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PROBABILISTIC VOLCANIC HAZARD ANALYSIS (PVHA) FOR YUCCA MOUNTAIN, NEVADA (SCPB: 8.3.1.8)

Reference: Ltr, Brocoum to Holonich, dtd 6/1/95

Enclosed is the report, "Probabilistic Volcanic Hazard Analysis for Yucca Mountain, Nevada". This report was prepared for the Yucca Mountain Site Characterization Office (YMSCO) by Geomatrix Consultants, Inc., under contract with the Civilian Radioactive Waste Management System Management and Operations Contractor (CRWMS M&O). The report documents the results of an expert elicitation to assess the probability of disruption of the potential high-level waste repository at Yucca Mountain, Nevada by igneous events and quantifies the uncertainties associated with this assessment.

The three major goals of this activity were to: 1) review existing data and develop or refine models for evaluating the future locations and recurrence of igneous activity, 2) assign weights to various physical system models for evaluation to arrive at representative cumulative probability distributions for probabilistic variables, and 3) evaluate all the appropriate variables for each model and quantify the uncertainties associated with each parameter value. The results of the PVHA analysis provide an aggregate expected annual frequency of intersection of the potential repository by an igneous event is $1.5 \cdot 10^{-8}$. These results will be used as direct input into the total system performance assessment for the potential repository.

The PVHA was initiated to assist the U.S. Department of Energy (DOE) in issue resolution activities with the U.S. Nuclear Regulatory Commission (NRC) on the subject of volcanic hazard. Igneous activity has since been identified by NRC staff as a key technical issue for the Yucca Mountain site. In the view of the NRC staff, the key technical uncertainties associated with igneous activity at Yucca Mountain, Nevada include:

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- Low resolution of exploration techniques to detect and evaluate igneous features
- Inability to sample igneous features
- Development and use of conceptual tectonic models as related to igneous activity
- Probability of igneous activity and resulting disruption of the candidate repository
- Consequences of igneous activity for repository performance
- Conceptual model representations of the natural and engineered systems
- Variability in model parametric values
- Appropriateness of assumptions and simplification in mathematical models
- Prediction of future system states

NRC staff has also concluded that the DOE has not bounded reasonable ranges of probability and consequence of igneous activity in their performance assessment program and that direct or indirect disruption of the site by igneous activity could have a significant impact on repository performance.

The PVHA for the Yucca Mountain site quantifies the uncertainties in the assessment of volcanic hazard, including uncertainty in both the models used to represent the key physical controls on volcanism and the parameter values used in the models. The results of this study support the DOE's position that YMSCO has developed reasonable bounds for the range of probability of igneous activity for the site and that direct or indirect disruption of the site by igneous activity is unlikely to have a significant impact on repository performance. In addition, the results of this study address each of the key technical uncertainties that the NRC considers relevant to the key technical issue of igneous activity.

Enclosure 2 provides a rationale for how the PVHA resolves Site Characterization Analysis comment 45 and several NRC open items from comments on Study Plan 8.3.1.8.1.1, Revision 1, "Probability of Magmatic Disruption of the Repository".

The preparation, conduct, and documentation of the PVHA elicitation was performed in accordance with the expectations established in the DOE's "Principles and Guidelines on the Formal Use of Expert Judgement for the Yucca Mountain Site Characterization Project" (reference). The PVHA report was prepared in accordance with the CRWMS M&O Quality Assurance Program procedures for preparation and review of technical documents.

If you have any questions or require further information, please call Thomas W. Bjerstedt of my staff at (702) 794-1362 or Martha W. Pendleton of the CRWMS M&O at (702) 295-5550.

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AMSL:TWB-2014

Enclosures: On the Shelf
1. "Probabilistic Volcanic Hazard Analysis for Yucca Mountain, Nevada" (NOT RECORD MATERIAL)
2. Applicability of the PVHA for Yucca Mountain, Nevada, in resolution of NRC open items (NOT RECORD MATERIAL)

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Enclosure 2

Applicability of the Probabilistic Volcanic Hazard Analysis for Resolving Open Items from the Site Characterization Analysis

The PVHA report documents the results of the volcanic hazard assessment and, therefore, provides additional support for resolution of Site Characterization Analysis (SCA) open item 45.

SCA Comment 45: 7/89 NUREG-1347

Reliance on volcanic rate calculations that are developed largely independent of consideration of the underlying volcano-tectonic processes appears likely to underestimate potential impacts on the performance of the repository.

Basis

- The SCP indicates that the annual probability of a volcanic eruption penetrating the repository is not greatly dependent on the regional model (Tables 8.3.1.8-7 and 8). However, regional tectonic models of crustal and mantle processes would appear to be essential in estimating whether magma generation will be increasing or decreasing in the future and, therefore, seemingly have a significant effect on the uncertainty of probabilities of future volcanic events. Chapter 1 (pp. 1-203) indicates that volcanism appears to be directly linked to tectonic processes in the region.

- Probability calculations appear to be based on establishing a rate of volcanic activity during the Quaternary which averages the activity over at least 2.0 million years. Probabilities calculated in this manner do not appear to be conservative in establishing the hazard to the repository in that they assume a uniform distribution of volcanism through time and appear to overlook possible structural control, uncertainty in the processes responsible for volcanism, and uncertainty in dating Quaternary volcanic events.

NRC Recommendation: More consideration should be given to characterizing volcanic processes acting in the geologic setting.

DOE Response: Ltr. dtd. 12/14/90 Shelor to Linehan

The three concerns in this comment are (1) volcanic rate calculations (the recurrence rate of volcanic events) were developed largely independent of volcano-tectonic processes, (2) probability calculations were not dependent on the regional tectonic models, and (3) calculations appeared to be based on averages of volcanic activity during the Quaternary. These concerns are discussed separately.

1. An idealistic approach to calculating the probability of magmatic disruption of a repository at Yucca Mountain would be to base the calculations on numerical models of volcanic and tectonic processes. However, this approach implies an understanding of these processes that is beyond the current capabilities of geosciences. Moreover, it is unrealistic to provide expectations that this expertise could be developed within the planned period of site characterization studies. The alternative is to base the volcanic recurrent rate calculations on the geologic record. This approach was used for the Site Characterization Plan (SCP). The implicit assumption of this approach is that the underlying volcano-tectonic processes of the region are reflected in the record of volcanism. It is a fundamental assumption of geology that the past geologic record provides the primary basis for predicting or bounding future geologic events.

2. The probability calculations are partly dependent on regional tectonic models. It is important to evaluate a range of permissible volcano-tectonic models for the patterns of basaltic volcanism in the Yucca Mountain region. For each model, evaluations need to be conducted to determine if the model could lead to predictions that recurrence rates of volcanic events are increasing, decreasing, or are steady-state. These predictions should be either factored into probability calculations or it should be demonstrated that an approach used is conservative from the perspective of volcano-tectonic models. The U.S. Department of Energy would consider revising SCP Tables 8.3.1.8-7 and -8 to indicate that the probability of repository disruption is partly dependent on regional tectonic models. These changes may be reflected in the SCP's technical baseline or a Study Plan revision.

At this stage of development of site characterization work, it is premature to expect probability calculations to reflect regional tectonic models. The models are under development as part of the process of site characterization. Future input for this part of revised probability calculations will be provided from Investigation 8.3.11.7.4, Preclosure Tectonics Data Collection and Analysis, and Activity 8.3.1.8.5.1.5, Evolution of Basaltic Volcanic Fields (the title of the activity has been renamed after publication of the SCP). An expanded discussion of Activity 8.3.1.8.5.1.5 is provided in Study Plan 8.3.1.8.5.1 (Characterization of Volcanic Features). The method for revising probability calculations using input from these two activities is described in Study Plan 8.3.1.8.1.1, Probability of Magmatic Disruption of the Repository (Activity 8.3.1.8.1.1.4, Probability Calculations and Assessment).

3. A stochastic approach to probability calculations is based on an assumption of rate uniformity of modeled events. This is a fundamental requirement of a probabilistic approach (Poisson event distribution, no event memory). This approach can be nonconservative if there have been changes (increases) in the modeled rate. However, the probability calculations discussed in the SCP used a dual approach to establishing volcanic rates: stochastic (cone counts) and magma volume versus time. The latter approach is based on an evaluation of the magma effusion rate, by plotting the curve of the cumulative magma volume of volcanic events versus age of the volcanic events. The slope of this curve is the magma effusion rate and it is very sensitive to changes in rates. This plot can be used to test whether a stochastic approach is conservative or nonconservative. Crowe and Vaniman (1981) and Crowe, Johnson, and Beckman (1982) presented evidence that magma effusion rates may be decreasing in the Yucca Mountain region during the Pliocene and Quaternary. If this interpretation is

consistent with more detailed work planned for the site characterization studies, it suggests that a stochastic approach to probability calculations for the Yucca Mountain site is a conservative approach. The development, use, and documentation of application of a diagram of cumulative magma volume versus time for calculating volcanic recurrent rates is described by Crowe and Perry (1990). A discussion of the advantages and disadvantages of different methods for calculating volcanic recurrent rates is also described in Study Plan 8.3.1.8.1.1, Probability of Magmatic Disruption of the Repository.

References:

DOE (U.S. Department of Energy), 1990. Study Plan 8.3.1.8.5.1, Characterization of Volcanic Features, Yucca Mountain Project Office, Las Vegas, NV.

DOE (U.S. Department of Energy), 1990. Study Plan 8.3.1.8.1.1, Probability of Volcanic Eruption Penetrating the Repository, Yucca Mountain Project Office, Las Vegas, NV.

Crowe, B. M., M. E. Johnson, and R. J. Beckman, 1982. "Calculation of the Probability of Volcanic Disruption of a High-Level Radioactive Waste Repository within Southern Nevada, USA," Radioactive Waste Management and the Nuclear Fuel Cycle, Vol. 3, No. 2, pp. 167-190.

Crowe, B. M., and F. V. Perry, 1990. "Volcanic Probability Calculations for the Yucca Mountain Site: Estimation of Volcanic Rates," in Proceedings of the Nuclear Waste Isolation in the Unsaturated Zone, FOCUS '89 Conference, American Nuclear Society, pp. 326-324.

Crowe, B. M., and D. T. Vaniman, 1981. "Geology and Petrology of the Basalts of Crater Flat: Applications to Volcanic Risk Assessment for the Nevada Nuclear Waste Storage Investigations," 167; LA0884-MS, Los Alamos National Laboratory, SCP Chapter 1.

NRC Evaluation of DOE Response to Comment 45: Ltr. dtd. 7/31/91 Bernero to Bartlett

- The response to this comment indicates that the only possible alternative in volcanic rate calculations is to rely on "a fundamental assumption of geology that the past geologic record provides the primary basis for predicting or bounding future geologic events." The staff supports such a deterministic approach. Further, the staff considers that supplemental activities exist (e.g., natural analog studies; deep seismic survey) that, combined with the geologic record, provide mechanisms for approaching an understanding of Quaternary geologic process at the site. In addition, the accuracy of assumptions stemming from an examination of the geologic record alone is largely dependent on the record being "robust" enough to provide an adequate data base for predicting or bounding future geologic events. The staff considers that evidence suggesting that the geologic record of Quaternary volcanism is "robust" to the point of accurately predicting the future likelihood of volcanic events has not been documented.

- DOE states that "At this stage of development of site characterization work, it is premature to expect probability calculations to reflect regional tectonic models." The staff considers that alternative tectonic models do exist for the Yucca Mountain region at the present time and that these alternatives should be incorporated into characterization activities and preliminary calculations about the likelihood of future volcanic events. An example of an alternative tectonic model for basaltic volcanism in the Yucca Mountain region is that proposed by Smith and others (1990) for structural control of basaltic volcanism at Yucca Mountain.

- DOE states that calculations of magma effusion rates suggest that a stochastic approach to probability calculations for the Yucca Mountain site is a conservative approach. The staff does not consider the calculations of magma effusion rates as presently defined to be robust enough to accurately or precisely predict whether magma production will increase or decrease in the next 10,000 years, particularly in the absence of the consideration of alternative models of magma rate production. Therefore, the staff does not consider the stochastic approach to probability calculations for volcanism at Yucca Mountain to necessarily be conservative.

- DOE suggests that this comment can be resolved after additional site characterization leads to development of regional tectonic models (Investigation 8.3.11.7.4; Study Plans 8.3.1.8.5.1 and 8.3.1.8.1.1) and calculations of magma effusion rates (Study Plan 8.3.1.8.1.1). Resolution of this comment must await NRC staff evaluations of the referenced study plans and results of investigations which should consider volcano-tectonic processes, regional tectonic models, and volcanic rate calculations.

- The NRC staff considers this comment open.

Reference:

Smith, E. I., Feuerbach, D. L., Naumann, T. R., and Faulds, J. E., 1990. "The Area of Most Recent Volcanism near Yucca Mountain, Nevada: Implications for Volcanic Risk Assessment," in Proceedings High Level Waste Management, 1990, American Nuclear Society, p. 81-90.

DOE Supplemental Response: Ltr. dtd. 7/12/93 Shelor to Holonich

The transmittal of Study Plan 8.3.1.8.1.1, Revision 2, "Probability of Magmatic Disruption of the Repository" provides the basis to explicitly address Site Characterization Analysis (SCA) Comment 45 open item. Two concerns are expressed by the NRC in Site Characterization Analysis Comment 45. First, NRC expressed concern that alternative tectonic models for the Yucca Mountain, Nevada, region should be incorporated into calculations of the probability of future volcanic events. The DOE fully intends to consider all structural/tectonic models and to calculate the disruption parameter iteratively as new information becomes available. Study Plan Section 3.2.2.2 has been revised to clarify this position. Ambiguous examples of disruption parameter calculations have been deleted and a summary paragraph has been added clarifying that all structural/tectonic models will be considered along with new information as obtained.

The second NRC concern is that the stochastic approach to probability calculations is not necessarily conservative and that alternative methods of calculating the volcanic recurrence rate should be considered. The DOE believes that a stochastic approach to probability calculations is conservative for the Yucca Mountain region based on several lines of evidence pointing to a decrease in magma production with time. However, DOE fully intends to incorporate all methods (e.g., stochastic, poisson, weibull) for probability calculations. Section 3.4.2.1 has been completely revised to replace incorrect examples of probability calculations with more accurate example calculations and an updated explanation of the strategy for their use. In addition to the above two major revisions, several sections of Study Plan 8.3.1.8.1.1 (Sections 1.1, 1.2, 3.4.2.2, and 4.0) have been revised to clarify that both the intrusion and eruption scenarios will be considered in the calculation of the probability of future volcanic activity in the Yucca Mountain region.

The NRC has not responded to this input.

Applicability of the PVHA in resolving Comment 45 open item: (this enclosure)

In the PVHA, the expert panel considered the structural control of volcanism in Yucca Mountain and the spatial and temporal relationships between volcanism and faulting in the region as two of the major technical issues to be addressed in the assessment of volcanic hazard for the Yucca Mountain site. Alternative tectonic models were considered by the expert panel through available reports, technical presentations, recently acquired geophysical lines, and deliberations among the panel members. Appendix E (Elicitation Interview Summaries) of the PVHA documents each expert's definition of the volcanic/tectonic setting of the Yucca Mountain region. The DOE considers the treatment of the volcanic/tectonic processes underlying volcanic rate calculations in the PVHA sufficient to resolve this comment.

Applicability of the Probabilistic Volcanic Hazard Analysis for Resolving Open Items on Study Plan 8.3.1.8.1.1

Study Plan 8.3.1.8.1.1 (Magmatic Disruption of the Repository), Revision 3, was sent to the NRC on May 22, 1996. Appendix A of this Study Plan provides the general procedure for the use of expert judgment for the assessment of volcanic hazard for the Yucca Mountain site. The PVHA report documents the results of the volcanic hazard assessment and, therefore, provides additional support for resolution of open items 1, 2, 3, 4, 5, 6, 7, 12, and 13 on Study Plan 8.3.1.8.1.1.

NRC Comment 1: Ltr. dtd. 7/10/92 Holonich to Roberts

The use of the term "event" in this study plan appears to be limited to cone formation, and therefore provides an incomplete description of magmatic processes and events, and the requirement to determine consequence of the resultant activity.

DOE Response: Ltr. dtd. 3/9/93 Shelor to Holonich

See referenced letter.

Evaluation of DOE Response: Ltr. dtd. 2/8/94 Holonich to Shelor

- The primary concern of the staff is that the analysis noted in the study plan consider the full range of potential magmatic processes and events when demonstrating compliance with the performance objectives. Therefore, the exploration program should be sufficient to provide the basis for demonstrating compliance.

- In Section 4.0 of this study plan, it is indicated that this study plan will provide the data for assigning event probabilities for all aspects of igneous activity which could disrupt the repository.

- However, in Subsection 3.4.2.1, the emphasis of the study plan appears aimed at resolving the "tripartite probability." The tripartite probability, and associated analysis, does not appear to consider all events of regulatory concern.

- On Page 25, Section 3.4.2.1, it is stated that the probability of intrusive events and extrusive events is equal. No data or references are provided to support this assumption.

- On Page 27 of section 3.4.2.1, the study plan infers that certain scenarios and events of regulatory concern will be addressed in Study Plan 8.3.1.8.1.2; however, the discussion is restricted to direct release. The staff considers that the total probability of disruption should include both direct and indirect disruption of the repository.

- Although Table 1 (Pages 12 and 14) provides a listing of other studies which are intended to supply information to this study, it is unclear how the other studies will supply the detail and

resolution necessary to distinguish "features" that may have formed as a result of non-cone forming events.

- The Shelor to Holonich letter (DOE, 1993) references Study Plan 8.3.1.8.5.1 as containing the characterization activities to identify all magmatic events, however, Study Plan 8.3.1.8.5.1 also appears to be aimed at only identifying large scale features, such as cones.

- The NRC staff considers this comment open.

Applicability of the PVHA: (this enclosure)

The expert panel considered the definition of a volcanic event a major technical issue by the expert panel for the PVHA. During each individual elicitation interview (Appendix E, Elicitation Interview Summaries), each expert was asked to define a volcanic event. The definitions are not limited to cone formation. The experts considered both the temporal and spatial aspects of a volcanic event and considered intrusive as well as extrusive features. The DOE believes that the PVHA provides an adequate description of magmatic processes and events to determine the volcanic hazard at the Yucca Mountain site and that this information is sufficient to resolve the comment.

NRC Comment 2: Ltr. dtd. 7/10/92 Holonich to Roberts

Use of surface extrusion rates to approximate magma production rates could underestimate the effects of the magmatic process on repository performance.

DOE Response: Ltr. dtd. 3/9/93 Shelor to Holonich

See referenced letter.

Evaluation of DOE Response: Ltr. dtd. 2/8/94 Holonich to Shelor

- The staff agrees that the volume/time approach has been shown to be useful in estimating volcanic eruptive probability. As is stated in the Shelor to Holonich letter (DOE, 1993), this relationship has not been used in estimating the probability of intrusive events. The use of magma effusion rates is one of the main methods used in Section 3.4.2.2 of the study plan for estimating recurrence rates. As it is the probability of the total events of the process, not just the probability of extrusion which is of concern to the NRC, the use of this methodology is of concern to the staff.

- The NRC staff's concern with the use of this method also is related to explicit statements such as those on Page 25 of the study plan where it is stated that "Because Pr = Pr the remaining discussion will only mention Pr recognizing that the described assessments apply to both events." No data or reference is provided to support this assumption.

- In the Shelor to Holonich (DOE, 1993) letter, it is stated that "The assumption that has been universally applied ... is that the same volume of magma pushing from the asthenosphere into the upper crust is required for each eruptive event." Considering the temporal and spatial separation of the various cones which are used in this calculation within the region, the potential variations in structure and stress field for each eruptive event, along with the change in magma properties, and supposed depth of source material, this assumption appears suspect.

- Even if this assumption is correct, the proportion of total material represented by the material at the surface is quite different for a cone of the size of Lathrop Wells when compared to a cone of the size of Little Cone.

- Although the basic assumption regarding magma volume is tied into eruptive events, the assumption appears to be used only to calculate a recurrence rate for "cone" formation. If, for example, Lathrop Wells cone is polycyclic and Little Cone is monocyclic, in addition to the material difference at the surface, the subsurface volume of Lathrop Wells cone would be some multiple of the subsurface volume of Little Cone as it would be necessary for each surface eruption at the Lathrop Wells cone to have the corresponding subsurface feeder material. The recurrence rate calculation that the magma volume calculations support does not appear to consider the possibility of multiple eruptive events.

- The DOE has suggested that the Yucca Mountain region is in a stage of waning volcanic activity; however, there are also suggestions that the cycle may be evolving, changing from few large events to more small events (see, for example, the discussion on page 160 of Crowe et al., 1993). The effects of this type of cycle change on magma production rate curves and on the probability calculations has not been addressed.

- In other DOE study plans, such as Study Plan 8.3.1.9.2.1, Natural Resources Assessment of Yucca Mountain, Nye County, Nevada, there is a recognized need to determine the inferred size, location, and age of the various intrusive bodies. Study Plan 8.3.1.9.2.1 recognizes that the ratio of intrusive to extrusive volumes normally range up to a factor of 6 to 1 for basaltic volcanism. There appears to be a variation in the assumptions in these two study plans.

- The NRC staff considers this comment open.

References:

U.S. Department of Energy, Letter from Dwight E. Shelor of DOE to Joseph J. Holonich of NRC, Subject: Response to NRC comments and questions regarding Study Plan 8.3.1.8.1.1, March 9, 1993.

Crowe, B. M., F. V. Perry, and G. A. Valentine, Preliminary Draft: Status of Volcanic Hazard Studies for the Yucca Mountain Site Characterization Project, Los Alamos National Laboratory, 326 pp, 1993.

Applicability of the PVHA: (this enclosure)

The expert panel for the PVHA considered temporal models and rates of occurrence of volcanic events (see Appendix E, Elicitation Interview summaries). They each individually defined a volcanic event and used event counts to evaluate rates for occurrence. The results of the PVHA analysis provide an aggregate expected annual frequency of intersection of the repository footprint by a volcanic event of $1.5 \cdot 10^{-8}$, with a 90-percent confidence interval of $5.4 \cdot 10^{-10}$ to $4.9 \cdot 10^{-8}$. The DOE believes that the results of the PVHA bound the probability of a volcanic event for the Yucca Mountain site and this information partially addresses the NRC comment. The expert panel was not asked to evaluate the effects of a volcanic event on repository performance. The results of the PVHA will be used in future total system performance assessments to address the consequences of magmatic processes on repository performance.

Comment 3: Ltr. dtd. 7/10/92 Holonich to Roberts

The evaluation of the presence of crustal magma bodies in the vicinity of Yucca Mountain must consider the requirements of 10 CFR Part 60.122(a).

DOE Response: Ltr. dtd. 3/9/93 Shelor to Holonich

See referenced letter.

Evaluation of DOE Response: Ltr. dtd. 2/8/94 Holonich to Shelor

In the response to this comment (DOE, 1993), the DOE indicates that the geophysical data will be reviewed to determine the need for additional investigations.

- Although this may be a prudent approach, the staff believes that sufficient information is present in the scientific literature to suggest the presence of low velocity zones and, therefore, the relationship of these zones to volcanic/magmatic activity must be adequately addressed.

- The NRC staff considers this comment open.

Reference

U.S. Department of Energy, Letter from Dwight E. Shelor of DOE to Joseph J. Holonich of NRC, Subject: Response to NRC comments and questions regarding Study Plan 8.3.1.8.1.1, March 9, 1993.

Applicability of the PVHA: (this enclosure)

The PVHA expert panel reviewed available geologic and geophysical data to evaluate the presence of crustal magma bodies in the vicinity of Yucca Mountain. Using these data, each expert documented their opinion of the potential presence of undetected events in the vicinity of

the site. The DOE considers the information contained in the PVHA sufficient to resolve this comment.

Comment 4: Ltr. dtd. 7/10/92 Holonich to Roberts

One of the main activities within this study plan, as stated on page 8, is to estimate the probability of future magmatic disruption of the Yucca Mountain site, however, the probability calculations that this study plan is intended to produce appear too limited to resolve the geologic and regulatory concerns.

DOE response: Ltr. dtd. 3/9/93 Shelor to Holonich

See referenced letter.

Evaluation of DOE Response: Ltr. dtd. 2/8/94 Holonich to Shelor

- The primary concern expressed by this comment was to assure that all significant processes and events which may affect the repository would be included in determining compliance with the performance objectives.

- Although it has been indicated in the response to Comment 1 (DOE, 1993) that characterization activities have included activities to identify all magmatic events, no other study plan that has been submitted to the NRC appears to contain information on how this is to be accomplished.

- The focus of the probability determination in Study Plan 8.3.1.8.1.1 is on the "tripartite" probability, and this calculation appears to produce probability numbers that do not consider all possible processes and events which are of regulatory concern (See also Comment 8).

- DOE's determinations of the probability of processes and events are partially based on the assumption that Pr_i is equal to Pr_v. The staff knows no basis which justifies this assumption (See also Comment 2).

- No program of investigation has been identified which is aimed at evaluating intrusive events of a size less than that of a cone, either with Study Plan 8.3.1.8.1.1 or Study Plan 8.3.1.8.5.1.

- Study Plan 8.3.1.8.2.1, "Analysis of Waste Package Rupture due to Tectonic Processes and Events," states that the probability of disruption of the waste package from igneous processes and events will come from Activity 8.3.1.8.1.1.4. Therefore, if Study Plan 8.3.1.8.1.1 does not provide a probability value for all magmatic processes and events which could affect the waste package, the analysis under 8.3.1.8.2.1 will be incomplete.

- It is unclear where the information needed for Study Plan 8.3.1.8.2.1, or the other studies listed in Table 2, will be obtained.

- The NRC staff considers this comment open.

Applicability of the PVHA: (this enclosure)

The purpose of the PVHA was to assess the probability of disruption of the repository by a volcanic event and to quantify the uncertainties associated with this assessment. These uncertainties included both the uncertainty in both the models used to represent the important physical controls on volcanism and the parameter values used in the models. The DOE considers the resulting probabilities representative of the knowledge and uncertainty related to volcanic hazard at the site. The DOE also believes this information is sufficient to resolve this comment.

Comment 5: Ltr. dtd. 7/10/92 Holonich to Roberts

It is unclear how a volcanic recurrence model can be constructed without knowledge of magmatic events of a size less than that needed to produce a cone.

DOE response: Ltr. dtd. 3/9/93 Shelor to Holonich

See referenced letter.

Evaluation of DOE Response: Ltr. dtd. 2/8/94 Holonich to Shelor

- The DOE suggests that analog information will be used. The NRC staff agrees that this may be helpful.

- No information has been presented that would demonstrate that volume predictive curves are valid for small scale fields, especially if the amount of material represented by the feeder system is neglected, and the question of monocyclic versus polycyclic volcanism is not resolved. (See also Comment 2.)

- The response in the Shelor to Holonich letter (DOE, 1993) suggests that seismic recurrence curves and volcanic recurrence curves differ in one particular area. "The smallest magnitude of seismic events is determined by the threshold of detection. For volcanism, there is a volume limited cut-off."

- The staff noted that the smallest surface eruption known was 2 cubic meters through ageothermal drill hole (Global Volcanism, 1975-1985). Although this is a special case, it demonstrates that, if there is a volume-limiting cut-off, this cut off can only be understood in reference to the other properties and features of the system. Although there may be a volume limiting cut-off, the DOE has not provided the data to demonstrate what this cut-off is in relation to the volcanism that has occurred in the Yucca Mountain region.

- The staff notes that the threshold of detection for seismic events is dependent on such things as the sensitivity of the detection equipment, the location of the equipment, and the number of monitors. In other words, the threshold of detection is a function of the exploration program

characteristics. A similar relationship exists for understanding of volcanic phenomena. For example, at Kilauea from 1975 through 1981, 2 eruptions and 15 intrusive episodes were documented. Documentation of these intrusive episode has been attributed to "Development of sensitive monitoring techniques." (Global Volcanism, 1975-1985)

- The staff notes in the study plan (i.e., Section 3.2.4.1) it is assumed that the probability of intrusion equals the probability of extrusion. The explicit assumption of the probability of intrusion, and therefore the intrusion ratio, does not appear justified as DOE has not identified a volcanic field in which this ratio has been documented. The staff believes that the assumption may not be justified.

- The NRC staff considers this comment open.

Reference:

Smithsonian Institution, 1991. "Global volcanism 1975-1985. The First Decade of Reports from the Smithsonian Institutions Scientific Event Alert Network (SEAN)," L. McClelland, T. Simkin., N Summers, E. Nielsen, and T. C. Stein, Editors, National Museum of Natural History, Smithsonian Institution, Washington D.C. Published by Prentice Hall and the American Geophysical Union.

Applicability of the PVHA: (this enclosure)

The PVHA employed a logic tree methodology to incorporate uncertainty into modeling the spatial and temporal distribution of future volcanic events in the vicinity of the Yucca Mountain site. During their individual elicitations, the experts were asked to evaluate the probability that volcanic events would ascend to shallow depths and not erupt at the surface. The DOE believes that the recurrence rates documented in the PVHA bound the probability of volcanic disruption of the repository, including the uncertainty from undetected events in the vicinity of the Yucca Mountain site and that this information is sufficient to resolve this comment.

Comment 6: Ltr. dtd. 7/10/92 Holonich to Roberts

This study plan does not appear to be calculating a "recurrence rate," but rather the average recurrence rate for the sampled population.

DOE response: Ltr. dtd. 3/9/93 Shelor to Holonich

See referenced letter.

Evaluation of DOE Response: Ltr. dtd. 2/8/94 Holonich to Shelor

- The staff agrees that the part of the issue raised in this comment has been discussed in previous publications. The staff was concerned, however, because the study plan did not appear to reflect the philosophy presented in the previous publications.

- DOE has suggested (DOE, 1993) that the problem will be resolved by using cumulative volume curves; however, the NRC staff still has concerns related to this method. The staff notes that on page 34 of the study plan it is stated that the reproducibility and uncertainty of volume calculations is not commonly considered in volcanism field studies. The staff is concerned with the manner in which this presently unquantified uncertainty will be propagated through the calculations to assure that effects of the uncertainty will not result in an under estimation of the hazard.

- The NRC staff does not consider that other investigations, such as those being conducted in geochemistry/petrology, provide an unambiguous conclusion as to the waxing/waning concerns, or to the concerns related to the proper time frame for use in averaging or projecting over the period of performance.

- The "paradox" to which the DOE refers (DOE, 1993) suggests that the choice is to site a repository in the area of either a large volcanic field or recognize that a large uncertainty will exist in the area of a small volcanic field. 10 CFR 60 recognized that siting a repository in the area of Quaternary igneous activity would make licensing more complicated than siting in an area where this phenomena need not be considered. The question that must be evaluated is whether the Yucca Mountain site can meet the performance objectives.

- The NRC staff considers this comment open.

Reference:

U.S. Department of Energy, Letter from Dwight E. Shelor of DOE to Joseph J. Holonich of NRC, Subject: Response to NRC comments and questions regarding Study Plan 8.3.1.8.1.1, March 9, 1993.

Applicability of the PVHA: (this enclosure)

The DOE believes that the recurrence rates documented in the PVHA bound the probability of volcanic disruption at the Yucca Mountain site (see response to Comment 5) and that this information is sufficient to resolve this comment.

Comment 7: Ltr. dtd. 7/10/92 Holonich to Roberts

The study plan does not appear to adequately consider models that assume volcanism is a non-poissonian process.

DOE response: Ltr. dtd. 3/9/93 Shelor to Holonich

See referenced letter.

Evaluation of DOE Response: Ltr. dtd. 2/8/94 Holonich to Shelor

- The staff recognizes the argument on the difficulty of using many of the potential "non-homogeneous poisson" or "non-poissonian" models with the limited data set available. However, the staff is concerned that, without explicit consideration of other types of mathematical models to describe the process, the possible effects resulting from igneous activity may be underestimated.

- Although the study plan and the comment response appear to consider the effects of other types of distributions, existing documents such as the "Volcanism Status Report" (Crowe et al., 1993) provide no assurance that this will be accomplished. This is evident on page 250 of the report where the argument for the homogeneous poisson model is advanced, on page 255 where the formulas for the probability calculations are developed, and on page 325 where the conclusions of the report argue for the use of the poissonian models.

- In Section 3.4 and the attachments to NRC 1993, an analysis is presented which indicates that the assumption of "homogenous poisson distributions does not appear to be supported."

- The NRC staff considers that the assumption of "homogeneous poissonian distribution" does not adequately describe the distribution of igneous features in time or space in the Yucca Mountain Region.

- The NRC staff considers this comment open.

References

Crowe, B. M, F. V. Perry, G. A. Valentine, Preliminary Draft Report Titled "Status of Volcanic Hazard Studies for the Yucca Mountain Site Characterization Project," Los Alamos National Laboratory, 1993.

U.S. Nuclear Regulatory Commission, Letter from Joseph J. Holonich of NRC to Dwight E. Shelor of DOE, Subject: Status of Volcanism Issues for the Proposed High-Level Waste Site at Yucca Mountain, August 18, 1993.

Applicability of the PVHA: (this enclosure)

The expert panel for the PVHA consider a full range of models during their deliberations, including non-poissonian processes. The probabilistic model in the PVHA assumes that the occurrence of volcanic events in a locally homogeneous zone conforms to a poisson process. Homogeneous poisson models are commonly used to represent rare events. The poisson model provides a reasonable representation of the combined effects on the contributions from multiple independent processes, including individual processes that are non-poisson in nature. The DOE considers the treatment of volcanism as a non-poissonian process in the PVHA sufficient to resolve this comment.

Comment 12: Ltr. dtd. 7/10/92 Holonich to Roberts

Bias is not necessarily reduced or limited by weighting alternative models as is implied on page 40. Use of weighted models may obscure information essential for regulatory decision.

DOE response: Ltr. dtd. 3/9/93 Shelor to Holonich

See referenced letter.

Evaluation of DOE Response: Ltr. dtd. 2/8/94 Holonich to Shelor

Refers to Comment 13 evaluation.

Applicability of PVHA: (this enclosure)

See discussion for Comment 13.

Comment 13: Ltr. dtd. 7/10/92 Holonich to Roberts

The study plan proposes to use expert judgment to weight alternative models. This is inconsistent with previous NRC comments on the Site Characterization Plan, does not necessarily reduce bias, and may reduce information essential for a regulatory decision.

DOE Response: Ltr. dtd. 3/9/93 Shelor to Holonich

See referenced letter.

Evaluation of DOE Response: Ltr. dtd. 2/8/94 Holonich to Shelor

- The DOE suggests (DOE, 1993) that the resolution of these two comments be deferred until the procedure on the use of expert judgment is available so that the concerns can be discussed in the context of calculational data.

- The staff consider Comments 12 and 13 open.

Applicability of PVHA: (this enclosure)

The proposed procedure, "Methods for Weighting Volcanic Probability Calculations Through the Use of Expert Judgment" will not be developed. Instead, Appendix A (The Use of Expert Judgment for Volcanic Hazard Assessment) was added to Revision 3 of Study Plan 8.3.1.8.1.1, (Probability of Magmatic Disruption of the Repository) to describe the general procedure for the use of expert judgment in the assessment of volcanic hazard for the Yucca Mountain site. Documentation of the results of this expert elicitation is provided in the report, "Probabilistic Volcanic Hazard Analysis for the Yucca Mountain Site." The DOE considers that the addition of Appendix A and the resulting application of the process described in Appendix A that is

documented in the PVHA provides sufficient information to resolve this comment. On June 1, 1995 the DOE provided the NRC with "Principles and Guidelines for Formal Use of Expert Judgement by the Yucca Mountain Site Characterization Office" (rev. 0) that explained the basic parameters by which formal applications of expert judgement would be conducted. The PVHA has been carried out consistent with these principles and guidelines.