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SEP 26 2002

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TRANSMITTAL OF REPORT ADDRESSING KEY TECHNICAL ISSUE (KTI) AGREEMENT ITEM IGNEOUS ACTIVITY (IA) 1.02

This letter transmits the report *Interpretation of Aeromagnetic Data,* which satisfies the subject KTI agreement. The KTI agreement states:

> IA 1.02: "Examine new aeromagnetic data for potential buried igneous features (see U.S. Geological Survey, Open-File Report 00-188, Online Version 1.0), and evaluate the effect on the probability estimate. If the survey specifications are not adequate for this use, the action is not required.
> DOE agreed and will document the results of the evaluation in an update to the AMR, *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (ANL-MGR-GS-000001), expected to be available in FY 2003."

The enclosure to this letter summarizes an evaluation of the effect of the aeromagnetic data in U.S. Geological Survey (USGS), Open File Report 00-188, as interpreted in USGS Open File Report 02-020 on the probability estimate for intersection of intersection of a dike with the repository. The enclosed evaluation is provided to satisfy the agreement item in advance of documentation in an update to the Analysis and Model Report *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (ANL-MGR-GS-000001).

The U.S. Department of Energy considers IA 1.02 to be fully addressed by the enclosed information, and pending review and acceptance by U.S. Nuclear Regulatory Commission, it should be closed.

NMSS07
WM-11

YMP-5

There are no new regulatory commitments made in the body of or the enclosure to this letter. Please direct any questions concerning this letter and its enclosure to Timothy C. Gunter at (702) 794-1343 or Eric T. Smistad at (702) 794-5073.

William Boyle for
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OL&RC:TCG-1820

Enclosure:
Interpretation of Aeromagnetic Data

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INTERPRETATION OF AEROMAGNETIC DATA

September 2002

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ENCLOSURE

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ACRONYMS AND ABBREVIATIONS

CNWRA	Center for Nuclear Waste Regulatory Analyses
DOE	U.S. Department of Energy
IA	igneous activity
KTI	key technical issue
mm	millimeter
MTU	metric ton of uranium
NRC	U.S. Nuclear Regulatory Commission
PVHA	Probabilistic Volcanic Hazard Analysis
yr	year

INTERPRETATION OF AEROMAGNETIC DATA

This report describes the basis to resolve and close agreement item igneous activity (IA) 1.02, associated with the probability subissue of the igneous activity key technical issue (KTI). The item in question stems from the agreement between the U.S. Department of Energy (DOE) and the U.S. Nuclear Regulatory Commission (NRC) that the DOE evaluate the effects of the aeromagnetic data (described in Blakely et al. 2000) on the volcanic probability estimate (Reamer and Williams 2000).

The interpretation of the aeromagnetic data (O'Leary et al. 2002) indicated that several of the magnetic anomalies are likely to be buried basaltic centers. Although the experts considered some of these interpreted buried centers during the elicitations supporting the Probabilistic Volcanic Hazard Analysis (PVHA) (CRWMS M&O 1996), a number of the anomalies identified in the recent aeromagnetic data were not considered in the PVHA. The DOE expert elicitation procedure includes requirements to evaluate the effects of new information on elicitation results.

1. BACKGROUND

The PVHA provides the basis for DOE volcanic hazard assessments at Yucca Mountain. The PVHA is documented in CRWMS M&O (1996) and summarized in CRWMS M&O (2000). The PVHA is based on the number and spatial distribution of volcanic events in the Yucca Mountain area that occurred during the past 10 million years (CRWMS M&O 2000, Section 6.2). One of the factors that experts considered for the development of the PVHA was the presence of buried basaltic volcanic centers. In general, the experts considered buried centers in two ways. First, several magnetic anomalies were identified in aeromagnetic surveys conducted prior to the PVHA (Langenheim et al. 1993) (see CRWMS M&O 2000, Figure 3). One of these was confirmed to be buried basalt with an age of 3.85 million years, and several others were interpreted to have characteristics indicative of buried basaltic volcanic centers (Langenheim et al. 1993). The PVHA experts included these confirmed and interpreted buried volcanic centers in developing their interpretations of the number of volcanic events that have occurred in the Yucca Mountain region. Second, in their estimates of rate of occurrence of volcanic events, the PVHA experts included an allowance for undetected events that resulted in an increase in the rate of events by 10 to 500 percent. The allowances for undetected events, buried volcanic events, or intrusive events that never reached the surface, are described in *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000, Section 6.3.1.5).

1.1 NRC INITIAL COMMENTS

The NRC has questioned the basis for the event counts in the PVHA and has suggested on several occasions that the experts' source zones were incorrectly and inconsistently constructed and did not include adequate consideration of buried magnetic anomalies and undetected volcanic centers. The NRC has also suggested that the PVHA expert panel should be reconvened to give the experts an opportunity to consider new information and revise their event counts and definitions of source areas.

Furthermore, the NRC has maintained that the PVHA underestimated the number of volcanic events that have occurred in the Yucca Mountain region and that the hazard, therefore, has been underestimated.

1.2 DOE INITIAL COMMENTS

The DOE has responded to the NRC questions by noting that the PVHA estimates are valid. These estimates represent a wide diversity of scientific opinion and, because they include allowances for hidden events, expressly account for potential increases in event counts that might occur based on new information about potential buried basalt centers. The DOE agreed to examine new aeromagnetic data for potential buried igneous features (e.g., *Aeromagnetic Survey of the Amargosa Desert, Nevada and California: A Tool for Understanding Near-Surface Geology and Hydrology*, Blakely et al. 2000) and evaluate the effect on the probability estimate (Reamer and Williams 2000).

The DOE sponsored an interpretation of the aeromagnetic data, and that interpretation is documented in *Aeromagnetic Expression of Buried Basaltic Volcanoes Near Yucca Mountain, Nevada* (O'Leary et al. 2002). The DOE then examined the effects of the new interpretation on the probability estimate, and the results of that examination are summarized in this report.

1.3 STATEMENT OF DIFFERENCES

The NRC maintains that the DOE hazard estimate did not adequately consider hidden events, that it has underestimated the number of volcanic events that occurred near Yucca Mountain, and, therefore, that it has underestimated the volcanic hazard. The NRC has stated that sensitivity-type analyses are not appropriate to examine the effects of the aeromagnetic data on the hazard estimate.

In addition, recent work by the Center for Nuclear Waste Regulatory Analyses (CNWRA) suggests that three times the number of basaltic volcanoes could be present in the Yucca Mountain region than was previously recognized (Hill and Stamatakos 2002). The CNWRA maintains that the uncertainty in the number of volcanoes could increase the volcanic hazard probability and suggests that an update to the volcanism expert elicitation may be necessary to support licensing. Additional discussion of the CNWRA report is provided in Section 3.

Conversely, the DOE has examined its estimates of the number of volcanic events and the hazard estimate. The DOE considers that the analysis provided below is adequate to examine the effects of the aeromagnetic data on the hazard estimate.

1.4 DEFINITION OF TECHNICAL TERMS

Aeromagnetic data–Information collected by an airborne device used to measure variations in the earth's magnetic field.

Basalt–A dark-colored, hard, dense, fine-grained volcanic rock.

Volcanic event–An occurrence of surface and near-surface igneous activity characterized by the development of intrusive (e.g., dikes) and extrusive (e.g., lava flow and cone) features (CRWMS M&O 1996, Section 1).

Volcanic center–Localization of surface or near-surface igneous activity such that extrusive or shallow intrusive features develop (e.g., Lathrop Wells volcanic center consisting of the Lathrop Cone and associated lava flows, tephra deposits, and feeder dikes). One or more volcanic centers may be associated with a volcanic event.

2. APPLICABLE NUCLEAR SAFETY STANDARDS AND REQUIREMENTS GUIDANCE

2.1 APPLICABLE REQUIREMENTS

The Yucca Mountain disposal regulations include requirements to include data related to the geology, hydrology, and geochemistry (including disruptive processes and events) of the Yucca Mountain site and the surrounding region (10 CFR 63.114(a)). 10 CFR 63.114 requires consideration of events that have at least one chance in 10,000 of occurring over 10,000 years. The volcanic hazard has been estimated to be slightly above the threshold for consideration, and this requirement is the basis to include evaluation of igneous scenarios in the total system performance assessments. Finally, 10 CFR 63.114(g) requires the DOE to provide the technical basis for models used in the performance assessment. The probability of future volcanic activity is used to weight the dose estimate for demonstrations of compliance. Hence, the model used to estimate the probability of future volcanic activity is a key component for performance assessment analyses related to igneous activity. Section 3 provides information related to the technical basis for the recurrence rate used to develop the estimate of the probability of future igneous activity.

2.2 KTI AGREEMENT

The following KTI agreement statement is based on Summary Highlights of the NRC/DOE Technical Exchange and Management Meeting on Igneous Activity that was held August 29–31, 2000 (Reamer and Williams 2000), as modified in the Summary Highlights of the NRC/DOE Technical Exchange and Management Meeting on Igneous Activity held September 5, 2001 (Krier 2001):

> Examine new aeromagnetic data for potential buried igneous features (see U.S. Geological Survey, Open-File Report 00-188, Online Version 1.0), and evaluate the effect on the probability estimate. If the survey specifications are not adequate for this use, the action is not required.
>
> DOE agreed and will document the results of the evaluation in an update to the AMR, Characterize Framework for Igneous Activity at Yucca Mountain, Nevada (ANL-MGR-GS-000001), expected to be available in FY 2003.

2.3 STATUS OF AGREEMENT

The DOE completed an evaluation of the aeromagnetic data (O'Leary et al. 2002) that increased the number of potential buried basaltic volcanic centers in the Yucca Mountain region. The DOE also agreed to evaluate the effect of the increased number of potential buried centers on the volcanic hazard estimate. The results of that evaluation are summarized in Section 3.2 and will be documented in an update to *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000).

3. BASIS FOR REGULATORY COMPLIANCE STATEMENT

Aeromagnetic anomalies seen in aeromagnetic data gathered by the U.S. Geological Survey in 1999 suggest the possibility that a number of basaltic volcanic centers are buried beneath alluvium in Crater Flat and the northern Amargosa Desert (Blakely et al. 2000; O'Leary et al. 2002; Hill and Stamatakos 2002). Interpretation of these data indicates that 20 to 24 aeromagnetic anomalies occur within Crater Flat and the northern Amargosa Desert that could represent buried basaltic volcanoes (O'Leary et al. 2002; Hill and Stamatakos 2002). In comparison, eight aeromagnetic anomalies were thought to possibly represent basalt at the time of the PVHA.

This report summarizes the methodology and results of an evaluation used to determine the effect of the possible presence of buried volcanic centers on the results of the PVHA.

3.1 APPROACH

Evaluation of the effect on the probability estimate from potential buried volcanic centers requires an estimate of the age of possible buried centers and an assessment of the likelihood that anomalies or groups of anomalies represent buried basaltic volcanic centers.

The probable age range of potential buried volcanic centers was estimated by using a range of calculated sedimentation rates in Crater Flat and the Amargosa Valley and the modeled depth of anomalies from *Aeromagnetic Expression of Buried Basaltic Volcanoes Near Yucca Mountain, Nevada* (O'Leary et al. 2002). For two cases, the basalt in Crater Flat encountered in drillhole VH-2 and the basalt of Anomaly B, sedimentation rates were calculated by dividing the known depth (from drilling) of the buried basalt by the measured age of the basalt. These calculations give sedimentation rates of 0.03 and 0.04 mm/yr, respectively. A third case, Little Cones, has buried flows that have been characterized by ground magnetic surveys (Stamatakos et al. 1997). Using a modeled depth to the top of the flows of 15 meters (Stamatakos et al. 1997), a flow thickness of 10 meters, and a measured age of 1 million years, the calculated sedimentation rate is 0.025 mm/yr. These results suggest that sedimentation rates can be estimated to within a factor of two within Crater Flat and the Amargosa Valley over the past several million years.

Using the range of calculated sedimentation rates discussed above and the modeled burial depth of anomalies (O'Leary et al. 2002), minimum and maximum ages were estimated for individual anomalies. Maximum ages for anomalies range from 2.5 to 8.3 million years, and minimum ages range from 1.25 to 6.25 million years. The exception to this age range is Anomaly T, which was estimated to be approximately 11 million years in age. Consideration of magnetic polarity

data adds another age constraint, and a "most likely" age was chosen for each anomaly within the age range estimated for that anomaly. This approach leads to most likely ages for the anomalies that range from 2.6 to 6.3 million years. All age ranges represent minimum ages (and, thus, are conservative for the purposes of volcanic hazard analysis) because they do not account for the thickness of the basalt bodies in calculating the depth of sediments deposited after basalt was emplaced.

The PVHA experts made evaluations of the likelihood that the magnetic anomalies identified at that time represented buried volcanic centers. An individual expert's confidence that an anomaly represented buried basalt generally depended on the expert's interpretation of the shape, magnetic signature, and geologic setting of the anomaly (CRWMS M&O 1996). O'Leary et al. (2002) and Hill and Stamatakos (2002) used similar criteria to rank their confidence that the 20 to 24 anomalies identified in their reports represent buried basalt using a scale of one to four (O'Leary et al. 2002) and high, medium, and low (Hill and Stamatakos 2002). Qualitatively, the rankings used in these two reports lead to similar conclusions regarding scientific confidence that particular anomalies represent buried basalt. The number of aeromagnetic anomalies identified in these reports that may represent buried basalt depends upon the resolution of the aeromagnetic data. Hill and Stamatokos (2002) suggest that basaltic features with areas smaller than 1 km^2 are generally undetectable using the data presented in *Aeromagnetic Expression of Buried Basaltic Volcanoes Near Yucca Mountain, Nevada* (O'Leary et al. 2002). The issue of data resolution and detectibility of volcanic features using aeromagnetic data will be discussed in more detail in future revisions of *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000).

The potential impact of the aeromagnetic data on the probability of igneous disruption of the proposed repository was assessed by developing distributions for the number of volcanic events represented by the anomalies, assigning these events to the volcanic sources defined by the experts in the 1996 PVHA, and calculating the annual frequency of intersection of the proposed repository footprint. The distributions for the number of volcanic events were developed by the authors of this letter report using the tendency of each expert to group or not group aligned anomalies into single or multiple volcanic events. Two cases were developed. In the 1996 PVHA, the experts did not consider all of the anomalies identified at that time to be buried volcanic centers. Instead, to varying degrees, they factored the likelihood that the anomalies represented buried volcanic centers into their assessments of the number of volcanic events that have occurred. Case 1 for this study was developed to be consistent with this approach. The distributions for the number of volcanic events represented by the magnetic anomalies for Case 1 were developed by the authors of this letter report using the qualitative likelihoods that the anomalies represent buried volcanic centers discussed above and using each expert's tendency for including anomalies with various levels of confidence into those experts' distributions for volcanic events. In Case 2, all anomalies were assumed to be buried volcanic centers, and the distributions for the number of volcanic events were developed by the authors of this letter report based only on each expert's tendency for grouping aligned volcanic centers into events.

3.2 SAFETY AND TECHNICAL BASES FOR THE COMPLIANCE DEMONSTRATION

The PVHA experts considered the time period of interest for computing the rate of volcanic events in the Yucca Mountain region to range from the past 1 million years to the past 10 million years, with the most likely time period to be the past 4.5 to 5 million years. With the exception of Anomaly T, the age estimates for the anomalies generally fall within the past 6 million years. For purposes of these sensitivity analyses, it was assumed that the ages of 22 anomalies (A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, 1, 2, 3, and 4) fall within the past 4.5- to 5-million-year time period. The age of Anomaly T was assumed to fall within the past 9- to 10-million-year time period. Two of the PVHA experts considered a time period of the past 2 million years. The range in age estimates for Anomalies O, 1, and 2 overlaps the 2-million-year time period, and, for these sensitivity analyses, these anomalies were given a 50 percent probability of being less than 2 million years in age.

Table 1 lists the results of the sensitivity analyses in terms of the mean number of volcanic events occurring within the time period used by the experts to define the rate of volcanic events. For those experts who considered a 5-million-year time period, the sensitivity analyses indicate an approximate 50 percent increase in the mean number of events for Case 1 (which incorporates the likelihood that the anomalies represent buried volcanic centers) and an approximate 100 percent increase in the mean number of events for Case 2 (which assumes that all of the anomalies represent buried volcanic centers).

Table 1. Comparison of Mean Number of Volcanic Events for 1996 PVHA Assessment with Sensitivity Analysis Values

Expert[1]	Time Period					
	Quaternary			Plio-Quaternary		
	1996	Case 1[2]	Case 2[2]	1996	Case 1[2]	Case 2[2]
AM	-	-	-	14.5	21.8	27.2
BC	-	-	-	16.7	24.0	29.7
GT	-	-	-	14.5	22.3	29.0
GW	-	-	-	14.8	22 8	30.6
MK	4.1	4 6	5.6	11.1	17.9	25.6
MS	-	-	-	14.4	24.5	25.6
RC	-	-	-	12.0	18.5	24.4
RF	4 4	5.1	5.9	-	-	-
WD	6.6	6.6	6.6	-	-	-
WH	-	-	-	15.7	18.4	30.4
Average	5.0	5.4	6 0	14.2	21.3	27.8

NOTES:

1. AM = Alexander McBirney ; BC = Bruce Crowe ; GT = George Thompson; GW = George Walker; MK = Mel Kuntz; MS = Michael Sheridan; RC = Richard Carlson; RF = Richard Fisher; WD = Wandell Duffield; WH = William Hackett.
2. Case 1 and Case 2 were developed by the authors of this letter report based on the 1996 PVHA experts' preferences for grouping aligned volcanic centers into volcanic events.

For the two experts who considered a 2-million-year time period, the sensitivity analyses result in increases of 10 and 20 percent for Case 1 and Case 2, respectively. Duffield considered only a 1-million-year time period but assigned low probabilities that some of the anomalies are less than 1 million years in age. Applying this assessment to the larger population of anomalies results in less than a 1 percent increase in the mean number of volcanic events.

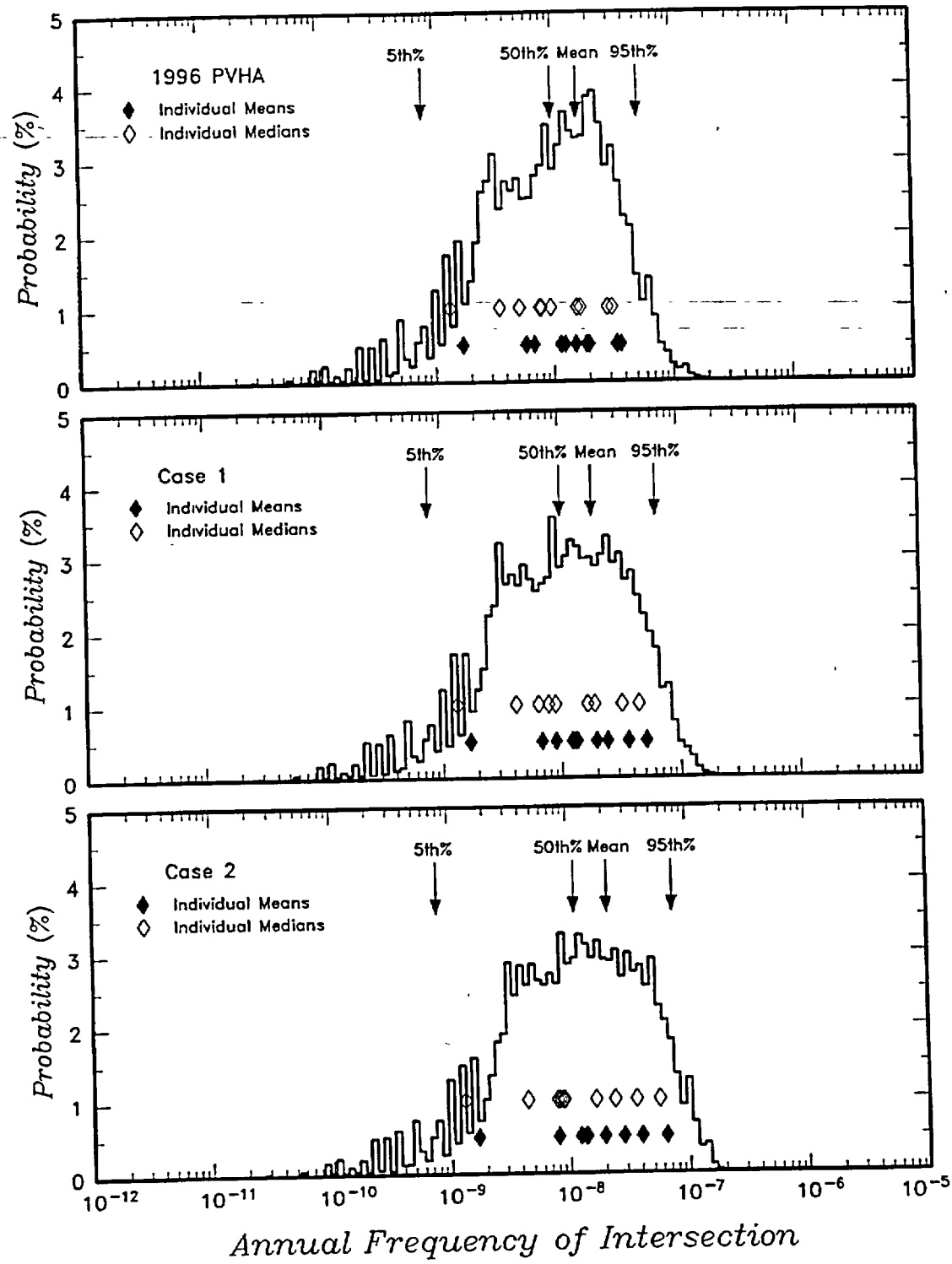
For each expert in this sensitivity study, the distributions for the number of volcanic events developed were assigned to the appropriate volcanic sources defined by the PVHA experts. In general, the magnetic anomalies lie within or slightly to the west of the experts' Crater Flat and Amargosa Valley sources. Therefore, for these sensitivity analyses, the volcanic events represented by the magnetic anomalies were assigned to the experts' Crater Flat and Amargosa Valley sources (i.e., source zones, Gaussian fields, kernel density functions), rather than to larger background source zones.

Figures 1 and 2 show the results of the sensitivity analyses in terms of the computed distributions for the frequency of intersection of the proposed repository footprint by a basaltic dike. The footprint used for these analyses is the 70,000-MTU no-backfill repository layout (primary-plus-contingency blocks) used in the characterization of igneous framework (CRWMS M&O 2000). The results are summarized in Table 2. The volcanic event count distributions developed for sensitivity Case 1 result in a 22 percent increase in the mean annual frequency of intersection, and those for sensitivity Case 2 result in a 40 percent increase. The increase in the frequency of intersection is less than the increase in the mean number of volcanic events because the additional events are located in the more active volcanic sources to the west of the site. As indicated in Figure 17 of *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000), a significant portion of the volcanic hazard results from the occurrence of volcanic events near or to the northeast of the proposed repository, areas in which the estimated rate of volcanic events is not greatly affected by inclusion of the additional magnetic anomalies in the volcanic event count distributions.

This sensitivity will be documented in future revisions of *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (CRWMS M&O 2000), using the license application proposed repository footprint. The report will also document an evaluation of the need for revised PVHA inputs to the TSPA based on the aeromagnetic data.

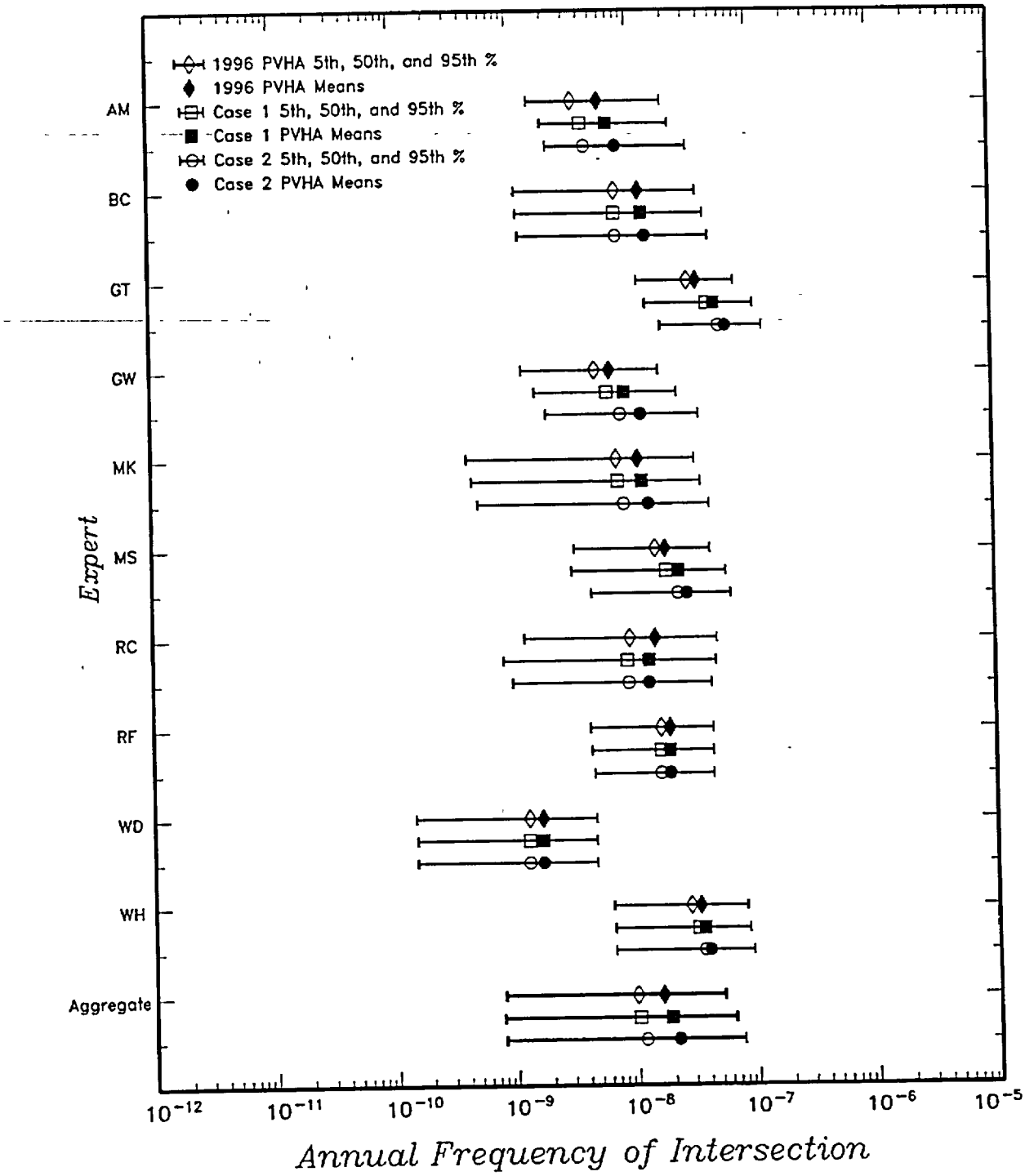
Table 2. Summary of Computed Frequency of Intersection for 70,000-MTU Primary-plus-Contingency Blocks

Input Parameters	Annual Frequency of Intersection			
	5th percentile	50th percentile	Mean	95th percentile
1996 PVHA	7.9E-10	9.8E-09	1.6E-08	5.2E-08
Sensitivity Case 1	7.8E-10	1.0E-08	1.9E-08	6.5E-08
Sensitivity Case 2	7.9E-10	1.1E-08	2.2E-08	7.6E-08



NOTE: Results labeled 1996 use the PVHA volcanic event counts; results labeled Case 1 and Case 2 use the volcanic event counts developed in this sensitivity analysis

Figure 1. Composite Annual Frequency of Intersection of the Proposed Repository Footprint for the Primary-plus-Contingency Block Case of the 70,000-MTU No-Backfill Layout



NOTE: Results labeled 1996 use the PVHA volcanic event counts; results labeled Case 1 and Case 2 use the volcanic event counts developed in this sensitivity analysis.

Figure 2. Individual Expert Results for Annual Frequency of Intersection of the Proposed Repository Footprint for the Primary-plus-Contingency Block Case of the 70,000-MTU No-Backfill Layout

4. REFERENCES

4.1 DOCUMENTS CITED

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4.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

10 CFR 63. Energy: Disposal of High-level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. Readily available.