COMMENTS ON DOE EROSION TOPICAL REPORT OUTLINE

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1.0 SUMMARY OF COMMENTS

The principal comments on the DOE supplied "Outline for Topical Report On Erosion Rates at Yucca Mountain Geologic Setting: Methodology and Results" are, first, that certain assumptions about past and future climatic conditions are not supported by the available data; and, second, that the methodology and data acquisition techniques already used or proposed to be used may not be rigorous enough to justify some of the conclusions that have been drawn.

The specific items and issues that deserve further DOE consideration are:

- The essential need for a rigorous evaluation of actual erosion rates - denudation and channel incision - based upon circumspect dating;
- The need for different dating techniques to be employed to corroborate cation ratio dating of desert varnish and thermoluminescence;
- Possible future environmental changes during the next 10,000 years, particularly climatic change, should be addressed and the likely impact on rates of weathering and erosion of such change should be assessed;
- Possible changes in the level of tectonic activity in the region, and the likely geomorphological effects of such changes, should be assessed; and
- The likelihood that human impact will adversely influence the future rates of erosion should be evaluated.

2.0 BACKGROUND TO EROSION STUDY AND AN OVERVIEW OF THE DOE ANNOTATED OUTLINE

The stated purpose of the DOE investigation of erosion rates at Yucca Mountain, Nevada, is to assess the likelihood of there being extreme erosion of the land surface within the area immediately above and extending horizontally no more than 5.0 km from the proposed subsurface nuclear waste repository (the controlled area) during the 10,000 years following closure of the repository. The main focus of the report, as outlined, is on the acquisition and verification of data on rates of erosion within the vicinity of the controlled area during the Quaternary Period (the past two million years or so). A strong emphasis has been placed on the dating of land surfaces and surficial materials in the area (Subsection 3.1.5 of the outline). Such an approach will tend to provide an evaluation of the geomorphological stability of the landscape - in essence it will present a landscape chronology. However, any inherent geomorphological instability might be overlooked. Hence, this approach is not necessarily an inclusive, valid methodology. Future environmental conditions may diverge from those of the past 20,000 or 30,000 years. In effect, the study should address the likelihood of extreme erosion occurring in the vicinity of Yucca Mountain in the event of environmental changes in the future which are unprecedented by conditions during the late Quaternary but which did occur within the

2,000,000 or so years of the entire Quaternary period. The rationale for requiring such an approach will be further discussed below.

The precise definition of "extreme erosion" has not been clearly elucidated. Additionally, in the context of the Yucca Mountain site, it will be necessary to clarify the exact amount of exhumation of the subsurface repository which would qualify as "extreme erosion." Surficial erosion is a continuous natural process throughout much of the controlled area. It takes the form of mechanical and chemical weathering of exposed bedrock and other surficial materials, and removal of material (weathered or not) by wind, water, and mass wasting phenomena. The specific mechanisms that dominate the erosional processes in any region are often determined mainly by lithology and climate. The rate of erosion at specific sites often depends on geomorphological factors such as topography and relief. However, numerous additional factors can influence the process of erosion. For example, in arid and semi-arid environments, landscapes may be protected from erosion by indurated soil crusts; and eolian processes may invert topographic features which evolved under earlier, more humid conditions. In some regions, tectonic events can have a preeminent influence on rates of erosion.

At the Yucca Mountain site, two main types of surficial erosion should be considered: first, surface lowering - denudation - which represents the gradual reduction in the average elevation of the surface; and, second, more localized incision of the landscape mainly along stream channels. The rates of erosion of either type should be reported in terms of the rate (in mm or mm/unit time) of exhumation of the repository. Since this portion of the Great Basin is experiencing net uplift, the net elevation of the land surface may increase despite active erosion.

At Yucca Mountain, both denudation and channel incision have occurred during the course of the Quaternary. Periods of accelerated erosion have been interrupted by periods of comparative inactivity. Nevertheless, erosion is an inexorable process in the long-term under the geomorphological and environmental conditions which have prevailed during the Quaternary. Since erosion rates are temporally variable (depending mainly on climatic conditions and tectonic events) any assessment of normal erosion rates or processes requires a temporal qualification. Erosion rates determined for extremely long periods of time (perhaps 5.0 million years or more) may bear little relevance to rates over the past 10,000 or even 100,000 years because markedly different climatic conditions prevailed prior to the Quaternary Period. This notwithstanding, it is possible to establish a best estimate of normal rates of erosion over the past 10,000 years or so using geomorphological criteria. On the basis of this information, a deterministic assessment of future trends can be formulated.

Superimposed upon the normal processes of denudation, however, there may be infrequent events which have a strong direct or indirect influence on erosion rates. Such events may include earthquakes and rifting, catastrophic meteorological phenomena such as exceptionally high winds or floods, volcanic episodes, or even meteorite impacts. The potential effects of these events can be evaluated probabilistically on the basis of the likely periodicity of incidents of certain magnitude. In addition to these deterministic and probabilistic assessments of the likely processes and possible events that will influence erosion rates in the future, the

effects that possible changes in the nature of environmental processes will have on erosion rates should also be taken into account. It is in this area that the annotated outline has some significant shortcomings. It has been stated that the "overall system performance objective for the geological repository..." should "conform to such generally applicable environmental standards.. .with respect to both anticipated.. .and unanticipated processes and events" (10 CFR 60.112). Yet, throughout the outline, the conclusion that "the climatological and geomorphic conditions expected over the next 10,000 years will not negatively impact...the site" (Section 1.2 of the annotated outline) is largely founded on the assumption "that those processes operating in the geological setting during the Quaternary Period continue to operate..." (10 CFR 60.2). In the outline, however, it is stated that "degradation...rates have been very low for the last several hundred thousand years" and "these are reasonable rates for the next 10,000 years" (3.1.12). Elsewhere, it is stated that "there were few periods of extreme erosion at the site during the past 300,000 years" (1.3.1). The concluding lines of the outline state that erosion "is expected to continue at its current rate." Such assumptions certainly do not take unanticipated environmental changes into account. Moreover, the outline further confines the range of likely conditions in the future only to those prevailing during the middle and late Quaternary. The likelihood that environmental conditions similar to those during the early Quaternary - a period of more than one million years - will occur in the next 10,000 years is summarily dismissed.

This line of reasoning is inappropriate. While the environmental history of the Yucca Mountain area is still poorly known, global patterns of climatic change during the Quaternary are being continually refined. A significant body of evidence suggests that global climate was cooler at the last glacial maximum - about 18,000 years B.P. - than at any prior time during the Quaternary, but this is included in the time frame discussed by the report. Furthermore, the periods of comparatively warm conditions prevailing during interglacial periods appear to have shortened during the course of the Quaternary. If these interpretations are correct, it is feasible that the next 10,000 years will see the onset of conditions at Yucca Mountain at least as cool (and possibly as wet) as during the last glacial maximum. Indeed, Oberlander (1989: p. 74) pointed out that the present arid to semi-arid conditions in the Great Basin are probably the driest that have occurred over the past 3.0 million years with the possible exception of an arid interlude between about 0.57 and 0.31 Ma. While any assessment of future trends is highly speculative, the likelihood that cooler, wetter conditions will be reestablished in the future is a possibility which should be reasonably anticipated (10 CFR 60.2).

Similarly, since tectonic activity (Dohrenwend, 1982) and volcanism (Wells et al., 1990) have occurred in the region during the Quaternary, their potential impact on erosion rates should be evaluated. In the case of tectonism, the impact of possible or likely changes in the current rate of regional uplift should be addressed.

3.0 SPECIFIC COMMENTS ON THE DOE ANNOTATED OUTLINE

Included below are CNWRA comments on the annotated outline for the DOE topical report on erosion. The appropriate segments of the DOE outline for which comments have been generated are identified and the CNWRA comments follow each identifier. Only those sections,

subsections, and parts of the annotated outline for which comments have been generated are included below.

SECTION 1.0 DOE POSITION

Subsection 1.1 Purpose of Report

It is desirable that the DOE provide their concept of the definition of both the terms "extreme erosion" and "erosion" as used in this annotated outline. There is an NRC definition of "extreme erosion" stated in NUREG-0804 on p. 382, as follows: "occurrence of substantial changes in landforms (as a result of erosion) over relatively short intervals of time." The DOE is confusing two distinct purposes in its annotated outline. The primary purpose deals with the dismissal of "extreme erosion" as a potentially adverse condition while the secondary purpose seeks to show that "erosion" will not prevent compliance with the geologic repository performance objectives of the NRC and DOE as stated in 10 CFR Part 60 and 40 CFR Part 191. The DOE stated purposes, in both cases, presuppose the DOE desired conclusions and appear to be premature assertions based on a dearth of physical evidence from the Yucca Mountain proposed repository site. The purpose of the topical report should be reformulated by the DOE to investigate "evidence of extreme erosion during the Quaternary" and to subsequently (not prematurely) determine the effect of such erosion on the appropriate regulations. If the acquired data allow a conclusion to be reached that "extreme erosion" and normal erosion are not conditions which will cause the performance objectives to be breached then the conclusions of the topical report could be what DOE is now calling the "purpose" of the report.

At the DOE/NRC Technical Exchange on the annotated outline for the extreme erosion Topical Report on May 27, 1992, the DOE used the NRC definition of "extreme erosion" but did not attempt to clarify what the DOE considered to be "substantial changes in landforms" or "relatively short intervals of time." The DOE should provide its interpretation of these phrases in the Extreme Erosion Topical Report and discuss their significance relative to the DOE consideration of such "extreme erosion" at the proposed Yucca Mountain repository site.

Subsection 1.2 Statement of Position

Again, the "position" seems premature, especially in light of the lack of site and regional geomorphologic studies to support the contention that "extreme erosion" did not exist during the two million years of the Quaternary. Data will either prove or disprove the "position." The topical report should separate "extreme erosion" events and discussion from the anticipated normal erosion which will occur at the proposed site. The current wording in the annotated outline confuses "extreme erosion" and "erosion." At the May 27, 1992, Technical Exchange on erosion the DOE acknowledged that "erosion" should be read as "extreme erosion" in the annotated outline. Changes to the Topical Report implementing this acknowledgement should be made when the report is submitted to the NRC.

Subsections 1.2; 2.4; 2.5; 2.6; 4.0 and Parts 1.3.1; and 1.3.2

References to "climatological (sic) and geomorphic conditions expected over the next 10,000 years' require clarification. As is discussed earlier, expectations regarding future conditions should be based upon anticipated trends in climatic change not merely extrapolation of current conditions. It is unlikely that the present environmental regime will persist for the next 10,000 years.

Subsection 1.3 History of Issue

Part 1.3.1 Position Taken in Environmental Assessment

The annotated outline should discuss what "cut-off" values the DOE are proposing to use for the various facets of "extreme erosion" and why these values were selected. References to "rates expected in the future" require clarification or a qualifying statement. The statement that "evidence indicates that there were few or no periods of extreme erosion..." should perhaps state that "currently, there is no available data to suggest that there has been extreme erosion."

Part 1.3.2 Position Taken in Site Characterization Plan

All NRC comments/issues raised in the NRC staff site characterization analysis of the SCP should be discussed and the DOE approach to resolve these issues should be treated in this subsection of the Topical Report.

Part 1.3.3 Position Taken in Early Site Suitability Evaluation

The discussion of the Early Site Suitability Evaluation (ESSE) (SAIC, 1992) requires elaboration. The ESSE contains some errors (for example, compare p. 2-78, paragraph 2, with table 2-8) and there are inconsistencies between it and the present outline. For example, the ESSE classifies Yucca Mountain as being in an arid climatic zone, expressly excluding it from a semi-arid climatic regime (SAIC, 1992: p. 2.7) whereas the annotated outline repeatedly refers to the present day semi-arid environment at the site (sections 3.1.1; 3.1.8; 3.1.10; 3.1.12). The discrepancies should be reconciled.

The DOE comments in the ESSE on the error in Purcell (1986, and 1988) are overblown. The typographical error was acknowledged and corrected in subsequent NRC documents.

SECTION 2.0 REGULATORY BASES FOR THE DOE POSITION

It is critical that "evidence that erosion evaluations are supported by adequate investigation" and that "erosion processes (are) adequately evaluated" and are not likely to be

underestimated. Hence, a less confined view of future climatic trends than that which is presented in this outline is essential.

Subsection 2.1 Impact of Erosion On the Geologic Setting

The definition of "controlled area" used by the DOE is contained within the definition of "controlled area" which is a part of 10 CFR Part 60 and has been set by the DOE at about 5km by 5km in order to conform the size of the "controlled area" to the size allowed by the EPA in their regulation 40 CFR Part 191.

The DOE plan not to gather additional information on erosion during site characterization assumes erroneously that sufficient knowledge of current and past erosion of the site exists at present. At the least, various engineered structures require intimate knowledge of current erosion rate and type in order for the structure to be designed and constructed appropriately. The collection of evidence of extreme erosion during the Quaternary may be insufficient at the present as well. For example, the current and past downcutting rates in Fortymile Wash and its tributaries are not well known, the hillslope retreat rates of the Solitario Canyon scarps are not documented, and movement rate and size of alluvial and colluvial materials in Yucca Mountain washes is not known. These and other erosion-related considerations will have to be well-understood at the site if erosion of any kind is to be dismissed in a blanket statement. It is hoped that past and present erosion rates at Yucca Mountain will be established by data collection and analysis at the site and not merely by assuming that analogs provide sufficient assurance that the performance objectives will not be breached by erosion-related effects. Based on the discussions by Herrington and Whitney at the May 27, 1992, Technical Exchange on erosion, it appears as if at least two very different erosional process regimes, including the current regime which is producing small clasts and current erosion around the boulder deposits and another erosional regime which produced the large clasts of the boulder fields themselves, were operative at Yucca Mountain during the Quaternary. The importance and implications to future erosion of each of these process regimes should be discussed thoroughly in the Extreme Erosion Topical Report.

Although "evidence of extreme erosion during the Quaternary Period" is a potentially adverse condition (10 CFR 60.122(c)(16)), it does not necessarily follow that though these adverse conditions are uncharacteristic of the site they will not occur over the next 10,000 years. Both anticipated and unanticipated conditions should be assessed on the basis of past environmental regional trends and subsequent effect as evidenced in the Quaternary geologic record; and not merely by considering only recent, local past conditions.

Subsection 2.2 Impact of Erosion on Repository Seals

The likely effect of erosion on seals is insignificant only if: 1) Local erosion rates are proved to be low and inconsequential to engineering design, and 2) Seals are properly designed (size, shape, composition, placement, installation, etc.) to withstand the rigors of anticipated erosion and any "extreme erosion" events or periods which may include

"unanticipated" events. The design of seals, monuments, and markers should take into account anticipated weathering phenomena by mechanical processes (for example, wind, water, ice, and salt) and chemical processes (for example, oxidation and dissolution). The effect of possible desert varnish encrustation should also be evaluated.

Subsection 2.3 Impact of Erosion On Repository Monuments and Markers

The likelihood that monuments might be buried by alluvial, colluvial, or eolian sedimentation should be addressed. Wells et al. (1990) have described evidence of eolian sedimentation around the Lathrop Wells cinder cone less than 10 km to the south of the proposed repository site.

With the statement "However, the NRC will promulgate similar requirements when it conforms 10 CFR 60 to 40 CFR 191.", DOE is assuming that NRC will promulgate similar wording to the EPA language. This assumption is presumptuous on the part of DOE. NRC may believe that the current language in 10 CFR Part 60 is necessary and sufficient. DOE should not attempt to presuppose and direct NRC activities.

Subsection 2.4 Impact of Erosion On the Engineered Barrier System

"Extreme erosion" and "erosion" should both be considered when designing the EBS even if their consideration results in their rejection as issues of importance to design. DOE seems to be confusing "extreme erosion" and "erosion". Although, there may be no "extreme erosion" at a given site, there most certainly will be "erosion" during a 10,000 year period which should be considered in any engineering designs.

As stated elsewhere in this evaluation of the DOE annotated outline, the tacit assumption that environmental conditions anticipated during the 10,000 years following closure will not differ from those conditions which have prevailed during the Holocene requires more thorough evaluation and discussion than the DOE seems intent on providing.

Subsection 2.5 Impact of Erosion on the Repository's Depth

Hillslope degradation (denudation) rates at Yucca Mountain are based on evidence of past rates that is not well documented at the site or within the general area. Published data on surface lowering and scarp retreat on similar lithologies in comparable environments provide a wide range of erosion rates (Oberlander, 1989; SAIC, 1992). A thorough evaluation of these data coupled with appropriate site-specific investigations is essential. Elsewhere in the Great Basin, Dohrenwend et al. (1985) determined rates of erosion of basaltic rocks of from 0.16 to 0.58 m/10,000 years over the past 5.9 Ma. Oberlander (1989) estimated an average rate of scarp retreat over the past 5.0 Ma of 0.10-2.0 mm/10,000 years on granites in the Mojave Desert. Elsewhere, considerably higher rates have been reported; for example, in Sinai - where current mean annual rainfall is about 25 mm - Yair and Gerson (1974) estimated a rate of granite

scarp retreat of 1.0 to 20 m/10,000 years. Factors such as past climate, weathering rates, and tectonic influences will have marked effects on very long-term denudation rates (years x 10^6).

The channel incision rates discussed in the annotated outline are based on some questionable assumptions regarding future climatic conditions and their geomorphic impact. The rates presented in the annotated outline and by SAIC (1992) require careful evaluation and further documentation.

The comments pertaining to likely maximum stream incision assume that tectonic activity is either absent or will be constant over the 10,000 years following closure of the site. A probabilistic assessment of the effects that increased tectonic activity would have on incision rates is appropriate.

The contentions which the DOE wishes to make should be supported with significant and meaningful hard data if the NRC is to accept the DOE position that the effects of "extreme erosion" and "erosion" are inconsequential to repository performance.

Subsection 2.6 Impact of Erosion On the Repository System (see also 3.1.10)

DOE prematurely arrives at a conclusion that because "extreme erosion" is not present, erosion will not be a problem to any aspect of the repository relative to the performance objectives.

Relative to the EPA groundwater protection requirements, the EPA definition of "undisturbed performance" should be presented by the DOE to demonstrate that "anticipated processes and events" are not a part of such "undisturbed performance." Also regarding groundwater protection requirements, the possibility that channel aggradation or blockage by wind-blown sand could lead to increased percolation of meteoric water and runoff into the vadose zone should be addressed. The possibility of an adverse impact on rates of erosion owing to human activity should be assessed. For example, the likely effect of disturbance of protective surficial boulder deposits, and soil crusts by human activities should be evaluated.

SECTION 3.0 TECHNICAL BASIS AND SUPPORTING ANALYSIS

Subsection 3.1 Technical Basis

This section may require a qualifying statement regarding human influences on erosion. Human influences on erosion are not addressed in any depth in the outline.

Part 3.1.2 Distribution of Quaternary Deposits Around Yucca Mountain

Information from the "generalized surficial geologic map" should be thoroughly evaluated - especially the dating of geomorphological units and surface deposits. The thickness of the regolith resting on sound bedrock is an important factor. The potential rate of erosion of unconsolidated or weakly consolidated materials is far higher than that of the more resistant bedrock. Hence, the presence of more readily eroded materials in topographically low areas (relative to the subsurface repository) could compromise the minimum depth requirement for the site.

The reason for the entrenchment of older deposits - whether regional uplift, or climatic change - should be carefully addressed. The assumption that the drainage pattern will remain the same as it is today over the next 10,000 years or so will be predicated by tectonic activity, and climatic and geomorphic factors. The present "well-defined drainage channels" could be completely choked by colluvial or eolian sedimentation in the future. However, subsequent incision need not necessarily lead to reexcavation of the former drainage pattern. Indeed, examples of topographic inversion along relict channels because of climatic fluctuations have been described (SAIC, 1992: pp. 76-77) (see also Part 3.1.9, No. 7 of the DOE outline).

Part 3.1.3 Quaternary Climate Changes in the Southern Great Basin

The current title is misleading. This part should be retitled "Response of Geomorphic Processes to Quaternary Climate Changes in the Southern Great Basin." The suggestion that hillslopes "aggrade" under cooler, wetter conditions will require elucidation and significant documentation.

Part 3.1.4 Preservation of Colluvial Boulder Deposits on Yucca Mountain Hillslopes

The coating of surfaces and deposits is of critical importance and the varnish dating techniques used should be carefully evaluated. SAIC (1992) reported dates from varnished boulder horizons of 170 ka to 760 ka. The suggestion that desert varnish chemistry and thickness can provide an estimate of age may be invalid (Krinsley et al, 1990). Such characteristics may provide a chronology relative to other geomorphological surfaces in the vicinity but the correlation of age and thickness is very tenuous. Furthermore, the ages of varnish on surficial boulders is not necessarily representative of the age of the land surface because the boulders might constitute a lag deposit which is itself being lowered.

Part 3.1.5 Cation-Ratio Dating of Yucca Mountain Hillslope Deposits

As is stated above, circumspect dating is absolutely critical. The validity of some dating techniques described in the annotated outline has been disputed. The accuracy of both the methods and interpretation of the cation-ratio dating results should be thoroughly discussed and documented.

Part 3.1.6 Age Estimates of Darkly Varnished Boulder Deposits on Hillslopes in the Yucca Mountain Area

The possibility that the boulder deposits are lag deposits should be evaluated. Again, the validity of the dating techniques which are used is of paramount importance. The accuracy of cosmogenic dating techniques (thermoluminescence) has been questioned in cases similar to those described by SAIC (1992: p. 2-77). Other more well-documented dating procedures such as radiometric dating of palaeosols and C-14 dating of varnishes should be considered.

Part 3.1.7 Hillslope Erosion Rates on Yucca Mountain, Skull Mountain, Little Skull Mountain, and Buckboard Mesa

This section is very vague, however, the information said to be "in hand" is some valuable and necessary data. It is difficult to give an accurate assessment of the DOE efforts without more detail. The aforementioned issue of the boulder horizons possibly being surficial lag deposits is again relevant. An estimated channel incision rate of 82 m/10,000 years has been disputed (SAIC, 1992: p. 2-78) by the DOE on the grounds that it pertains to a more humid regime than that at Yucca Mountain today, however, future climatic change could result in optimal conditions for incision. A critical parameter in the evaluation of potential incision is the thickness of the unlithified material throughout the controlled area.

Part 3.1.8 Comparison of Yucca Mountain Erosion Rates With Older Semiarid Environments

The time scale over which the average denudation rate has been estimated should be clearly stated. "Long-term" might range from tens of years to millions of years. Moreover, the longer the time period being considered, the more likely it is that past major environmental changes have resulted in significant variations in rates of erosion. Some relevant published rates exceed the rate of 43 mm/1,000 years mentioned in the outline including 82m/10,000 yrs. reported by Purcell (1986) (see comments on Subsection 2.5).

Part 3.1.9 Reasons For Low Erosion Rates At Yucca Mountain

The following are comments on the DOE itemized reasons for suggesting low rates of erosion at Yucca Mountain:

ITEM

2. This is questionable. While this assertion is supported by Dorn and Oberlander's (1982) work on varnish hardness, Engel and Sharp (1958) found that varnish readily dissolves under wet climatic conditions, and Allen (1978) found that it is destroyed by abrasion by windborne sand.

3. This statement requires verification.

4. The phrase "relatively small fluctuations in climate" requires qualification (relative to something) and verification. Some authors have suggested marked variations in climate in the Southern Great Basin in the past 2,000,000 years.

5. The relevance of this assessment is unclear. Phases of sediment storage may be temporary depending on the course of environmental change or other influences such as human impact.

6. The protective influence of boulder deposits on underlying unconsolidated materials could be lost in the event of exceptional precipitation or tectonic activity disrupting the cover thereby exposing an inherently unstable material to accelerated erosion. A probabilistic evaluation of the likelihood of such an event should be made.

7. This sentence requires further explanation.

Part 3.1.10 Stream Incision Rates on Fortymile Wash and Tributaries

The presence of eolian sand deposits at Lathrop Wells cinder cone just south of the controlled area raises the possibility that stream channels may become choked with blown sand. The effect that such a phenomenon would have on the movement of water into the vadose zone, and on the character of the drainage network should be evaluated.

Part 3.1.11 Alternative Erosion Models

The question whether the dated boulder deposits are surficial lags which may themselves be undergoing topographic lowering should be addressed. Erosional stone pavements are a common feature of arid and semi-arid landscapes (though not all desert pavements are erosional). Such surfaces do not necessarily "represent the average land surface position at the time they were emplaced." In addition, the "worst-case scenario" for erosion requires precise definition.

Part 3.1.12 Summary of Yucca Mountain Erosion Rates

The DOE states that rates of denudation and stream channel incision at Yucca Mountain are "lower than those rates measured in nearby regions", if this is a result of climatic factors (rather than lithological or tectonic influences) it seems plausible that future climatic change could lead to increased rates of erosion. It is not reasonable to project a "dry, semi-arid climate" and "low rates of tectonic deformation" into the future without further justification. There is insufficient evidence to argue that climatic conditions have been stable for the past 10,000 years, certainly not the past 20,000 years. Hence, it is inappropriate to suggest that current conditions will prevail for the next 10,000 years.

SECTION 4.0 CONCLUSIONS

The statement that "erosion is a natural process that is expected to continue at its current rate" is not supported by the data as presented. Also, "extreme erosion" and "erosion" are not distinguished from one another. Moreover, in view of the apparent variability in climatic conditions even as recent as the late Quaternary Period, it is invalid to project only the current climate induced environmental conditions 10,000 years into the future.

REFERENCES

Allen, C. C. 1978. Desert varnish of the Sonoran Desert - optical and electron probe analysis. *Journal of Geology* 86: 743-752.

Dohrenwend, J. C. 1982. Tectonic control of pediment distribution in the western Great Basin. *Geological Society of America, Abstracts with Programs* (Cordilleran Section), 14 (4): p. 161.

Dohrenwend, J. C., B. D. Turrin, and M. F. Diggles. 1985. Topographic distribution of dated basaltic flows in the Reveille Range, Nye County, Nevada: implications for late Cenozoic erosion of upland areas in the Great Basin. *Geological Society of America, Abstracts with Programs* (Cordilleran Section), 17 (6): p. 352.

Dorn, R. I. and T. M. Oberlander. 1982. Rock varnish. *Progress in Physical Geography* 6: 317-367.

Engel, C. G. and R. Sharp. 1958. Chemical data on desert varnish. *Bulletin of the Geological Society of America* 69: 487-518.

Krinsley, D. H. , R. I. Dorn and S. W. Anderson. 1990. Factors that interfere with the age determination of rock varnish. *Physical Geography* 11: 97-119.

Oberlander, T. M. 1989. Slope and pediment systems. *In Arid Zone Geomorphology*, Thomas, B. E. G. (Ed.). Wiley, New York, NY: 56-84.

SAIC. 1992. Report of early site suitability evaluation of the potential repository site at Yucca Mountain, Nevada. *Technical and Management Support Services*, Contract No. DE-AC08-87NV41O576.

Wells, S. G., L. D. McFadden, C. E. Renault, and B. M. Crowe. 1990. Geomorphic assessment of late Quaternary volcanism in the Yucca Mountain area, Nevada: implications for the proposed high level radioactive waste repository. *Geology* 18: 549-553.

Yair, A. and R. Gerson. 1974. Mode and rate of escarpment retreat in an extremely arid environment. *Zeitschrift fur Gemorphologie*, N.F. 21: 106-121.