate erosion rate estimates, it is unlikely that the potentially adverse condition could be present but undetected.

The information in the topical report and these responses shows that DOE has adequately studied and evaluated the Quaternary record for the period of about 1,380 ka to present. Additionally, for comparative purposes, DOE has assumed the potentially adverse condition to be present and examined the estimated amount of erosion that would result from projections of erosion rates over the performance period. (See responses to Concern 1 and Comment 3a especially footnotes 1 and 2, respectively).

Comment 9

There does not appear to have been follow-up, or resolution, to recommendations made in the Peer Review Report on Rock-Varnish Studies Within the Yucca Mountain Project (Birkeland, Oberlander and Hawley, 1989). This apparent deficiency in the qualification process has resulted in the subsequent submittal to the NRC staff of a milestone document, the Topical Report, that places considerable reliance upon a dating method (i.e., the varnish cation ratio (varnish cation ratio) dating technique) that appears to the staff, based in part on the results of the peer review, to be unsuitable for its intended use.

Response

DOE does not agree that a deficiency exists in the qualification process for the data supporting the Extreme Erosion topical report. As explained below, the Los Alamos (LANL)Peer Review was not an element of the data qualification process, and there was no need to resolve the LANL Peer Review suggestions to qualify the data. The purpose and scope of the LANL peer review has been explained by DOE in a letter (DOE, 1994a) as follows:

> The Los Alamos peer review on the varnish cation ratio (varnish cation ratio) dating technique was requested by Los Alamos management as a means to conduct an internal technical verification that the varnish cation ratio dating technique was suited for the applications that were, at that time, underway to establish Quaternary geochronologic frameworks for erosion, volcanism, and tectonic studies. The Los Alamos peer review was not conducted with the expectation that it was the means by which the data set was to be qualified.
>
> The Los Alamos peer review constituted supporting information in DOE's qualification exercise that: (1) placed into the record an independent, critical review of the varnish cation ratio technique that was beyond the materials considered by the technical assessment team; (2) provided confidence that the technique applied was superior to a competing varnish cation ratio dating methodology; (3) provided confidence that the varnish cation ratio results obtained with Los Alamos' methodology represented the best achievable for the technique. NRC stated that several points (Reference 1)[Reference 4 to this package] were not considered in the Los Alamos peer review report. Most of these points (Section IV[4] of NUREG-1297) are, in fact, present in the Los Alamos' 1989 peer review. However, they are commingled and may not be itemized in a way that would allow easy traceability.

> All of the major requirements for a peer review are reflected in the 1989 Los Alamos peer review record; namely, that the Los Alamos review constituted "a documented, critical review performed by peers who are independent of the work being reviewed." Moreover, the criteria for peer reviewer technical qualifications and independence in NUREG-1297 (Section IV[3][a] and [b]) are faithfully preserved in the Los Alamos peer review.

The basis for establishing the suitability of the data for qualification was the determination that scientific notebooks, which described the details of sample collection, preparation, and analysis, had been prepared by the investigators. These notebooks were prepared under procedures which provided quality assurance equivalent to that under the subsequently approved YMSCO Quality Assurance Program. (For additional description, please refer to the response to Concern 3.)

The LANL Peer Review Report (Hawley and others, 1989) was reviewed during the Technical Assessment for the Qualification of Data for the Erosion Rates at Yucca Mountain (DOE, 1992). But the Peer Review was requested by LANL Principal Investigator not YMSCO. Since YMSCO had neither requested the review, nor relied on the results to determine that the data was suitable for qualification, DOE saw no direct connection between the LANL review and report, and the qualification of the data. Therefore, DOE saw no need to pursue after-the-fact actions, such as follow-up on, or resolution of, suggestions made in the Peer Review Report. Hence, DOE undertook no such actions.

DOE also does not agree that the varnish cation ratio dating method is not suitable for its intended use. In contrast to the staff's statement that "... based ... on the results of the peer review...[the varnish cation ratio dating technique] appears ... to be unsuitable for its intended use[,]" the Peer Review Report endorsed the varnish cation ratio method for use in all of the studies for which it was designated (Hawley and others, 1989, p. 7). In fact, the Peer Review Report contained nothing to indicate that the varnish cation ratio technique was not suitable for the intended use, which was estimating the ages of Quaternary colluvial boulder deposits. Furthermore, the report conclusion contains the following endorsement:

> We conclude that the varnish cation ratio age determinations by C. D. Harrington and his collaborators are the best presently being done (Hawley and others, 1989, p. 9).

Comment 9a

The Peer Review Report (Birkeland, Oberlander and Hawley, 1989) *stated the following in the discussion of the varnish cation ratio calibration curve: "Calibration needs to be a continuing part of the project, especially as more detailed field work or discussions with other workers suggests potentially good [calibration] sites. Additional calibration points should use all suitable dating methods (tephrachronology, magnetostratigraphy, K/Ar, Ar/Ar, U-trend, U-series, thermoluminescence, etc.), particularly in a collaborative effort with the USGS."*

Response

The Peer Review Report explained the validity of the calibration curve as follows: "What gives the Yucca Mountain Project varnish cation ratio curve validity is that it plots as a straight line when plotted against log age, as do all other published varnish cation ratio curves" (Hawley and others, 1989, p. 4).

The Criteria for Selection of a Dating Method are discussed in detail in section 3.3.2.1 of the topical report (DOE, 1993b), and Calibration of the Cation Ratio Dating Technique was described in section 3.3.2.1.2 of the topical report. Furthermore, DOE discussed the number of calibration points and their adequacy to establish the calibration curve as follows:

> Although more data points might reduce the curve uncertainty to a minor degree, the concentration of data points is adequate to establish a calibration curve. Most age estimates for the boulder deposits in this report are derived from within the calibrated interval of the dating curve (11 of 12 deposits). The remaining point lies in immediate proximity to the calibrated interval. Any additional reduction in the uncertainty of the curve that could be obtained with the addition of a grater number of calibration points would not affect any of the technical conclusions in this report that are based on the dating curve (DOE, 1993b, p. 42).

DOE also has data which corroborates the varnish cation ratio age dates. Whitney and Harrington (1993) sampled three darkly varnished boulders at Buckboard Mesa for surface exposure dating using cosmogenic chlorine 36 (^{36}Cl). The estimated ages range from about 600 (actual range 671-549) ka to about 310 (actual range 336-288) ka for the samples. However, the ^{36}Cl accumulation in rocks is calibrated in radiocarbon years which, when adjusted, will increase calculated ages by about 10 percent. Additionally, the oldest sample has a measured ^{36}Cl content of greater than 92 percent of the saturation value. Because this sample is close to the theoretical saturation, the sample may represent the maximum ^{36}Cl concentration effectively measurable. The age estimate may represent the practical upper limit of this dating technique and not closely limit the age of the deposit (Whitney and Harrington, 1993). It should be noted, however, that even if the 310 ka age estimate were to be accurate for the Buckboard Mesa deposits and were used with the measured channel incision of 0.3 meters (DOE, 1993b, p. 48), to estimate channel incision rates, that rate estimate would be about 0.1 cm/ka.

Additionally, DOE has limited cosmogenic beryllium 10 (^{10}Be) dating in progress to support various paleoclimate studies. The results of this work are expected to provide verification and validation of some of the data points used to establish the varnish cation ratio calibration curve for Yucca Mountain. DOE intends to provide the data to the NRC by the end of FY 1995.

Comment 9b

The varnish cation ratio calibration curve presented in the Topical Report and by Whitney and Harrington (1993) appears to have no more data than that originally published by Harrington and Whitney in 1987.

Response

The calibration curve is the same as the one developed in 1987. No new potential calibration points have been identified, but DOE wishes to point out that the curve calibration was considered valid when it was reviewed during the LANL peer review (Hawley and others, 1989, p. 4).

The ages of the deposits identified in the topical report lie within the calibrated interval, and the calibration line is a "best fit" line through the calibration points. Therefore, including additional calibration points would not significantly change the "best fit" line. This is the basis for the statement that additional calibration points would not change any of the technical conclusions in the topical report.

Comment 9c

The Peer Review Report (Birkeland, Oberlander, and Hawley, 1989) stated the following in the discussion of the evaluation of thick varnish films: "The consistency of their [Harrington et al.] results suggests that the Los Alamos investigators know by experience when the varnish is correctly averaged -- without requiring an obtrusive display of substrate contamination. Nevertheless, we believe that there should be a check on the procedure." Later, in the same report, "We urge expanded use of the electron microprobe to produce varnish transects and chemical averages as a check on SEM results, particularly where thick varnish films may not be fully (or unequivocally) penetrated by *the 30 kev electron beam." The Peer Review Report further recommended that the behavior of immobile elements (in addition to TiO_2) should be investigated to better define the leaching process that is the basis of cation-ratio dating.*

Response

The Peer Review Report (Hawley and others, 1989, p. 7) discussed the consistency of Harrington's and his collaborators' results and suggested vertical transects across the margins of "some rocks sampled" to check for variations in barium and titanium contents. Subsequently in the same discussion, the Peer Review Group noted:

> We realize that production of such transects is time-consuming, and thus suggest that they be used only as a periodic independent check on SEM - EDAX results, not as the major analytical procedure.

DOE has found no data that would support the existence of the "leaching process" noted in the comment. In fact, DOE considers that this process is irrelevant because changes in cation ratios through time apparently are not the result of leaching, and Reneau and Raymond (1991) report that "... preferential leaching of elements from rock varnish--has not been demonstrated." Since the scanning electron microscope analyzes only a thin film (a few microns) of varnish (DOE, 1993b, p. 39 and Hawley and others, 1989) leaching of varnish cannot be used to explain the differences found in the varnish analyses. The chemical composition of the upper surface of old varnishes is different from that of young varnishes. The cation contents of the layers must be different at the time the layers are formed and are not results of changes that occur after deposition.

Comment 9d

There is no information in either the Topical Report or in Whitney and Harrington (1993) to indicate that there has been any follow-up, or resolution, of the above Peer Report suggestions.

Response

A description of the purpose and scope of the LANL peer review has been provided in the response to Comment 9. For details on this aspect of the peer review, the reader is referred to that response.

DOE felt that there was no need to follow-up on the Peer Review Report suggestions because endorsement of the LANL varnish cation ratio method was not contingent on acceptance of any of the suggestions. Furthermore, the suggestions described measures that might be applied if additional work were done. The suggestions were not recommendations deemed necessary to correct deficiencies in the methods. In fact no deficiencies were identified.

DOE used the existence of scientific notebooks developed under conditions equivalent to the subsequently-approved QA program as the basis for determining the suitability of the data for qualification. DOE did not rely on the results of the peer review to establish the suitability of the data for qualification.

Since DOE did not rely on the results of the LANL Peer Review to provide elements to establish the suitability of the data, DOE saw no reason to pursue any follow-up actions on the peer review report suggestions. Therefore, DOE has not initiated any specific follow-up or resolution actions on the Peer Review Report suggestions. The Peer Review was neither requested by DOE/YMSCO nor, as explained above, was the Peer Review Report (Hawley and others, 1989) used in the technical assessment of the suitability of the data for qualification (DOE, 1992).
The data to support the topical report were qualified in a Technical Assessment Report under the requirements of DOE QARD, Revision 3. The Technical Assessment was performed in accordance with QMP-02-08, Revision 1. Since the peer review was requested by LANL and not by YMPO (YMSCO) and was not part of the data qualification process, DOE felt, and maintains, there was no requirement to pursue activities directed at resolution of the Peer Report suggestions and report such activities in the topical report.

However, DOE wishes to point out that the Peer Review Report concluded (Hawley and others, 1989, p. 8):

> "We are impressed with the excellent work being done on varnish cation ratio age determination by the LANL research and technical staff and their associates .... The members of this high-quality team ... are extremely careful in all phases of the work, from the initial field sampling, through the laboratory work, to the final age estimation. Moreover, they are adequately cautious in terms of recognizing and dealing with the limitations of the method. We conclude hat the varnish cation ratio age determinations by C.D. Harrington and his collaborators are the best presently being done ...."

As discussed in the response to Comment 4, DOE has not specifically undertaken work to corroborate the results of the varnish cation ratio dating; however, limited results from cosmogenic chlorine 36 (^{36}Cl) dating support the results of varnish cation ratio dating at Buckboard Mesa (Whitney and

Harrington, 1993). Additionally, DOE anticipates that the results of cosmogenic beryllium 10 (^{10}Be) dating now in progress will provide corroboration of the varnish cation ratio dates and will address some of the Peer Review Report suggestions. DOE intends to provide the data to the NRC by the end of FY 95.

Comment 9e

The NRC (in Subpart G of 10 CFR Part 60, through reference to Appendix B of 10 CFR Part 50), requires documentation of activities affecting quality. The DOE (in DOE/RW-0333P, and its successors) requires implementation of a program to meet the NRC requirements. Since the work in question is being done for DOE, Los Alamos National Laboratory must meet these requirements. The Birkeland, Oberlander, and Hawley (1989) Peer Review Report comes within the scope of these references. Since the peer review process is incomplete without the resolution of comments, either the Topical Report or Whitney and Harrington (1993) should report how the comments in Birkeland, Oberlander, and Hawley (1989) Peer Review Report were resolved.

Response

A description of the purpose and scope of the LANL peer review has been provided in the response to Comment 9. For details on this aspect of the peer review, the reader is referred to that response.

DOE felt that there was no need to follow-up on the Peer Review Report suggestions for several reasons: (1) The peer review results were not used in the assessment of the suitability of the data for qualification (DOE, 1992). (2) The suggestions were not recommendations deemed necessary to correct deficiencies in the methods. In fact no deficiencies were identified. The suggestions described measures that might be applied if additional work were done. (3) Endorsement of the LANL varnish cation ratio method by the peer review group was not contingent on acceptance of any of the suggestions for future work that were provided in the peer review report.

DOE determined that QA, equivalent to that available under the current, approved QA program, existed at the time the varnish cation ratio dating was done. DOE relied on the demonstration of the existence of equivalent QA at the time the work was done, the development and preservation of scientific notebooks, and the determination that no significant differences in results would occur under the approved QA program, as the bases for qualifying the data. This qualification process is explained in the Technical Assessment Report (DOE, 1992). Significantly, DOE did not rely on the results of the LANL peer review to establish the suitability of the data for qualification.

Therefore, DOE has not initiated any specific follow-up or resolution actions on the Peer Review Report suggestions.

Recommendation

In its review of the Topical Report, the NRC staff was unable to identify any evidence that the Los Alamos Peer-Review Group recommendations had been acknowledged and/or implemented. Given this concern, and the concerns expressed earlier in Review Comments 4 and 5, the NRC staff believes that the qualification process for the varnish cation ratio dating technique (and, consequently, the data acquired through employment of the technique) has not been demonstrated to be acceptable. In order to demonstrate the acceptability of the varnish cation ratio dating technique, DOE should provide documentation to show that it has an acceptable qualification process in place.

Response

For Topical Report YMP/TPR-92-41, DOE completed the process to qualify the existing data that was used. To do this, DOE implemented an assessment process to (1) examine if the collection, transportation and storage, record keeping, and analysis of samples for the varnish cation ratio dating method, and the field work performed to measure erosion, (2) establish that this work had procedural controls and documentation sufficient to demonstrate that an equivalent quality assurance (QA) program was in place for this work. This assessment (DOE, 1992) not only met, but exceeded, the breadth and depth of examination anticipated by NUREG-1298 for qualifying existing data. A five-member team consisting of independent and qualified peers conducted this assessment in two phases. Phase I examined the nature of procedural controls in place both before and after an approved QA program. Phase II performed a compliance assessment of the work to those procedural controls.

In Phase I, the technical and quality assurance procedures in place at the time that the field and laboratory work was done were compared to those procedures in place after DOE approval of Los Alamos National Laboratory's and the United States Geological Survey's QA programs. Twenty-nine procedures were reviewed including those dealing with sample collecting, handling, shipping, and storing of samples, data, records, and document control, controls on calibration, data measurement, and analytical equipment, and procedures for research and development work documented in scientific notebooks.

There were four questions that were addressed as part of the Phase I evaluation: 1) what procedures were in place prior to DOE approval of the organization's QA program, 2) what procedures were in place subsequent to approval of the organization's QA program, 3) was there a difference between the two sets of procedures, and 4) was that difference significant to the conduct of the work or the interpretations based on it?

The conclusion of Phase I was that procedural controls were quite similar before and after approval of each agency's QA program. The answer to question 4 above, therefore, was that significant differences did not exist. The team concluded that an additional step (Phase II) was needed to examine the implementation of these procedures. This involved sampling of a vertical slice through the process.

Phase II of the assessment centered on 1) examining sample collection, handling, and shipping that occurred prior to the approval of the procedures controlling this activity, and 2) assessing compliance with the procedures that were in place. Phase II conclusions were that (1) the results of sampling would not be significantly different if this sampling were repeated under procedures in the approved QA program, and (2) the work complied with procedures under which the work was done, namely documentation in scientific notebooks.

After completion of these two phases of work, the assessment team unanimously concluded that the data set could be recommended for qualification. DOE accepted this recommendation in September 1992. The documentation produced by the technical assessment team for this data qualification process was audited by the DOE, with NRC observing, in October 1992. No corrective actions were identified.

Based on the results of the qualification process described and the audit, DOE expects the NRC to accept the results of the assessment on the basis of the record that has been submitted (DOE, 1992). DOE has produced an analysis for qualifying existing data that meets fully the requirements of NUREG-1298. The process has looked at the procedural controls under which the work was done, and the results of a compliance assessment based on vertical slices beginning with field collection of samples through shipment, storage, and laboratory analysis with the scanning electron microscope. The assessment showed that the documentation kept by the principal investigators for this work was meticulous and complete. One of the team members concluded that the documentation was sufficient to allow a qualified peer to repeat the investigation with comparable results without recourse to the original investigators.

The NRC has not responded to DOE's January 26, 1994 letter (DOE, 1994a) which explained aspects of the data qualification exercise and which stated that DOE believed it had successfully qualified this data set. DOE is concerned that technical questions about the varnish cation ratio technique or uncertainties over its application or interpretation have overshadowed and obscured the conclusions of the DOE's technical assessment team. DOE concluded that these data were collected and handled under a QA program equivalent to one meeting the requirements of 10 CFR Part 60 Subpart G. DOE (1992) has shown that samples were collected, stored, handled, and analyzed according to the procedures that were extant, that there was very little likelihood of the materials being handled differently under an approved QA program, and that vertical slices have demonstrated the traceability of the data set.

DOE's position is that existing data have been qualified even though there are outstanding concerns over uncertainties or questions bearing upon the technical basis for the technique. With the current situation with respect to NRC's evaluation of the data qualification process used for Topical Report YMP/TPR-92-41, DOE is concerned that (1) technical questions or uncertainties are acting as hold points requiring resolution before NRC accepts a conclusion that work was conducted according to the requirements of an equivalent QA program, and (2) an assessment, which meets the requirements of NUREG-1298, has been successfully completed but has not been acknowledged by the NRC.

The Yucca Mountain Site Characterization Project is likely to face many types of technical uncertainties and challenges to the data and conclusions that are put forth in the future. We urge NRC not to let the very important process of data qualification suffer as a consequence, because these issues are separable. DOE believes that resolution of technical concerns should not be a prerequisite for acceptance of qualified data sets.

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(Note: The reference list includes only sources cited in the responses; references cited by the staff in the comments may not have been included.)

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DOE COMMITMENTS TO THE NRC CONTAINED IN THIS LETTER

1. Provide a report describing cosmogenic dating of sampled colluvial boulder deposits to the NRC before the end of fiscal year 1995.

2. Provide, as a separate transmittal and within a month of this letter, the references cited in the DOE responses to the NRC staff comments on the Extreme Erosion Topical Report and requested by the staff in a letter (Bell to Brocoum, dated January 30, 1995).