TESTING OF SEISM 1.1: SENSITIVITY ANALYSIS

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PREVIOUS REPORTS IN SERIES

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ABSTRACT

A previous SEISM 1.1 analysis using published data from the Yucca Mountain region was recalculated with the addition of one and two background seismic zones. A background seismic zone was not used in the initial analysis. Reasonable assumptions about background zones are potential subjects of expert opinion. For this reanalysis, only two sets of assumptions were used with several permutations. Expert opinions were not formally elicited. In the reanalysis, most fault sources were assumed not to generate earthquakes less than magnitude 5.8 because earthquakes below this magnitude are usually not associated with known faults in the western Basin and Range tectonic province unless they are aftershocks of larger earthquakes. The *a*-values used in the analysis derived from the number of magnitude 4 earthquakes in the literature were mostly based on Quaternary fault information rather than historical seismicity. The average recurrence relation *a*-value for all faults used by each pseudoparticipant of the original analysis was used as the best estimate for each pseudoparticipant's background zone *a*-value for the single background zone model. The background zone was assumed to have magnitude 4 to 5.7 earthquakes occurring randomly within it. There are two categories of experts, those who included large distant faults capable of very large earthquakes, and those who believe that such faults are too distant to affect hazard at Yucca Mountain. The *a*-values, which dictate the level of earthquake activity, are higher for those experts who included the more distant large faults in the original calculation. These high *a*-values suggested that a background zone local to Yucca Mountain may have a lower seismic activity rate than used in this study, which included some expert opinions regarding distant large faults. A test of this hypothesis is made by a second computation in which two background zones are specified. Initially, each computation had a background *a*-value that is equal to the sum of all the *a*-values used for the faults the background zone enclosed. The sum of *a*-values for the background zone enclosing the Death Valley-Furnace Creek and Owens Valley fault zones was exceedingly high because of paleo-activity determinations. SEISM 1.1, operating on a Sun Workstation, could not manage the large number of calculations required, probably because of limited storage and memory. Subsequently, the exceedingly high *a*-value was arbitrarily reduced by one half but still remained high. This calculation did not change the 50th constant percentile acceleration, but it did increase the 85th and 95th percentile accelerations. Quaternary activity based upon fault dimension information may differ from historic seismic activity. Adding the background seismicity zone had little effect on 50th constant percentile hazards with the exception of the 10^{-2} per year hazard. A background seismic zone defined differently is likely to have a different effect on the resultant hazard. Regional recurrence relationships are observed to be linear with respect to magnitude. Recurrence relationships on a fault plane are rarely known. They cannot be specified as linear in probabilistic seismic hazard analysis if a linear regional recurrence is to be preserved. The sensitivity of probabilistic seismic hazard analysis accuracy to the usual practice of assigning all faults and a background zone with linear recurrence relationships is beyond the scope of this study, but such a study is recommended. Approximately 50 pages of input data require modification to produce calculations that include a background zone. The calculation was nearly identical to the original one without a background zone.

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LIST OF ACRONYMS, SYMBOLS, AND NONSTANDARD TERMS

a	The intercept or level of activity term for an earthquake recurrence function
ACRS	Advisory Committee on Reactor Safety of the Nuclear Regulatory Commission
Ave.	Average
b	The slope term for an earthquake recurrence function
BE	Best estimate
CDS	Compliance Determination Strategy
CFR	Code of Federal Regulation
cm	Centimeter
CNWRA	Center for Nuclear Waste Regulatory Analyses
CP	Constant percentile
CPHC	Constant percentile hazard curve
DOE	U.S. Department of Energy
DWM	Division of Waste Management of the NRC
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
EUS	Eastern United States
g	Gravitational constant - 980 cm/s^2
GS	Geologic Setting Element of the CNWRA
HLW	High-Level Nuclear Waste
KTU	Key Technical Uncertainty
LLNL	Lawrence Livermore National Laboratory
M	Magnitude — a measure of earthquake size. In this document, M represents Richter magnitude defined as M_L to 6.5, M_S from 6.6 to 8, and M_W for 8+

LIST OF ACRONYMS, SYMBOLS AND NON STANDARD TERMS (Cont'd)

M_L	Richter local magnitude
M_{max}	Maximum magnitude
M_{min}	Minimum magnitude
M_S	20-s surface wave magnitude
M_W	Moment magnitude
N_4	Number of earthquakes of M=4 and greater
N_C	Number of earthquakes equal to or greater than a specified magnitude, C
NMSS	Office of Nuclear Material Safety and Safeguards of the Nuclear Regulatory Commission
NPP	Nuclear power plant
NRC	Nuclear Regulatory Commission
NRR	Nuclear Regulatory Commission Office in Nuclear Reactor Regulation
NTS	Nevada Test Site
NWTRB	Nuclear Waste Technical Review Board - oversight board for DOE
PA	Performance Assessment
PFD&SHA	Probabilistic fault displacement and seismic hazard analysis
Pseudoparticipant	An artificial expert whose opinions are derived from published literature
PSHA	Probabilistic seismic hazard analysis
s	Second (of time)
SEISM 1.1	CNWRA western U.S. version of the LLNL-NRC/NRR SEISM 1 code (also called SHC or SHC software)
SHC	Seismic Hazard Characterization — also Seismic Hazard Codes (of LLNL)
YM	Yucca Mountain

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This report is in fulfillment of Geologic Setting (GS) Element Subtask 2.5 of subtask 2: Analysis of Codes and Methods in Center for Nuclear Waste Regulatory Analyses (CNWRA) FY95 Operations Plans Rev 4 Chg 2, Intermediate Milestone 20-5702-425-501: Letter Report on Testing SEISM 1.1 Sensitivity.

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This report was prepared to document work performed by the CNWRA for the NRC under Contract NRC-02-93-005. Activities reported here were performed for the NRC NMSS, Division of Waste Management (DWM). This report is an independent product of the CNWRA and does not necessarily reflect the views or regulatory position of the NRC. Opinions expressed are intended to apply only to the application of probabilistic seismic hazard analysis (PSHA) codes to a high-level nuclear waste (HLW) repository.

QUALITY OF DATA, ANALYSIS AND CODE DEVELOPMENT

DATA: Data used in this report were obtained from published literature or provided by the Lawrence Livermore National Laboratory (LLNL) with the SEISM 1 code. These data have not been quality assured by the CNWRA. Sources for the data should be consulted for determining the level of quality for those data.

ANALYSES AND CODES: The SEISM 1.1 computer code was used in this analysis. Development of SEISM 1.1 is described in Report CNWRA 94-014, however, the code has not been sufficiently developed to be placed under the CNWRA Configuration Management System.

1 INTRODUCTION

Probabilistic seismic hazard analysis software developed by the Lawrence Livermore National Laboratory (LLNL) for the Nuclear Regulatory Commission's (NRC) Seismic Hazard Characterization (SHC) of the eastern United States was acquired and modified by the Center for Nuclear Waste Regulatory Analyses (CNWRA) to operate for sites in the western United States. This modified software is designated as SEISM 1.1. A test computation was made with published data pertinent to the proposed Yucca Mountain (YM) high-level nuclear waste (HLW) repository (Hofmann, 1994). Difficulties with completing this calculation resulted in exceeding the resource requirement estimates. Sensitivity studies for various inputs to the calculation had been proposed. This report documents the sample sensitivity analysis performed to determin resourse requirement. The sample analysis chosen was to add a background seismic zone to the previous calculation to determine the sensitivity of hazard to the addition of a background zone. Several configurations were possible. Other sensitivity analyses would require substantially fewer resources than the analysis chosen.

1.1 PURPOSE

To plan for possible future code development tasks, it was necessary to determine the resources needed to perform a typical sensitivity analysis of changed input parameters for a SEISM 1.1 calculation, at the proposed YM HLW repository, using published data. A byproduct of the analysis is an estimate of the sensitivity of calculated seismic hazard to the addition of a background zone having several possible configurations. A background seismicity zone is called a "complementary" zone in SHC-related publications by LLNL (e.g. Bernreuter et al., 1989). A background seismicity zone is assumed to have randomly occurring seismicity from low-magnitude earthquakes.

SEISM 1.1 uses expert opinions. Experience in developing input files will facilitate future possible hazard analyses to determine the effect of proposed seismic or tectonic model changes in the course of the licensing process.

The NRC has requested that both deterministic and probabilistic methods be used in licensing an HLW repository. The U.S. Department of Energy (DOE) has stated that it will use probabilistic seismic hazard methodologies for application to a potential YM HLW repository, e.g. (Sullivan 1994; Quittmeyer 1994; Kennedy et al. 1990; and U.S. Department of Energy, 1988). The NRC staff will be required to evaluate DOE results. The DOE view (e.g. Quittmeyer, 1994) is that deterministic analysis will comprise a disaggregation of the multiple-expert probabilistic seismic hazard analysis (PSHA) with identification of the principal contributor(s) to a prescribed (by DOE) hazard level. Therefore, the selection of the earthquake to be used in the deterministic analysis appears to be a property of the multiple-expert PSHA and the selected hazard level. Details of these intended procedures are subject to change. The NRC/Division of Waste Management (DWM) does not have a probabilistic code with which to make independent hazard analyses for western U.S. sites. The purpose of probabilistic fault displacement and seismic hazard analysis (PFD&SHA) efforts at the CNWRA is to provide an updated computer code, SEISM 1.1, to permit the NRC staff to evaluate the DOE PFD&SHA submittals. Exercising the code will aid in determining if probabilistic methods employing expert opinion to fault displacements and earthquakes can effectively support an HLW repository license application for a western U.S. site. The schedule for repository investigation, construction, and license review requires that tools for analyzing PFD&SHA be quickly available.

An expert-opinion based methodology is desirable because the short period of historic seismicity requires that paleo-fault data be used for projections of seismic activity for time periods as long as 10,000 yr. Interpretation of such data has been the subject of debate among professionals in this technical area, for example, see the opinions of Arabasz, Bell, Rogers, Slemmons, Swan, Whitney, and Wong in Electric Power Research Institute (1993) and of Somerville et al. (1987).

Concern with repository siting criteria, particularly potentially adverse conditions [see 10 CFR 60.122(c)(12-14)] and specific references to earthquakes was the primary motivation for initiation of this project. Other sections of 10 CFR Part 60 that also relate to or allude to seismic and related concerns are:

- Content of Application, Safety Analysis Report, Description and assessment of the site [60.21(c)(1)(i)(A) and (B), and (ii)(A) and (C)]
- Permanent Closure [60.51(a)(3)]
- Additional design criteria for the underground facility [60.131(b)(1)]
- Performance Confirmation and Processing Pertaining to the Geologic Setting, General requirements, parameters and processes pertaining to the geologic setting; [60.140(d)(2)]
- Confirmation of geotechnical and design parameters, rock deformations and displacement [60.141(c)]

Hofmann (1992c) has a more thorough discussion of the applicable sections of 10 CFR Part 60 that were of concern upon initiation of this project by the NRC/DWM.

Environmental Protection Agency (EPA) requirements for radionuclide releases are in probabilistic terms in its currently remanded regulation and in proposed revisions. The NRC 10 CFR Part 60 regulations include the EPA regulation by reference. By inference, the probabilities of exceeding design criteria and consequent effects on radionuclide release must be known. PFD&SHA methodologies provide a means of estimating the first of these probabilities. Seismic risk and probabilities of fault displacement presented in a license application or in hearings must be analyzed by regulatory staff. The SEISM 1.x codes (also referenced as SHC software), after adaptation to HLW repository requirements, are a means of performing such analyses. The efforts described in this report have the purpose of providing a version of the SEISM code that can be efficiently used for such analyses.

An exploration of the concept of PFD&SHA, as it applies to the much longer times of performance concern for an HLW repository, was deemed prudent if not critical to meet the limited 3-yr license review time for an HLW repository required of the NRC.

Compliance Determination Strategies (CDSs) were developed by the NRC and the CNWRA for the earthquake-related potentially adverse conditions. Key Technical Uncertainties (KTUs) were found for several of the earthquake related potentially adverse conditions. Where such uncertainties existed, NRC research and independent analyses are anticipated to be required to resolve related licensing issues before submission of the license application.

CDSs corresponding to 10 CFR 60.122(c)(12-14) address: (i) Historical earthquakes, (ii) More-frequent/higher magnitude earthquakes, and (iii) Correlation of earthquakes with tectonic processes. KTUs as described in these CDSs are:

- "The inability to predict the likelihood of earthquake occurrence over the next 10,000 yr."
- "Paleofaulting data indicate that seismic activity has migrated randomly from one major range front fault system to another in the Basin and Range tectonic province. Therefore, there is considerable uncertainty that the relatively low seismicity at YM will continue over a 10,000-yr period."
- "Many fault plane solutions from the historical seismic record do not agree with the fault movement indicated by striae (slickensides) on exposed fault planes; therefore fault movement, earthquake strong motions and their radiation patterns, which will be used in tectonic models, are uncertain."
- "Correlation of Earthquakes with Tectonic Processes" (*the lack thereof*).

Other KTUs, applicable to a broad range of CDSs whose uncertainty may be at least partially quantified through PFD&SHA, are:

- "Predicting long-term performance of seals for the underground test boreholes"
- "Variability (temporal, spacial, etc.) in model parametric values"
- "Prediction of future system states (i.e., disruptive scenarios)"

The reasons for research or independent analysis to reduce or quantify uncertainties are summarized in the CDS for correlation of earthquakes with tectonic processes:

(1) Quantitative knowledge about tectonic processes, including the ability to predict the occurrence of earthquakes for the next 10,000 yr or the ability to correlate earthquakes with known structures, in the YM area is, and will most likely remain, uncertain;

(2) Alternative conceptual models for tectonic processes will remain at the time of licensing;

(3) The alternative models for addressing both the probability of tectonic activity and potential effects from this activity may span several orders of magnitude;

(4) There is no proven method for extrapolating relatively short-term seismic data and experience to the long-performance periods (i.e., 10,000 yr) required for a geologic repository; and

(5) The effects of tectonic activity on the ability to demonstrate compliance with the overall system and subsystem performance objectives will be highly contentious during licensing.

These items all lie at the cutting edge of current technology, yet are critical to licensing the nation's first HLW repository. It is expected that DOE, in the process of developing its license

application, will address these subjects. However, because these uncertainties are at the state-of-the-art in their resolution and are contentious among well-qualified investigators, the NRC must be cognizant of and capable of addressing these technical areas. Methods and tools (e.g. computer codes) capable of assessing whatever arguments are presented by the licensee and those in opposition, with the goal of facilitating a licensing review within the allotted 3-yr period of time, are of potential benefit.

A method of quantifying uncertainties in data interpretation by well-qualified experts is needed. Such a process (PSHA) was used in the eastern U.S. SHC. This method requires the elicitation of expert opinions regarding the interpretation of available or reasonably obtainable data and its application in a probabilistic analysis system that is known to function properly. Without a probabilistic seismic and fault displacement analysis tool and experience in using it to analyze the considerable data being developed by DOE, NRC staff may be less effective in developing and presenting their findings.

Investigation of probabilistic methods is important to a timely resolution of geoscience licensing concerns. A concerted effort is required to ensure that probabilistic methodologies are properly framed and developed for the unique conditions of a permanent HLW repository. Research regarding PSHA for the NRC Office of Nuclear Reactor Regulation (NRR), the DOE and the Department of Defense (DOD) should be followed to assure that it is available to the repository licensing activity and that its impact on potential licensability is assessed. Efforts must begin early to identify uncertainties that are particularly large and cannot be reduced without concerted research efforts. PSHA tools (computer codes and elicitation methodologies) are in a formative stage. They have been applied primarily to estimating hazards at facilities with expected lifetimes of only a few decades. Application of PFD&SHA to an HLW repository presents new problems that require technical effort to resolve.

The efforts described in this report are preliminary attempts to apply and investigate probabilistic tools in their application to much longer term nuclear hazards. The entire spectrum of probabilistic input and analysis methods, geoscientific data including seismology, and computer modeling of tectonic and dynamic earthquake-generating processes, must be approached from the standpoint of a long-term (e.g., 10,000 yr) hazard to the public. This effort cannot be performed only by the license applicant. Because of its state-of-the art content, it must be understood by the regulator who must anticipate how to resolve such issues from the point-of-view of all parties at a licensing hearing.

1.2 BACKGROUND

LLNL developed SEISM 1 for the NRC NRR Seismic Safety Margins Research Program. The code was later modified to evaluate probabilistic seismic risk for central and eastern U.S. nuclear power plants (NPP). Observed data, or their average plus deviations, and a range of expert opinions are input to the code. Expert self assessments of uncertainty in their estimated input parameters are also used in the calculations. Resulting hazards are aggregated to provide final hazard curves for the arithmetic mean, best estimate data only, and for various constant percentile hazards.

PSHA has been applied to NPPs with much shorter nominal life spans than an HLW repository. CNWRA tasks have been to determine the basis in current regulations for performing probabilistic analyses, to modify SEISM 1 for western U.S. locations, and also to calculate probabilistic fault displacements. A work plan and a series of nine reports document work to date. This report is the tenth in the series. Resources to reach the test analysis computation goal with SEISM 1.1 were underestimated. Consequently, this task, to perform one sensitivity study of significant difficulty, was undertaken to better

estimate potential future resource requirements. This report documents the sensitivity of calculated seismic hazard to the addition of a background seismic zone.

1.3 SUMMARY

A background zone, which encompassed the published fault sources used in Hofmann (1994), was added to the PSHA calculation of seismic hazard at YM. Earthquakes generated by the fault sources were limited to M=5.8 or greater unless the fault was insufficiently large to generate earthquakes of that magnitude. This scheme was adopted because earthquakes of 5.7 or lower only rarely cause visible fault offset at the surface in the Basin and Range tectonic province. For the few faults in this category, magnitudes were limited to the maximum magnitude that the fault could generate. A second background zone calculation used two background zones, one for near-site background and a separate one for higher activity more distant faults like the Death Valley - Furnace Creek and Owens Valley faults.

Earthquakes were assumed to occur randomly throughout the zones. For the first computation, background seismicity was set to the average rate for each expert's fault zones. As in the Hofmann (1994) calculation, all rates (*a*-values of the recurrence relation) were based on the Somerville et al. (1987) estimates of the number of M=4 earthquakes (N_4) that could occur at each fault, and an average *b*-value of 0.91. The eight pseudoparticipants all chose different faults as being important in the determination of hazard at YM or Nevada Test Site (NTS). Therefore, their average rate of earthquake occurrence varied. The *a*-values were determined from measured geologic slip rates or inferred slip rates from fault length. No attempt was made to determine background seismic activity by subtracting the sum of paleo-faulting derived seismicity from historic seismicity as did Somerville et al. (1987) and Wong (1994). For the second computation, the *a*-value for each zone was the sum of *a*-values for faults within that zone.

In the first computation, seismic hazard did not change significantly as a result of adding the background seismic zone. The second computation was an attempt to not perturb the regional recurrence relationship when adding the background zone. Hazard increased for the 85th and 95th constant percentiles using this assumption.

Another calculation was made with an added background zone without eliminating small magnitudes on the fault source zones. This assumption resulted in a *b*-slope which was not linear for small earthquakes as observed from complete data sets, for example, Abercrombie and Brune (1994). Resulting hazard increased in this calculation. More earthquakes were added to the region, and some would have occurred very close to the site. In the previous calculation, the addition of the background zone did not add earthquakes to the region.

This study suggests that maintaining a constant regional *b*-slope is required for an accurate PSHA. Assumptions for background zone seismicity, other than the two investigated, are possible. One assumption proposed by Wesnousky (1982) was that faults may produce only magnitudes near the maximum that they can support, plus aftershocks (which do not follow a regional *b*-slope). Whatever assumptions are made, fault sources cannot produce small earthquakes at the rate a constant *b*-slope (as observed in complete data sets of seismicity) would indicate. This conclusion suggests that Krinitzsky (1994) has a valid point in criticizing the use of constant *b*-slopes for individual fault planes. Data have been inadequate to prove the assumption, usually used in PSHA, that regional *b*-slopes apply to discrete fault sources. However, there probably is enough instrumentation for some recent California

earthquakes, to investigate this problem further. Wesnousky (1994) suggests a characteristic earthquake recurrence for parts of the San Andreas fault system.

2 INPUT FILE CHANGES TO ADD A BACKGROUND SEISMIC ZONE

Three input files require changes or additions to implement a background or complementary zone. These files are the a/x/j, c/j/sis, and c/j/altz files. The number of zones must be increased by one for each expert for most entries, although some remain the same. The background zone must be described on each expert's pages of input. The description includes its digitized coordinates, zone number, *a*-value, *b*-value, maximum magnitude, minimum magnitude, the region in which the zone is located (NE, SE etc.) and other details which are repeated from previous entries. This value is requested several times in the input files.

Figure 2-1 depicts all the fault zones recommended by the pseudoparticipants, largely derived from published literature, and an outline of the background zones.

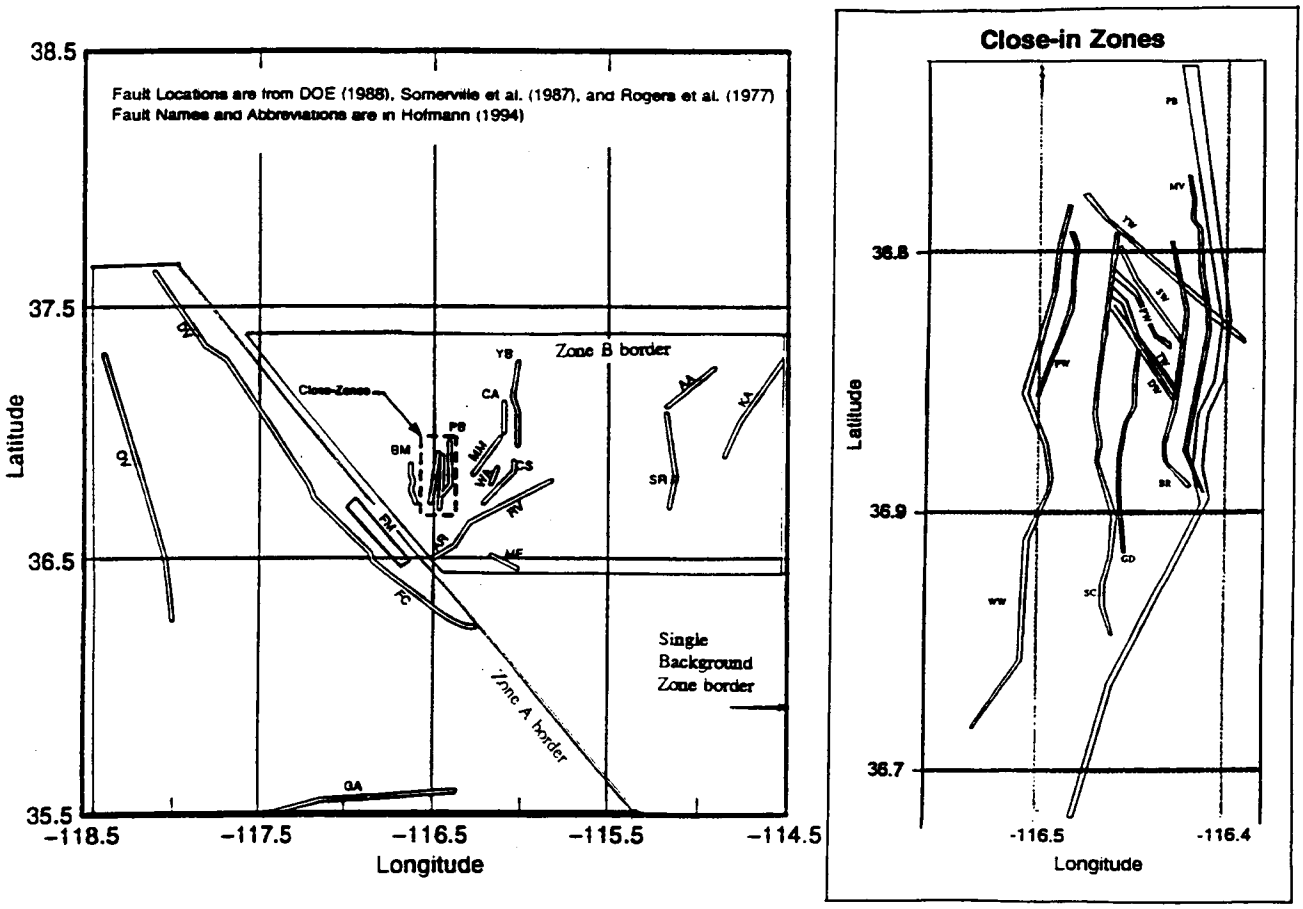

Figure 2-1. Outlines of background and fault seismic source zones

3 HAZARD COMPUTATION

Seismic hazards were recomputed using SEISM 1.1. Expert opinions derived from published literature (Hofmann, 1994) provided most of the input for the calculations described in this study. The previous calculation was based upon seismic recurrence derived from fault data, and published recurrence *b*-values from the literature. The purpose of the previous calculation was to ensure that code modifications made to the SEISM 1 computer code (Bernreuter et al., 1989), also named SHC software (Davis, 1991), to permit its use at western U.S. sites, performed properly. The calculations reported here include a background seismic zone, or zones, in addition to discrete fault sources. Figure 3-1 contains the aggregated hazard curves for the background zone models calculated in this sensitivity analysis.

3.1 BACKGROUND ZONE MODELS

Several background models were employed to determine the effect of varying their specifications.

3.1.1 Background Zone Model 1

The initial background zone was modeled with the average seismic activity (*a*-values) for faults proposed by the various experts to be used in a PSHA at YM. To better maintain a constant *b*-value (slope of number of earthquakes per given magnitude and larger), earthquakes occurring on faults were limited to magnitude values between 5.8 and M_{max} for each fault declared by an expert. Earthquakes of magnitudes less than 5.7 were permitted to occur randomly throughout the background zone.

3.1.2 Background Zone Model 2

The second calculation used two background zones. Both zones allowed magnitudes from 4 to 5.7 with fault sources restricted to magnitudes of 5.8 and greater. Background zones were assigned an *a*-value equal to the sum of *a*-values assigned to the faults they both enclose. One background zone encompassed the low-seismicity area around the site. The other background zone encompassed only the more active distant faults like the Death Valley - Furnace Creek and Owens Valley faults. For this test however, there was no difference in *a*-values. Three seismic source zone experts used large distant faults enclosed by background zone A. Five of the experts used only the relatively nearby faults of Zone B. This configuration did not produce a seismic hazard greatly different from the original PSHA without a background zone.

3.1.3 Background Zone Model 3

CNWRA was unable to find a way to assign differing *a*- and *b*-values, and M_{max} and M_{min} to two different background zones. Two complementary zones are possible, but they must both have the same properties. Because Model 2 did not produce a significant effect on hazard, zone B was the only zone assigned to the three experts who declared faults in it for this test. In this test, zone B was allowed to have a high value comparable with the sum of the *a*-values determined for the large distant faults. Again, there was little effect on the 50th constant percentile (CP) hazard, although the 85th and 95th CP hazards increased somewhat. As in the first model, M_{min} for each fault zone was set to 5.8 unless the fault zone had an $M_{max} < 5.8$. In the latter case, earthquakes on the fault were restricted to their M_{max}. Earthquakes in background zones were permitted to range from magnitude 4 to 5.7 in a random manner.

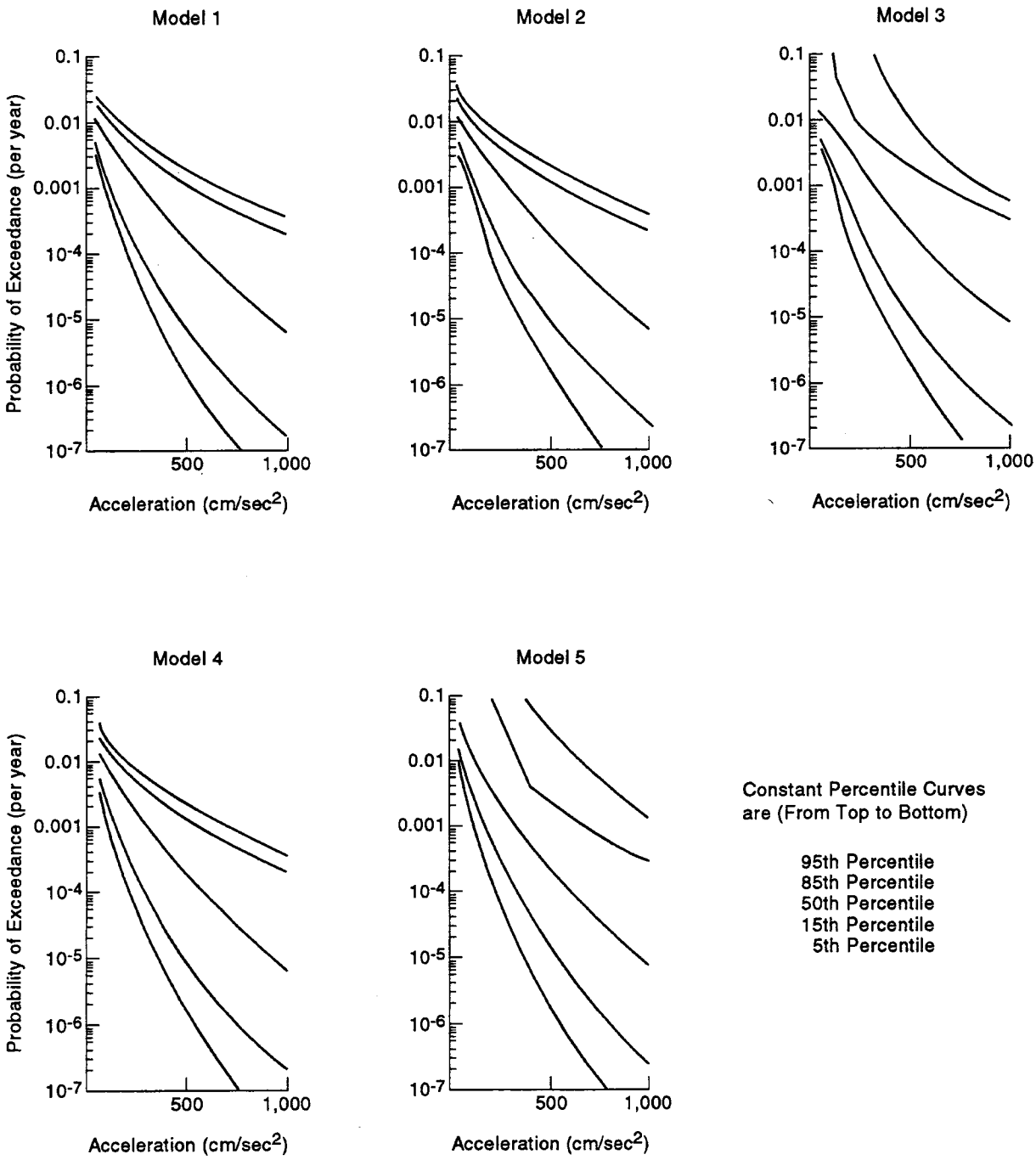

Figure 3-1. Aggregated hazard curves with background zone

3.1.4 Background Zone Model 4

In this model, M_{min} was set to 4 for fault zones and the background zones. M_{max} was set to 6.25 as in Wong et al. (1994). In this case, hazard increased at the 50th, 85th, and 95th percentiles.

3.1.5 Background Zone Model 5

Background zones were as in Model 3, except they were declared in the code as enclosing zones rather than complementary zones. This condition permitted assigning two background zones with different characteristics, to the three experts who declared faults in both of the zones. The effect on CP hazard is little different from that of Model 3. However, the arithmetic means are several times higher than for Model 1. The 10^{-2} per year 50th CP hazard is about doubled, but other values are little changed. This doubling reflects some very high accelerations being generated in the A background zone near to the repository.

3.2 THE PROBLEM OF REGIONAL *b*-VALUES

If a background zone with a limited M_{max} but significant *a*-value is added to seismicity from faults, the regional *b*-value will change for small earthquakes such that the calculation will show relatively more small earthquakes compared to larger ones, in the site region, than would be observed. The *b*-value would vary with magnitude. This effect is not observed for well recorded data sets, for example, Abercrombie and Brune (1994). Models other than those proposed here could be devised to maintain a constant regional *b*-value while adding small random earthquakes to a background zone. Such models might include variable *b*-values for faults and a nonstandard recurrence relationship for the background zone such that the regional seismicity would follow a constant *b*-value for all magnitudes, as observed. However, convincing evidence to support such a model is limited.

The proposal of Wesnousky et al. (1982) for western Honshu could be adopted, that is, faults only produce earthquakes near the maximum possible for the fault, plus after shocks. All earthquakes smaller than those that are represented by larger faults, consistent with an acceptable *b*-value, would be allowed to occur randomly throughout the background zone. The background zone *b*-value would have to be adjusted so that the regional *b*-value, including earthquakes on faults, would be constant for all magnitudes in the region. Differentiating between the Gutenberg-Richter (1954) and Wesnousky et al. (1982) or other hypotheses for regional and fault-specific *b*-values in the Basin and Range tectonic province does not appear possible because of the limited seismic data available. Certain parts of the San Andreas system may be active enough to make such a determination for small earthquakes recorded by increased amounts of instrumentation installed in recent years.

Wesnousky (1994) determined that segments of the San Andreas Fault between major asperities and some of its branches have recurrence relationships that look like those proposed for characteristic earthquakes, but that the entire San Andreas zone has a Gutenberg-Richter type recurrence with a *b*-value near 1.0. His zone-surrounding faults, within which he selected earthquakes to develop the recurrence relations, were narrow but wide enough to include smaller ancillary faults. For most faults, this type of analysis would produce results that would be difficult to distinguish from the Wesnousky et al. (1982) analysis. However, the new analysis suggests strongly that individual fault planes do not follow a Gutenberg-Richter type recurrence. This conclusion is also drawn from development of this sensitivity study. Reanalysis of hazard using characteristic earthquake relationships for individual fault planes is

beyond the scope of this study. Clearly however, hazard analyses based on the premise that individual fault planes support numbers of earthquakes in various magnitude categories in the same manner as regional Gutenberg-Richter recurrence curves would predict, cannot be correct. All such analyses using this procedure published to date are therefore suspect.

Figure 3-2 is a sketch showing the effect on a regional *b*-value of adding a background zone with a limited M_{max} to that of an enclosed fault. Both the background zone and the enclosed fault have the same *a*- and *b*-values. If several faults are enclosed with different M_{max}, the change in the regional *b*-value is exacerbated. Also illustrated in Figure 3-2 are the effect of assuming that recurrence on a fault plane has a characteristic earthquake configuration as proposed by Wesnousky (1994) or recurrence of the maximum magnitude only plus aftershocks as proposed earlier by Wesnousky (1982).

Because only regional *b*-values are usually known with confidence (e.g., Krinitzsky 1994), the sum of fault and background zone *a*- and *b*-values must conform to a regional linear *b*-slope as a function of magnitude. The use of constant *b*-values near 1.0 for individual faults is therefore suspect.

The region-wide *b*-values produced from a SEISM 1.1 code calculation could be derived during processing using diagnostics that save all M and distance values chosen by the Monte Carlo routine. However, such diagnostic files are extremely large and challenge available work station storage capacities. A subroutine could be coded to retain a matrix of M and distance category sums, thereby providing a more manageable file from which a recurrence curve could be generated. This plot could be used to verify that the regional *b*-slope developed during a calculation satisfied a straight line for all magnitudes. This verification is beyond the scope of this sensitivity study, but it remains as a possible future effort. Although attempts were made in this study to preserve the regional recurrence relationship, it is likely that the relationship deviates from the form observed in complete data sets. That a regional recurrence relationship is a straight line with a slope near 1.0 appears to be an important criteria to test in PSHA calculations.

3.3 POTENTIAL EXPANSION OF ADJACENT MORE HIGHLY ACTIVE ZONE TO ENCOMPASS YUCCA MOUNTAIN

Larger more distant faults are more directly related to the plate boundary system and would be expected to differ in their activity rates from typical Basin and Range faults. However, the site is closer to these large faults than most of the Basin and Range tectonic province, and seismic activity near the site may be influenced by large earthquakes occurring on these large, more distant faults. The effect of strain changes consequent to large earthquakes on the Death Valley-Furnace Creek fault zone or within the Walker Lane seismic belt may be significant. For example, the activity rate increased near the site, (as evidenced by the occurrence of the 1992 Little Skull Mountain earthquake following the 1992 Landers, California earthquake. Such an increase may be of more importance than the shaking induced at the site by large earthquakes on these distant large faults. This potential effect was not tested in this sensitivity study but could be approximated by assigning the high average *b*-value derived from large distant faults to both zones A and B of Model 5. Because an enlargement of the adjacent high activity zone (Walker Lane or the Ventura-Winnimucca zone of Ryall et al., 1966) is likely to occur only for a part of any 10,000-yr period, this procedure would produce an upper bound. Therefore, there is some uncertainty in seismotectonic models proposed for the region. Some faults may be more prone to movement than others from the activation of these large nearby faults or fault zones, Morris et al. (1994). This theory could be employed in a PSHA calculation to quantify its effect on hazard. Other new or more complex hypotheses can be expected prior to and during licensing and the hearing process.

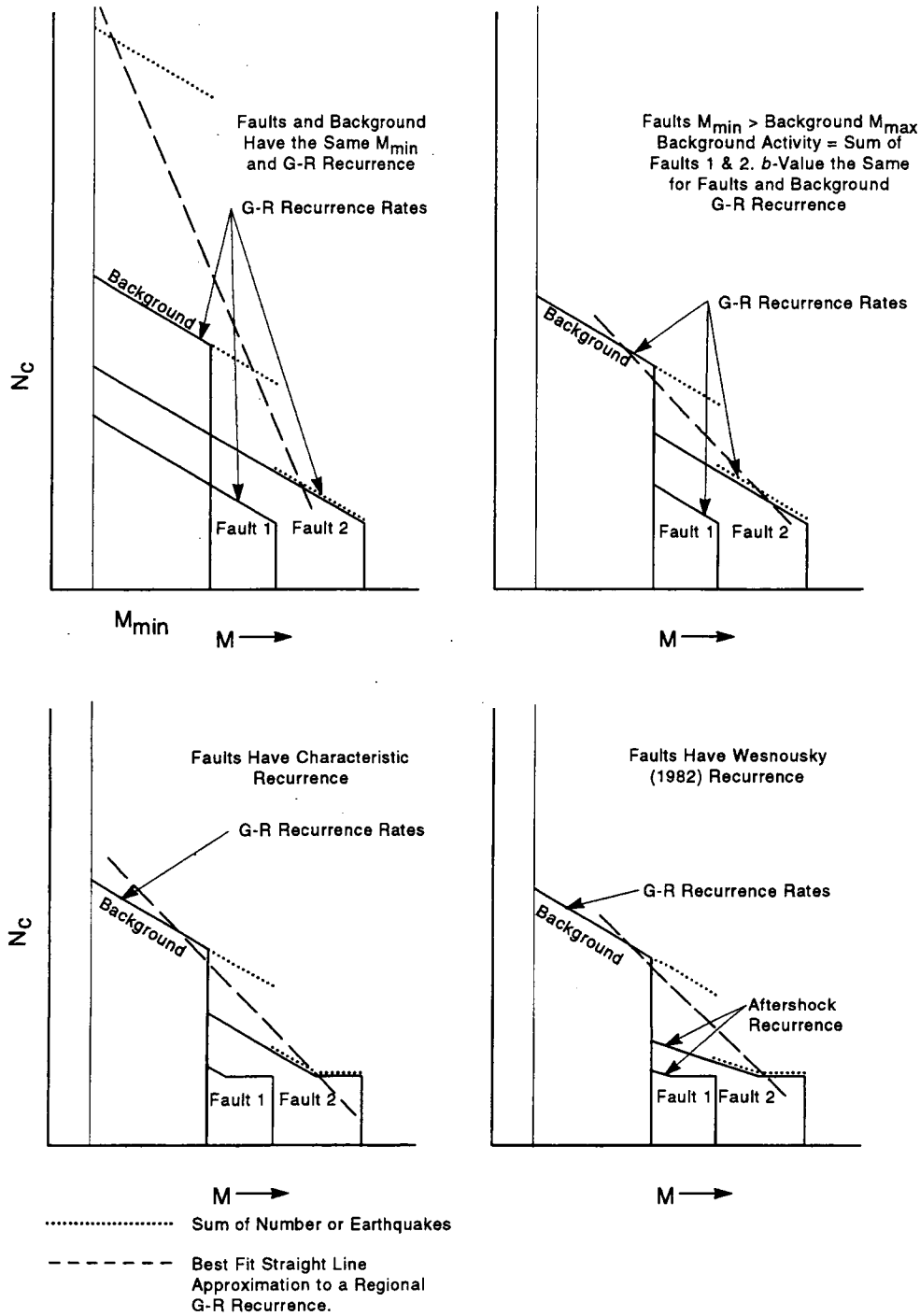

Figure 3-2. Sketch of effect on regional *b*-values of adding a background zone

4 COMPARISON WITH PUBLISHED PROBABILISTIC SEISMIC HAZARD ANALYSIS RELATING TO YUCCA MOUNTAIN

Table 4-1 is a summary of the original computation, the revised computation with two background zones, and several published hazard results including those summarized in Hofmann (1994). Results from two other studies are also summarized, those of Campbell (1980) and of Wong et al. (1994), which is also reported with additional detail in Quittmeyer et al. (1994).

The Wong et al. study for YM includes recently gathered data on fault slip rates by the DOE and uses a fault tree procedure with a background zone. M_{max} for the background zone, 6.25, is stated to control the hazard except for the 1 in 10,000-yr value. The use of an M_{max}=6.25 could be justified on the basis that several earthquakes near this magnitude have occurred on previously unknown blind thrusts in California during the past decade. Smith and Arabasz (1991) suggest this value for the Intermountain Seismic belt at the eastern margin of the Basin and Range. An M_{max} of 6.25 without surface breakage may be high for the environment surrounding YM. The Wong et al. (1994) *b*-value for seismic recurrence is 0.83 rather than the 0.91 in this study. The 0.83 value is stated to be the result of deletion of all aftershocks from the seismic record. The probabilistically determined peak accelerations are similar to those of this study based upon published expert opinion. However, this study would attribute a somewhat higher contribution to peak acceleration from larger earthquakes occurring on faults rather than to a random earthquake in a background zone.

The Campbell (1980) analysis also used a *b*-value of 0.83 but did not use a background zone. Earlier publications, also summarized, included the NTS or YM, sometimes in broad regional evaluations of risk e.g., the Algermissen et al., (1982) seismic risk map for the United States. Where authors published several models, they are presented in addition to the primary or principal model. Models that are similar (for example those which use a background zone and the same *b*-value) should indicate similar hazards unless new data have resulted in changed parameters. Dissimilar assumptions would be expected to have a wider dispersion in the hazards calculated. Table 4-1 indicates that there is a considerable variation in the way in which various experts have interpreted the same or similar data, and a corresponding variation in resulting hazard. If all hazards are assumed to be 50th CP values, the once in 10,000-yr hazard ranges from 0.28 to 0.70 g and the once in 500-yr acceleration ranges from 0.10 to 0.34 g. Accelerations determined without a background zone for the previous two hazard values (Hofmann, 1994) were 0.61 and 0.18 g. This study, with two background zones, also yields 0.61 g and 0.18 g for the once in 10,000- and once in 500-yr hazards respectively.

Somerville et al. (1987) subtracted fault-source activity rates, determined by paleo-dating of fault offsets or fault length relationships, from a broad regional historic total activity rate to set the background rate. The historic activity rate had been determined by Greensfelder et al. (1980) as 0.015 M=4 events per 1,000 km^2. Results from this procedure showed that background seismicity significantly contributed to the seismic hazard in the 10^{-2} to 10^{-3} per year range. M_{max} for the background zone was 6.5.

If M_{max} is set to 6.25, as in the Wong et al. (1994) study, and smaller earthquakes are not deleted from the fault sources, a larger increase in hazard would be expected to accompany a background zone. The Model 4 background zone of this study also showed a significant influence on seismic hazard from a background zone, with these assumptions. Clearly, the choice of M_{max} has a significant effect on hazard, although other factors (e.g., use of M_W or a *b*-value of 0.83 rather than 0.91, etc.) may account for differences between this study and that of Wong et al. (1994).

	This Study Hofmann/Menchaca (1994) Model 5				Somerville et al. (1987)	Rogers et al. (1977)		Perkins et al. (1987)			Campbell (1980)	Wong (1994)	Algermissen et al. (1982)
	BE and AVE.		50th CP			A Model	B Model	Model 1		Model 2		50th CP	
Basis: Background Zone?	F N	F Y	F N	F Y	F Y (Seis.)	S Y	F N	F & S N	F N	S Y	S & F Y	S Yes	S & F Yes
M_{MAX} of bknd Zone	--	5.7	--	5.7	6.5	4.5 Includes W. NV Seismicity	--	--	--	5.7	3.5	6.25	Various
SITE	YM				YM	NTS		NTS Region		YM (Site A)	YM	YM	YM
Area or Radius of Study	100k km^2				100k km^2	F to 150 km S to 400 km	B & R Seis. Less W. NV Seismicity	400 km Less W. NV Seismicity	400 km	≈2000 km^2≈	31.5 km^2		
Multiple/Single Expert or Expert-Team	M		S		S	S A_S B_F	A_S B_F	S	S	S	S	S?	S
b-Value	-0.91		-0.91		-0.91	-0.83	-0.83 Variable	-0.83		-0.83	-0.83	-0.83	Variable
Recurrence Interval	Hazard (g's)												
100 years	0.08	0.51	0.07	0.13	0.20	0.2 0.06	0.2 0.06	0.28	0.04	0.06	0.12		0.05*
456/500	0.14	0.60	0.18	0.18	0.30	0.34 0.12	0.4 0.12	0.34	0.10	0.2	0.21	0.19	0.12
1,000	0.38	0.92	0.31	0.36		0.4 0.17		0.42	0.14		0.30	0.27	
2,500						0.5 0.25	0.6 0.26	0.52	0.19	0.25	0.41	0.37 (2ky)	0.25
10,000	0.95	1.14	0.61	1.61	0.70	0.65 0.32		0.66	0.28	0.32	0.63	0.66	0.32

* As interpreted by Perkins et al. (1986)
F in "Basis" row = fault
S in "Basis" row = seismicity

M in "Multiple/Single" row = multiple experts or expert teams
S in "Multiple/Single" row = a single expert or expert team
A_S = Model A, based on seismicity
B_F = Model B, based on fault offsets

Table 4-1. Summary of seismic hazard computations at YM from published data

Variations in the *b*-value are caused by several factors:

- Choice of earthquakes identified as aftershocks and eliminated from the determination
- Choice of magnitude scales
- Choice of area over which the *b*-value is determined

The same choices or expert opinions also apply to the determination of *a*-values.

5 CONCLUSIONS AND RECOMMENDATIONS

The process of including a background zone or zones into a PSHA for YM resulted in consideration of alternative recurrence functions for individual fault sources of earthquakes and their aggregate relationship to regional earthquake recurrence. The background zones as formulated for this study did not appreciably add to the 50th CP 10^{-4} per year hazard but increased higher percentile hazards in some cases. In another study, Wong et al., (1994) and Quittmeyer (1994) indicate that hazard was largely controlled by the background zone for all but the 10^{-4} per year hazard. This study and Wong et al., (1994) are in reasonable agreement. Clearly, the formulation of a background zone has an important bearing on PSHA, and there are different opinions on the matter. Therefore, expert opinion should be sought in multiple expert PSHA regarding background zone formulation. Feedback concerning the effect on regional *a*- and *b*-values should be a part of the elicitation process.

5.1 CONCLUSIONS

Several conclusions can be made from this sensitivity study:

- Hazard could increase or possibly decrease when small earthquakes are permitted to occur randomly in a background zone. The direction of hazard change depends on the presence of nearby faults close to the site and whether regional recurrence is accurately modeled by reducing the number of small earthquakes on faults in proportion to the number of small earthquakes permitted to occur randomly in a background zone. If the total regional recurrence does not follow a linear *b*-slope near 1.0, the PSHA model cannot be expected to produce the best possible results.

- *a*-values are an important factor in the amount of hazard increase, and these values are uncertain for periods of time substantially longer than the historic seismic record.

- *b*-values for faults and for an encompassing background zone with different M_{max} cannot all follow a constant Gutenberg-Richter recurrence slope and still maintain a constant regional *b*-slope, as observed in complete seismicity data sets.

- *a*- and *b*-values determined after eliminating aftershocks from the seismic record (a heuristic endeavor) also eliminate the risk posed by those aftershocks. Such a calculation may be less conservative than one in which aftershocks are not removed.

- Published expert opinions concerning the models used in PSHA are varied. As a minimum, this level of variation may be expected from those participating in a licensing hearing based upon PSHA. Therefore, if some procedures or models are less acceptable than others to NRC staff, they are potential topics in an NRC Staff Technical Position.

- Resource requirements for PSHA analyses are nontrivial, although some of the costs for this sensitivity study are a part of the learning process. A background zone was not used in the original calculation to reduce difficulties in performing the first CNWRA western U.S. test calculation with SEISM 1.1. Other possible sensitivity studies require only changing a variable already in place in the input files. Such analyses should require fewer resources.

5.2 RECOMMENDATIONS

The sensitivity of PSHA accuracy resulting from the assignment of linear recurrence relationships to all faults and a background zone should be investigated. If SEISM 1.1 is to be used for this purpose, some additional coding will be necessary to track the total number of earthquake magnitudes and distances generated by the Monte Carlo process.

No other recommendations are made at this time, pending an assessment by NRC and CNWRA concerning this project's future level of activity. Several recommendations or suggestions for further investigation or code development are delineated in chapters 6 and 7 of Hofmann (1994), which could be considered at an appropriate time. The output from this and the original calculation are being integrated with tasks of Repository Design Construction and Operation and the Performance Assessment elements of CNWRA to provide tentative input for the selection of strong motion time functions for structural analyses. It is understood that new data from DOE studies or expert elicitation and PSHA by them may cause future revisions of the time functions to be used.

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TESTING OF SEISM 1.1: SENSITIVITY ANALYSIS (REVISION MAY 24, 1995)

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Prepared by

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PREVIOUS REPORTS IN SERIES

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8	SEISM 1 Code: Adaptations for Use in the Western U.S.	May 1993
9	SEISM 1.1 Test Analysis (CNWRA 94-014)	August 1994

ABSTRACT

A previous SEISM 1.1 analysis using published data from the Yucca Mountain region was recalculated with the addition of one and two background seismic zones. A background seismic zone was not used in the initial analysis. Reasonable assumptions about background zones are potential subjects of expert opinion. For this reanalysis, only two sets of assumptions were used with several permutations. Expert opinions were not formally elicited. In the reanalysis, most fault sources were assumed not to generate earthquakes less than magnitude 5.8 because earthquakes below this magnitude are usually not associated with known faults in the western Basin and Range tectonic province unless they are aftershocks of larger earthquakes. The *a*-values used in the analysis, derived from the number of magnitude 4 earthquakes in the literature, were mostly based on generalized Basin and Range tectonic province Quaternary fault information rather than historical seismicity or specific age dating of fault offset. The average of sums of recurrence relation *a*-values for all faults used by each pseudoparticipant of the original analysis, who considered only faults local to the site, was used as the best estimate for the background zone *a*-value of the single background zone model. The background zone was assumed to have magnitude 4 to 5.7 earthquakes occurring randomly within it. Assigning of small earthquakes to the background zone and larger ones to faults produces a regional recurrence more like the linear Gutenberg and Richter e.g., (1954) recurrence. There are two categories of experts, those who included large distant faults capable of very large earthquakes, and those who believe that such faults are too distant to affect hazard at Yucca Mountain. The *a*-values, which dictate the level of earthquake activity, are higher for those experts who included the more distant large faults in the original calculation. These high *a*-values suggested that a background zone local to Yucca Mountain may have a lower seismic activity rate than those in which some expert opinions regarding distant large faults were included. A test of this hypothesis is made by a second computation in which two background zones are specified. Initially, each computation had a background *a*-value that is equal to the sum of all the *a*-values used for the faults the background zone enclosed. The sum of *a*-values for the background zone enclosing the Death Valley-Furnace Creek and Owens Valley fault zones was exceedingly high because of paleo-activity estimations based on fault lengths. SEISM 1.1, operating on a Sun Workstation, could not manage the large number of calculations required, probably because of limited storage and memory. Subsequently, the exceedingly high *a*-value was arbitrarily reduced but still remained high. This calculation did not change the 50th constant percentile acceleration, but it did increase the 85th and 95th percentile accelerations. Hazards corresponding to shorter return periods were most affected. Quaternary activity based upon fault dimension information may differ from historic seismic activity. Adding the background seismicity zone had little effect on 50th constant percentile hazards with the exception of the 10^{-2} per year hazard. A background seismic zone defined differently is likely to have a different effect on the resultant hazard. Regional recurrence relationships are observed to be linear with respect to magnitude. Recurrence relationships on a fault plane are rarely known. However, recurrences on individual fault planes cannot be specified as linear in probabilistic seismic hazard analysis if a linear regional recurrence is to be preserved. The sensitivity of probabilistic seismic hazard analysis accuracy to the usual practice of assigning all faults and a background zone with linear recurrence relationships is beyond the scope of this study, but such a study is recommended. Approximately 50 pages of input data require modification to produce calculations that include a background zone. Most 50th constant percentile calculations were nearly identical to the original ones without a background zone.

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LIST OF ACRONYMS, SYMBOLS, AND NONSTANDARD TERMS

a	The intercept or level of activity term for an earthquake recurrence function
ACRS	Advisory Committee on Reactor Safety of the Nuclear Regulatory Commission
Ave.	Average
b	The slope of the straight line resulting from a Gutenberg-Richter earthquake recurrence function
BE	Best estimate
CDS	Compliance Determination Strategy
CFR	Code of Federal Regulation
cm	Centimeter
CNWRA	Center for Nuclear Waste Regulatory Analyses
CP	Constant percentile
CPHC	Constant percentile hazard curve
DOE	U.S. Department of Energy
DWM	Division of Waste Management of the NRC
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
EUS	Eastern United States
g	Gravitational constant - 980 cm/s^2
G-R	Gutenberg-Richter
GS	Geologic Setting Element of the CNWRA
HLW	High-Level Nuclear Waste
KTU	Key Technical Uncertainty
LLNL	Lawrence Livermore National Laboratory

LIST OF ACRONYMS, SYMBOLS AND NON STANDARD TERMS (Cont'd)

M	Magnitude — a measure of earthquake size. In this document, M represents Richter magnitude, defined as M_L to 6.5, M_S from 6.6 to 8, and M_W for 8+
M_L	Richter local magnitude
M_{max}	Maximum magnitude
M_{min}	Minimum magnitude
M_S	20-s surface wave magnitude
M_W	Moment magnitude
N_4	Number of earthquakes of M=4 and greater
N_C	Number of earthquakes equal to or greater than a specified magnitude, C
NMSS	Office of Nuclear Material Safety and Safeguards of the Nuclear Regulatory Commission
NPP	Nuclear power plant
NRC	Nuclear Regulatory Commission
NRR	Nuclear Regulatory Commission Office of Nuclear Reactor Regulation
NTS	Nevada Test Site
NWTRB	Nuclear Waste Technical Review Board - oversight board for DOE
PA	Performance Assessment
PFD&SHA	Probabilistic fault displacement and seismic hazard analysis
Pseudoparticipant	An artificial expert whose opinions are derived from published literature
PSHA	Probabilistic seismic hazard analysis
s	Second (of time)
SEISM 1.1	CNWRA western U.S. version of the LLNL-NRC/NRR SEISM 1 code (also called SHC or SHC software)
SHC	Seismic Hazard Characterization — also Seismic Hazard Codes (of LLNL)
YM	Yucca Mountain

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This report was prepared to document work performed by the CNWRA for the NRC under Contract NRC-02-93-005. Activities reported here were performed for the NRC NMSS, Division of Waste Management (DWM). This report is an independent product of the CNWRA and does not necessarily reflect the views or regulatory position of the NRC. Opinions expressed are intended to apply only to the application of probabilistic seismic hazard analysis (PSHA) codes to a high-level nuclear waste (HLW) repository.

QUALITY OF DATA, ANALYSIS AND CODE DEVELOPMENT

DATA: Data used in this report were obtained from published literature or provided by the Lawrence Livermore National Laboratory (LLNL) with the SEISM 1 code. These data have not been quality assured by the CNWRA. Sources for the data should be consulted for determining the level of quality for those data.

ANALYSES AND CODES: The SEISM 1.1 computer code was used in this analysis. Development of SEISM 1.1 is described in Report CNWRA 94-014, however, the code has not been sufficiently developed to be placed under the CNWRA Configuration Management System.

1 INTRODUCTION

Probabilistic seismic hazard analysis software developed by the Lawrence Livermore National Laboratory (LLNL) for the Nuclear Regulatory Commission's (NRC) Seismic Hazard Characterization (SHC) of the eastern United States was acquired and modified by the Center for Nuclear Waste Regulatory Analyses (CNWRA) to operate for sites in the western United States. This modified software is designated as SEISM 1.1. A test computation was made with published data pertinent to the proposed Yucca Mountain (YM) high-level nuclear waste (HLW) repository (Hofmann, 1994). Difficulties with completing this calculation resulted in exceeding resource requirement estimates. Sensitivity studies for various inputs to the calculation had been proposed. This report documents a sample sensitivity analysis of significant difficulty performed to determine resource requirements. The sample analysis chosen was to add a background seismic zone to the previous calculation to determine the sensitivity of hazard to the addition. Several configurations were possible. Other sensitivity analyses would require substantially fewer resources than the analysis reported here.

1.1 PURPOSE

To plan for possible future code development tasks, it was necessary to determine the resources needed to perform a typical sensitivity analysis of changed input parameters for a SEISM 1.1 calculation, at the proposed YM HLW repository, using published data. A byproduct of the analysis is an estimate of the sensitivity of calculated seismic hazard to the addition of a background zone having several possible configurations. A background seismicity zone is called a "complementary" zone in SHC-related publications by LLNL (e.g. Bernreuter et al., 1989). A background seismicity zone is assumed to have randomly occurring seismicity from low-magnitude earthquakes.

SEISM 1.1 uses expert opinions. Experience in developing input files will facilitate future possible hazard analyses to determine the effect of proposed seismic or tectonic model changes in the course of the licensing process.

The NRC has requested that both deterministic and probabilistic methods be used in licensing an HLW repository. The U.S. Department of Energy (DOE) has stated that it will use probabilistic seismic hazard methodologies for application to a potential YM HLW repository, e.g. (Sullivan 1994; Quittmeyer 1994; Kennedy et al. 1990; and U.S. Department of Energy, 1988). The NRC staff will be required to evaluate DOE results. The DOE view (e.g. Quittmeyer, 1994) is that deterministic analysis will comprise a disaggregation of the multiple-expert probabilistic seismic hazard analysis (PSHA) with identification of the principal contributor(s) to a prescribed (by DOE) hazard level. Therefore, the selection of the earthquake to be used in the deterministic analysis appears to be a property of the multiple-expert PSHA and the selected hazard level. Details of these intended procedures are subject to change. The NRC/Division of Waste Management (DWM) did not have a probabilistic code with which to make independent hazard analyses for western U.S. sites. The purpose of probabilistic fault displacement and seismic hazard analysis (PFD&SHA) efforts at the CNWRA is to provide an updated computer code, SEISM 1.1, to permit the NRC staff to evaluate the DOE PFD&SHA submittals. Exercising the code will aid in determining if probabilistic methods employing expert opinion to fault displacements and earthquakes can effectively support an HLW repository license application for a western U.S. site. The schedule for repository investigation, construction, and license review requires that tools for analyzing PFD&SHA be quickly available.

An expert-opinion based methodology is desirable because the short period of historic seismicity requires that paleo-fault data be used for projections of seismic activity for time periods as long as 10,000 yr. Interpretation of such data has been the subject of debate among professionals in this technical area, for example, see the opinions of Arabasz, Bell, Rogers, Slemmons, Swan, Whitney, and Wong in Electric Power Research Institute (1993) and of Somerville et al. (1987).

Concern with repository siting criteria, particularly potentially adverse conditions [see 10 CFR 60.122(c)(12-14)] and specific references to earthquakes was the primary motivation for initiation of this project. Other sections of 10 CFR Part 60 that also relate to or allude to seismic and related concerns are:

- Content of Application, Safety Analysis Report, Description and assessment of the site [60.21(c)(1)(i)(A) and (B), and (ii)(A) and (C)]
- Permanent Closure [60.51(a)(3)]
- Additional design criteria for the underground facility [60.131(b)(1)]
- Performance Confirmation and Processing Pertaining to the Geologic Setting, General requirements, parameters and processes pertaining to the geologic setting; [60.140(d)(2)]
- Confirmation of geotechnical and design parameters, rock deformations and displacement [60.141(c)]

Hofmann (1992c) has a more thorough discussion of the applicable sections of 10 CFR Part 60 that were of concern upon initiation of this project by the NRC/DWM.

Environmental Protection Agency (EPA) requirements for radionuclide releases are in probabilistic terms in its currently remanded regulation and in proposed revisions. The NRC 10 CFR Part 60 regulations include the EPA regulation by reference. By inference, the probabilities of exceeding design criteria and consequent effects on radionuclide release must be known. PFD&SHA methodologies provide a means of estimating the first of these probabilities. Seismic risk and probabilities of fault displacement presented in a license application or in hearings must be analyzed by regulatory staff. A version of the SEISM 1 code (also referenced as SHC software), after adaptation to HLW repository requirements, is a means of performing such analyses. The efforts described in this report have the purpose of providing a version of the SEISM code that can be efficiently used for such analyses.

An exploration of the concept of PFD&SHA, as it applies to the much longer times of performance concern for an HLW repository, was deemed prudent if not critical to meet the limited 3-yr license review time for an HLW repository required of the NRC.

Compliance Determination Strategies (CDSs) were developed by the NRC and the CNWRA for the earthquake-related potentially adverse conditions. Key Technical Uncertainties (KTUs) were found for several of the earthquake related potentially adverse conditions. Where such uncertainties existed, NRC research and independent analyses are anticipated to be required to resolve related licensing issues before submission of the license application.

CDSs corresponding to 10 CFR 60.122(c)(12-14) address: (i) Historical earthquakes, (ii) More-frequent/higher magnitude earthquakes, and (iii) Correlation of earthquakes with tectonic processes. KTUs as described in these CDSs are:

- "The inability to predict the likelihood of earthquake occurrence over the next 10,000 yr."
- "Paleofaulting data indicate that seismic activity has migrated randomly from one major range front fault system to another in the Basin and Range tectonic province. Therefore, there is considerable uncertainty that the relatively low seismicity at YM will continue over a 10,000-yr period."
- "Many fault plane solutions from the historical seismic record do not agree with the fault movement indicated by striae (slickensides) on exposed fault planes; therefore fault movement, earthquake strong motions and their radiation patterns, which will be used in tectonic models, are uncertain."
- "Correlation of Earthquakes with Tectonic Processes" (*the lack thereof*).

Other KTUs, applicable to a broad range of CDSs whose uncertainty may be at least partially quantified through PFD&SHA, are:

- "Predicting long-term performance of seals for the underground test boreholes"
- "Variability (temporal, spacial, etc.) in model parametric values"
- "Prediction of future system states (i.e., disruptive scenarios)"

The reasons for research or independent analysis to reduce or quantify uncertainties are summarized in the CDS for correlation of earthquakes with tectonic processes:

(1) Quantitative knowledge about tectonic processes, including the ability to predict the occurrence of earthquakes for the next 10,000 yr or the ability to correlate earthquakes with known structures, in the YM area is, and will most likely remain, uncertain;

(2) Alternative conceptual models for tectonic processes will remain at the time of licensing;

(3) The alternative models for addressing both the probability of tectonic activity and potential effects from this activity may span several orders of magnitude;

(4) There is no proven method for extrapolating relatively short-term seismic data and experience to the long-performance periods (i.e., 10,000 yr) required for a geologic repository; and

(5) The effects of tectonic activity on the ability to demonstrate compliance with the overall system and subsystem performance objectives will be highly contentious during licensing.

These items all lie at the cutting edge of current technology, yet are critical to licensing the nation's first HLW repository. It is expected that DOE, in the process of developing its license

application, will address these subjects. However, because these uncertainties are at the state-of-the-art in their resolution and are contentious among well-qualified investigators, the NRC must be cognizant of and capable of addressing these technical areas. Methods and tools (e.g. computer codes) capable of assessing whatever arguments are presented by the licensee and those in opposition, with the goal of facilitating a licensing review within the allotted 3-yr period of time, are of potential benefit.

A method of quantifying uncertainties in data interpretation by well-qualified experts is needed. Such a process (PSHA) was used in the eastern U.S. SHC. This method requires the elicitation of expert opinions regarding the interpretation of available or reasonably obtainable data and its application in a probabilistic analysis system that is known to function properly. Without a probabilistic seismic and fault displacement analysis tool and experience in using it to analyze the considerable data being developed by DOE, NRC staff may be less effective in developing and presenting their findings.

Investigation of probabilistic methods is important to a timely resolution of geoscience licensing concerns. A concerted effort is required to ensure that probabilistic methodologies are properly framed and developed for the unique conditions of a permanent HLW repository. Research regarding PSHA for the NRC Office of Nuclear Reactor Regulation (NRR), the DOE and the Department of Defense (DOD) should be followed to assure that it is available to the repository licensing activity and that its impact on potential licensability is assessed. Efforts must begin early to identify uncertainties that are particularly large and cannot be reduced without concerted research efforts. PSHA tools (computer codes and elicitation methodologies) are in a formative stage. They have been applied primarily to estimating hazards at facilities with expected lifetimes of only a few decades. Application of PFD&SHA to an HLW repository presents new problems that require technical effort to resolve.

The efforts described in this report are preliminary attempts to apply and investigate probabilistic tools in their application to much longer term nuclear hazards. The entire spectrum of probabilistic input and analysis methods, geoscientific data including seismology, and computer modeling of tectonic and dynamic earthquake-generating processes, must be approached from the standpoint of a long-term (e.g., 10,000 yr) hazard to the public. This effort cannot be performed only by the license applicant. Because of its state-of-the art content, it must be understood by the regulator who must anticipate how to resolve such issues from the point-of-view of all parties at a licensing hearing.

1.2 BACKGROUND

LLNL developed SEISM 1 for the NRC NRR Seismic Safety Margins Research Program. The code was later modified to evaluate probabilistic seismic risk for central and eastern U.S. nuclear power plants (NPP). Observed data, or their average plus deviations, and a range of expert opinions are input to the code. Expert self assessments of uncertainty in their estimated input parameters are also used in the calculations. Resulting hazards are aggregated to provide final hazard curves for the arithmetic mean, best estimate data only, and for various constant percentile hazards.

PSHA has been applied to NPPs with much shorter nominal life spans than an HLW repository. CNWRA tasks have been to determine the basis in current regulations for performing probabilistic analyses, to modify SEISM 1 for western U.S. locations, and also to calculate probabilistic fault displacements. A work plan and a series of nine reports document work to date. This report is the tenth in the series. Resources to reach the test analysis computation goal with SEISM 1.1 were underestimated. Consequently this task, to perform one sensitivity study of significant difficulty, was undertaken to better

estimate potential future resource requirements. This report documents the sensitivity of calculated seismic hazard to the addition of a background seismic zone.

1.3 SUMMARY

A background zone, which encompassed the published fault sources used in Hofmann (1994), was added to the PSHA calculation of seismic hazard at YM. Earthquakes generated by the fault sources were limited to M=5.8 or greater unless the fault was insufficiently large to generate earthquakes of that magnitude. This scheme was adopted because earthquakes of 5.7 or lower only rarely cause visible fault offset at the surface in the Basin and Range tectonic province. For the few faults in this category, magnitudes were limited to the maximum magnitude that the fault could generate. A second background zone calculation used two background zones, one for near-site background seismicity and a separate one associated with higher activity more distant faults like the Death Valley - Furnace Creek and Owens Valley faults.

Earthquakes were assumed to occur randomly throughout the zones. For the first computation, background seismicity was set to the average sum of seismic activity rates for each expert's fault zones. As in the Hofmann (1994) calculation, all rates (*a*-values of the recurrence relation) were based on the Somerville et al. (1987) estimates of the number of M=4 earthquakes (N_4) that could occur at each fault, and an average *b*-value of 0.91. The eight pseudoparticipants all chose different faults as being important in the determination of hazard at YM or the Nevada Test Site (NTS). Therefore, their average rate of earthquake occurrence varied. The *a*-values were determined from measured geologic slip rates or inferred slip rates from fault length. No attempt was made to determine background seismic activity by subtracting the sum of paleo-faulting derived seismicity from historic seismicity as did Somerville et al. (1987) or using historic seismicity for a background zone, Quittmeyer, et al (1994). For the second computation, the *a*-values for each zone were approximately the sum of *a*-values for faults within that zone.

Seismic hazard did not change significantly as a result of adding a single background seismic zone with an *a*-value based on nearby faults. The second computation, also an attempt to not perturb the regional recurrence relationship when adding the background zone, produced an increased hazard for the 85th and 95th constant percentiles.

Another calculation was made with an added background zone without eliminating small magnitudes on the fault source zones. This assumption resulted in a regional *b*-slope which was not linear for small earthquakes as observed from complete data sets, for example, Abercrombie and Brune (1994). Resulting hazard increased in this calculation. More earthquakes were added to the region, and some would have occurred very close to the site. In the previous calculation, the addition of the background zone did not add earthquakes to the region.

This study suggests that maintaining a constant regional *b*-slope is required for an accurate PSHA. Assumptions for background zone seismicity, other than the two investigated, are possible. One assumption proposed by Wesnousky et al. (1982) was that faults may produce only magnitudes near the maximum that they can support, plus aftershocks (which do not follow a regional *b*-slope). Whatever assumptions are made, fault sources cannot produce small earthquakes at the rate a constant *b*-slope (as observed in complete data sets of regional seismicity) would indicate. This conclusion suggests that Krinitzsky (1994) has a valid point in criticizing the use of constant *b*-slopes for individual fault planes.

Data have been inadequate to prove the assumption, usually used in PSHA, that regional *b*-slopes apply to discrete fault sources. However, there probably is enough instrumentation for some recent California earthquakes, to investigate this problem further. Wesnousky (1994) suggests a characteristic earthquake recurrence for parts of the San Andreas fault system. Other recent analyses of earthquake recurrence indicate a considerable variation of opinion, Savage (1994), Petersen and Wesnousky (1994), Scholz (1994), Romanowicz (1994), Romanowicz and Rundle (1994), and Romanowicz (1992).

2 INPUT FILE CHANGES TO ADD A BACKGROUND SEISMIC ZONE

Three input files require changes or additions to implement a background or complementary zone. These files are the a/x/j, c/j/sis, and c/j/altz files. The number of zones must be increased by one for each expert for most entries, although some remain the same. The background zone must be described on each expert's pages of input. The description includes its digitized coordinates, zone number, *a*-value, *b*-value, maximum magnitude, minimum magnitude, the region in which the zone is located (NE, SE etc.) and other details which are repeated from previous entries. This description is requested several times in the input files.

Table 2-1 lists fault names and the abbreviations used in Figure 2-1. Figure 2-1 depicts all the fault zones recommended by the pseudoparticipants, largely derived from published literature, and outlines of the background zones.

Table 2-1. Fault name abbreviations

Abbreviation	Fault Name	Abbreviation	Fault Name
AA	Alamo Area	MM	Mine Mountain
AR	Amargosa Valley	MV	Midway Valley
BM	Bare Mountain	OV	Owens Valley
BR	Bow Ridge	PB	Paintbrush Canyon
CA	Carpet Bag	PW	Pagany Wash
CS	Cane Springs	RV	Rock Valley
DV	Death Valley	SC	Solitario Canyon
DW	Drill Hole Wash	SR	Sheep Range
FC	Furnace Creek	SW	Sever Wash
FM	Funeral Mountain	TW	Teacup Wash
FW	Fatigue Wash	WA	Wahmonie
GA	Garlock	WW	Windy Wash
GD	Ghost Dance	YB	Yucca Boundary
KA	Kane Springs	YW	Yucca Wash
ME	Mercury Valley		

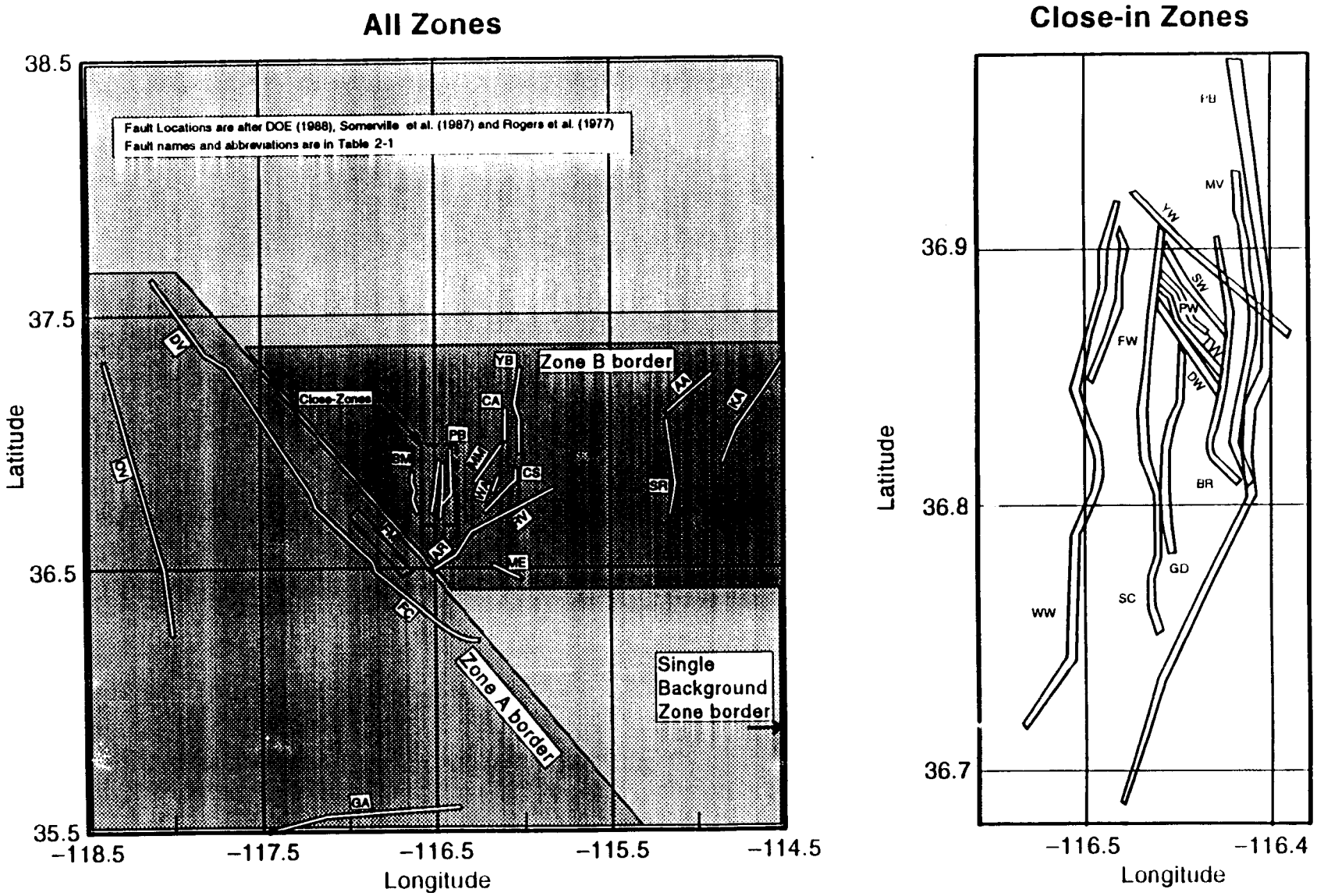

Figure 2-1. Outlines of background and fault seismic source zones

3 HAZARD COMPUTATION

Seismic hazards were computed using SEISM 1.1. Expert opinions derived from published literature (Hofmann, 1994) provided most of the input for the calculations described in this study. The previous calculation was based upon seismic recurrence derived from published fault data and recurrence *b*-values. The purpose of the previous calculation was to ensure that code modifications made to the SEISM 1 computer code (Bernreuter et al., 1989), also named SHC software (Davis, 1991), to permit its use at western U.S. sites, performed properly. The calculations reported here include a background seismic zone, or zones, in addition to discrete fault sources. Figure 3-1 contains the aggregated hazard curves for the background zone models calculated in this sensitivity analysis.

3.1 BACKGROUND ZONE MODELS

Several background models were employed to determine the effect of varying their specifications. Unless otherwise specified, the mean *b*-value was held to -0.91. The *a*-value for background zones initially were the average of the sum of *a*-values used by each expert for all the faults each expert declared within the expert's background zone. Each expert chose different faults as being important to the hazard analysis. Therefore the background zone or zones had different *a*-values for most experts. The average *a*-values of all the experts who declare only local faults to YM, provides an estimate for the single background zone model. Three background zone boundaries are specified: i) a large single zone, Figure 2-1, encompassing the boundaries of the larger map, ii) two smaller background zones, also identified on Figure 2-1, and iii) the same two smaller background zones but declared as enclosing zones rather than background (complimentary) zones. A summary of the *a*-values for each fault, by expert, is on Table 3-1. Various models use these background zones with different parameters, e.g. *a*- and *b*-values and M_{max}. Results from the no-background zone calculation are the faded grey lines on each of the plots. There is no detectable difference between the no-background zone model and the first two models with background zone *a*-values of 2.96 and M_{max} of 5.7. The 10^{-2}, 10^{-3} and 10^{-4} per year hazard accelerations are compared for each model on Table 3-2.

Table 3-1 is a list of *a*-values mostly determined from the N_4 values listed in Sommerville et al. (1987). If a fault declared of concern to YM or NTS safety, by one of the published experts, was not on the Somerville et al. (1987) list, its *a*-value was determined from its length through the formulae provided in Somerville et al. (1987). There were only a few faults in this category and all had low *a*-values which suggests a minimal effect on hazard. The $a=2.96$ value, arbitrarily used in the initial background zones for this study, is equivalent to the average sum of *a*-values for faults declared by the five published experts who did not believe that distant large high-activity faults need be considered for a PSHA at YM or NTS. The *a*-values for all faults were initially rounded to two decimal places. The rounding may have caused the difference between 2.9179, in Table 3-1, and 2.96 as used in the PSHA calculation. The difference would have a negligible effect on hazard. For the two background zone models with different *a*-values for each zone, the maximum *a*-value that could be used without resulting error messages or calculation failure was about 7.5. Therefore, 7.5 was used to test the effect of increased activity on an adjacent background zone enclosing high activity faults but not the site, instead of the average 10.9 sum of *a*-values for faults declared of importance by various experts, in background zone A.

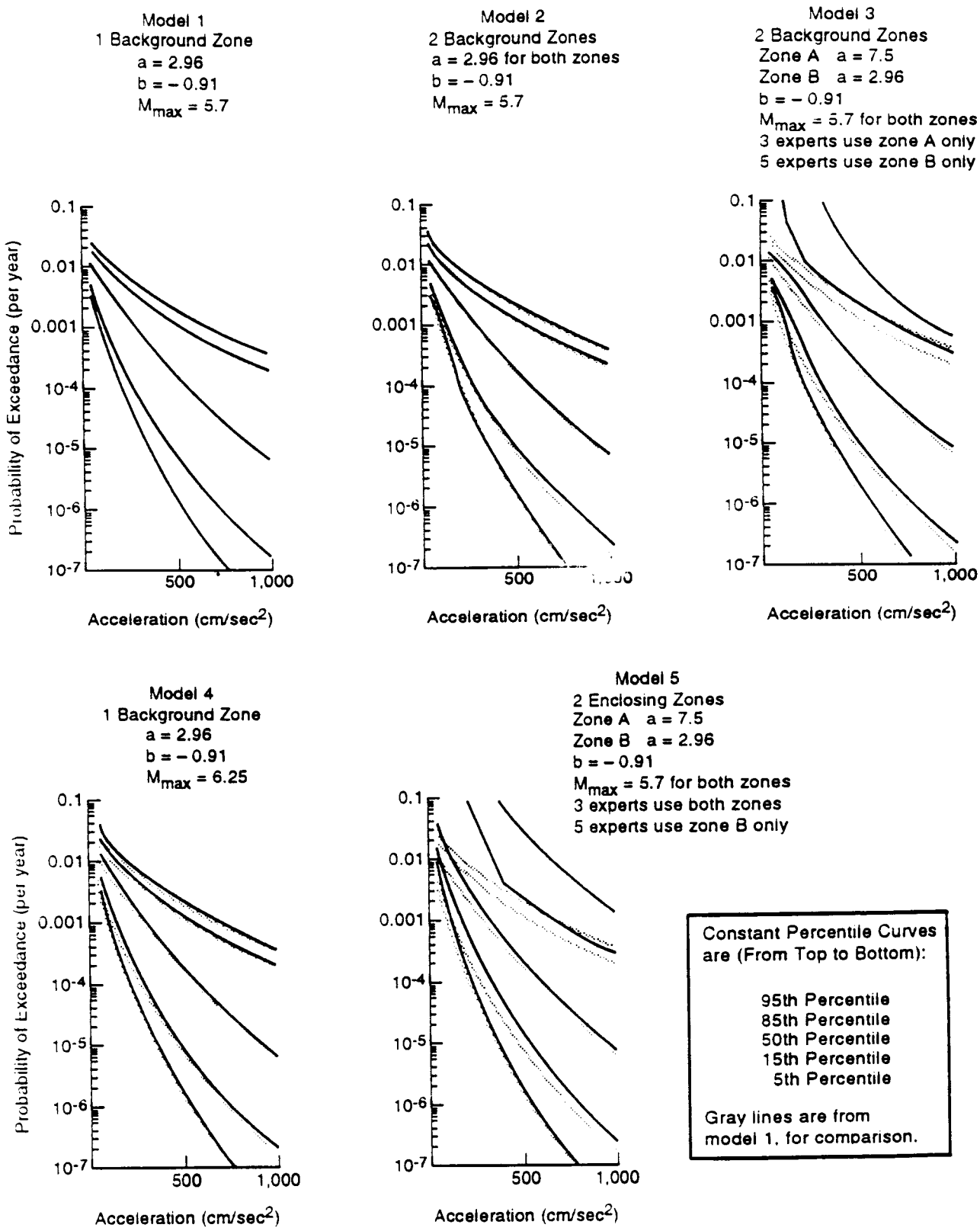

Figure 3-1. Aggregated hazard curves with background zone

3.1.1 Background Zone Model 1

The initial background zone was modeled with the average of the sum of *a*-values, 2.96, for faults proposed by the 5 experts who did not specify faults outside of zone B, which encloses the site. To better maintain a constant regional *b*-value (slope of line describing the number of earthquakes, of a given magnitude and larger, versus magnitude), earthquakes occurring on faults were limited to magnitude values between 5.8 and M_{max} for each fault declared by an expert. Earthquakes of magnitudes less than 5.7, that would be predicted by a Gutenberg-Richter (G-R) recurrence for the fault, were permitted to occur randomly throughout the background zone. This process is justified to some extent, by the observation (e.g. Rogers et al., 1987) that smaller earthquakes in the Basin and Range tectonic province are seldom associated with known faults. The *a*-value of 2.96 was assigned to the large single zone. The reason for this choice is the belief that distant large earthquakes that may potentially occur on the Owens Valley and Death Valley - Furnace Creek faults in Zone A of the two-zone case, are not likely to strongly effect the site. However, this belief is investigated in other background zone models to be described. The mean *b*-value used is −0.91.

3.1.2 Background Zone Model 2

The second calculation used two background zones. Both zones allowed magnitudes from 4 to 5.7 with fault sources restricted to magnitudes of 5.8 and greater. Background zones were assigned an *a*-value equal to the sum of *a*-values assigned to the faults they both enclose. Background zone B encompassed the low seismicity area around the site. Background zone A encompassed only the more active distant faults like the Death Valley — Furnace Creek and Owens Valley faults. These two triangular background zones are illustrated on Figure 2-1. For this test however, *a*-values for both zones were held at 2.96 to observe the effect of two smaller zones compared with one larger single zone. Three seismic source zone experts used large distant faults enclosed by background zone A. Five of the experts used only the relatively low activity faults of Zone B, which includes the site. This configuration did not produce a seismic hazard greatly different from the single background model or the original PSHA without a background zone.

3.1.3 Background Zone Model 3

CNWRA was unable to find a way to assign differing *a*- and *b*-values, and M_{max} and M_{min} to two different background zones. Background zones are called complementary zones in LLNL publications on the seismic hazard characterization (SHC) of the eastern United States (e.g. Bernreuter et al., 1989). More than one complimentary zone may be used but all must have the same properties. Because Model 2 did not produce a significant effect on hazard, it can be concluded that a background zone of this size, with an *a*-value of 2.96 and M_{max} of 5.7, has no perceptible effect on hazard. Therefore, zone A was the only zone assigned to the three experts who declared the faults encompassed by this zone for model 2. In this model, zone A was allowed have a high value, 7.5, comparable with the sum of the *a*-values determined for the large distant faults. Zone B, again was assigned an *a*-value of 2.96. There was little effect on the 50th constant percentile (CP) hazard, although the 85th and 95th CP hazards increased somewhat and have a different curvature compared to other percentile hazard curves. This increase at higher hazard (shorter return periods) is caused by the proximity of the zone A boundary to the site and the high activity level assigned to zone A. Large numbers of earthquakes, near the zone's M_{max} of 5.7, will occur near this boundary.

Table 3-1. Average sum of *a*-Values, by Expert.

Background Zone		Expert Number (*a*-values are below)								Average of Experts
		1	2	3	4	5	6	7	8	
Fault										
SC	B	0.7984	0.7984	0.7984	0.7984	0.7984	0.7984			
GD	B	0.1171	0.1171	0.1171	0.1171	0.1171	0.1171			
BR	B	0.4661	0.4661		0.4661	0.4661	0.4661		0.4661	
MV	B						0.6931	0.6931		
ME	B							0.0004	0.0004	
PB	B	1.3635	1.3635	1.3635	1.3635		1.3635			
YW	B						0.1963			
FW	B	0.0590	0.0590							
PW	B	−0.4058					−0.4058			
TW	B						−0.4058			
DW	B	−0.4058								
BM	B						0.7984	0.7984	0.7984	
MM	B						1.0730	1.0730	1.0730	
WA	B						0.1963		0.1963	
WW	B	1.1286	1.1286		1.1286		1.1286		1.1286	
RV	B						1.5909	1.5909	1.5909	
SW							0.0799			
AR	B						0.3724		0.3724	
AA	B							1.1728		
CA	B						0.7984		0.7984	
YB	B						1.4876	1.4876	1.4876	

Table 3-1. Average sum of *a*-Values, by Expert. (cont.)

Background Zone		Expert Number (*a*-values are below)								Average of Experts
		1	2	3	4	5	6	7	8	
Fault										
CS	B						0.9704	0.9704		
SR	B						1.4973	1.4973	1.4973	
KS	B						1.7306			
Sums:		3.1211	3.9327	2.2790	3.8737	1.3816	14.5467	9.2839	9.4094	5.9785
		[Ave. of experts using B only = 2.9176]								
GA	A						3.6877	3.6877		
OV	A						3.8790	3.8790		
DV	A						2.8426	2.8426	2.8426	
FM	A							2.2633		
FC	A						2.2720	2.2720	2.2720	
Sums:							12.6813	14.9446	5.1146	10.9135
Total A&B Sum:		3.1211	3.9327	2.2790	3.8737	1.3816	27.2280	24.2385	14.5240	10.0723
Average/fault by expert		0.3901	0.6555	0.7597	0.7747	0.4605	1.1345	1.7306	1.1172	0.8779

Average *a*-value sum the large single background zone	10.0723
Average *a*-value sum the A background zone	10.9135
Average *a*-value sum the B background zone	5.9785
Average *a*-value sum for experts in background zone B, who used only faults from Zone B	2.9176

Note: *a*-values were derived from N4s from Somerville et al. (1987) or fault length comparisons.

Table 3-2. Comparisons of selected hazard accelerations for several background zone models.

Background Zone Model	1		2		3		4		5	
	Acceleration (g)									
Percentile Hazards	50th	85th	50th	85th	50th	85th	50th	85th	50th	85th
10^{-2}	0.05	0.11	0.05	0.11	0.10	0.21	0.08	0.12	0.11	0.36
10^{-3}	0.31	0.51	0.31	0.53	0.32	0.63	0.31	0.56	0.33	0.66
10^{-4}	0.61	1.33_{os}	0.61	1.26_{os}	0.61	1.33_{os}	0.61	1.24_{os}	0.61	1.33_{os}
os - off scale estimate										

It is presumed that accelerations in the higher numerical limb of the probability distribution function for acceleration at a given distance, for a magnitude 5.7, add significantly to the high percentile curves for higher hazards (short return periods) for Model 3 (and Model 5) on Figure 3-1. M = 5.7 earthquakes, however, do not generate many accelerations as high as those associated with lower hazard levels, e.g. the 10^{-4} per year hazard. As in the first model, M_{min} for each fault zone was set to 5.8 unless the fault zone had an M_{max} =5.8. In the latter case earthquakes on the fault were restricted to this M_{max}. Earthquakes in background zones were permitted to range from magnitude 4 to 5.7 in a random manner.

3.1.4 Background Zone Model 4

Wong et al. (1994) and Quittmeyer et al. (1994) became available during preparation of this report. These investigators used an interpretation of recent U.S. Department of Energy age dating of paleo-offsets in trenches to determine fault activity levels, rather than the Somerville et al. (1987) N_4 values used in this report. A different *b*-value, −0.83 for recurrence (determined from an earthquake data set with aftershocks removed), a different M_{min} and M_{max} for the background zone and fault source zones, different list of faults, and a different analytical procedure were used by these authors. A SEISM 1.1 computation using the parameters of Wong et al. (1994) and Quittmeyer et al. (1994) was beyond the scope of this report. However, to test the effect of one parameter, M_{max} was changed from 5.7 to 6.25 on one of our models, the two-zone case with both having an *a*-value of 2.96.

In this model, M_{min} was set to 4 for faults, and background zone parameters were as in Model 2 except that M_{max} was set to 6.25 as in Wong et al. (1994). The best-estimate *b*-value remained at −0.91. In this case, hazard increased slightly at the 50th, 85th, and 95th percentiles. With the background zone M_{max} set to 6.25, earthquakes between magnitude 5.8 and 6.25 would be added together in a regional recurrence. Apparently Wong et al. (1994) allow all earthquakes from all fault source zones, including a background zone, to be additive. If so, this may produce a regional recurrence slope that is rich in small earthquakes compared to observed regional recurrences, assuming a truncated exponential (G-R) recurrence for individual faults. This problem is further discussed in Section 3.2 of this report. Quittmeyer et al. (1994) state that both a truncated exponential and characteristic earthquake type recurrence were used in their calculation. This (presumably weighted) use of the two types of recurrence

may ameliorate, to some degree, the problem of a regional recurrence consequent to such an analysis, having more low magnitude earthquakes than observed.

3.1.5 Background Zone Model 5

Background zones have the same parameters as in Model 3 except the zones were declared in the code as enclosing rather than complementary. To use an enclosing zone, all the other zones (faults) that are enclosed, must also be described in the input data for the enclosing zone. By using enclosing zones, a higher *a*-value could be assigned to zone A, in which three experts declared large distant highly active faults. Zone B was assigned a lower activity rate, *a*-value, commensurate with the lower activity faults enclosed with in it. Zone B also encloses the site. The effect on CP hazard is little different from that of Model 3. However, the arithmetic means (not shown) were several times higher than for Model 1. The 10^{-2} per year 50th CP hazard is about doubled, but hazards equivalent to longer return periods are little changed. As in Model 3, this doubling reflects some very high accelerations being generated in background zone A, near its boundary close to the repository.

At the request of Dr. Ibrahim of the NRC, two additional computations were made using DOE's *b*-value of -0.83 and their M_{max} of 6.25 in Model 5. One of the added calculations let the zone A *a*-value=5.23, the average of the two background zone *a*-values used in our calculations. This *a*-value is very similar to the one used by DOE for their single background zone. Zone A, in the other added computation was assigned an *a*-value of 7.5 and Zone B was assigned on *a*-value of 2.91. Results are in Appendix A. The first of the added calculations increased the hazard contribution of the background zone as observed by DOE. The second calculation showed the same sharp increase in the 85th and 95th percentile hazards for short return periods as observed in our models 3 and 5 but overall hazard also increased. These computations are not parallel to DOE's, however, because different fault zones and different *a*-values for the fault zones were also used by them.

3.2 THE PROBLEM OF REGIONAL *b*-VALUES

If a background zone with a limited M_{max} but significant *a*-value is added to seismicity from faults, [that is, let $M_{min} = 4$ for both the background zone(s) and for faults] the regional *b*-value will change for small earthquakes such that the calculation will show relatively more small earthquakes compared to larger ones in the site region, than would be observed. The regional *b*-value may vary with magnitude. This effect is not observed for well recorded data sets, for example Abercrombie and Brune (1994). Models other than those proposed here, could be devised to maintain a constant regional *b*-value while adding small random earthquakes to a background zone. Such models might include variable *b*-values for faults and a non standard recurrence relationship for the background zone such that the regional seismicity would follow a constant *b*-value for all magnitudes. However, convincing evidence to support such a model is lacking.

The proposal of Wesnousky et al. (1982) for western Honshu could be adopted. That is, faults only produce earthquakes near the maximum possible for the fault, plus aftershocks. All earthquakes smaller than those that are represented by larger faults, consistent with an acceptable *b*-value, would be presumed to occur on small presently unknown faults distributed randomly throughout the background zone. The background zone *b*-value would have to be adjusted so that the regional *b*-value, including earthquakes on faults, would be constant for all magnitudes in the region. Differentiating between the Gutenberg-Richter (1954) and Wesnousky et al. (1982) or other hypotheses for fault-specific *b*-values in

the Basin and Range tectonic province does not appear possible because of the limited seismic data available. Certain parts of the San Andreas system may be active enough to make such a determination for small earthquakes recorded by increased amounts of instrumentation installed in recent years.

Wesnousky (1994) determined that segments of the San Andreas fault between major asperities and some branches of the San Andreas Fault have recurrence relationships that look like those proposed for characteristic earthquakes. However, the entire San Andreas zone is shown to have a Gutenberg-Richter type recurrence with a *b*-value near 1.0. Wesnousky's (1994) zone surrounding faults, within which he selected earthquakes to develop the recurrence relations, were narrow. However, they were wide enough to include some smaller ancillary faults. For most faults, this type of analysis would produce results that would be difficult to distinguish from the Wesnousky et al. (1982) analysis. The new analysis suggests strongly that individual fault planes do not follow a Gutenberg-Richter type recurrence. This conclusion is also drawn from development of this sensitivity study. Reanalysis of hazard using characteristic earthquake relationships for individual fault planes is beyond the scope of this study. Clearly, however, hazard analyses based on the premise that individual fault planes support numbers of earthquakes in various magnitude categories in the same manner as regional Gutenberg-Richter recurrence curves would predict, cannot be correct. Analyses using this procedure are therefore suspect.

Figure 3-2 is a series of sketches showing the effect on a regional *b*-value of adding a background zone with a limited M_{max} to that of two enclosed faults. The dotted lines on the sketches represent the numbers and magnitudes of earthquakes that will be generated by the Monte Carlo routine of SEISM 1.1 for the boundary conditions discussed. The dashed line represents the best fit line for all magnitudes and their numbers which will describe the regional recurrence. The grayed lines are extensions of fault-zone recurrence lines into the part of the sketch where such recurrences must be added to obtain a regional recurrence. The number of earthquakes represented by each angled line is additive in Figure 3-2. That is, each earthquake source, whose activity is represented by a truncated straight line recurrence must be added to that of the other sources, including the background zone, to define the regional recurrence, which should have a slope near -1.0. Usually the resulting slope will be much steeper unless some means is used to limit the regional numbers of low magnitude earthquakes assumed in the PSHA analysis. Figures 3-2, b, c and d represent possible methods to implement such a limitation. If several faults are enclosed with different M_{max}, the change in the regional *b*-value may be exacerbated. Figure 3-2 b illustrates the effect of assuming that earthquakes below a certain magnitude do not occur on faults but do occur scattered throughout a background zone. This approach was used in the PSHA described in this report. Figure 3-2 c combines this effect with that of assuming earthquake recurrence on a fault plane has a characteristic earthquake configuration as proposed by Wesnousky (1994). Figure 3-2 d illustrates the effect of using a recurrence based on the assumption that a fault can produce a maximum magnitude only (commensurate with fault length or other fault parameter) plus aftershocks, as proposed earlier by Wesnousky et al. (1982). The latter assumptions produces regional *b*-value most similar to the regionally observed G-R recurrence.

The effected noted here is most pronounced for faults that are major contributors to seismic activity in the region and have N_c values within an order of magnitude of each other. Background zone N_c values are a function of zone size as well as seismic activity. Therefore, the severity of the regional recurrence error from assuming that individual fault plane seismic recurrence is also of the Gutenberg-Richter form. is dependent on the relative activity of the faults being modeled.

Because only regional *b*-values are usually known with confidence, e g. (Krinitzsky, 1994), fault and background zone *b*-values and sums of their values must produce a recurrence that conforms to a

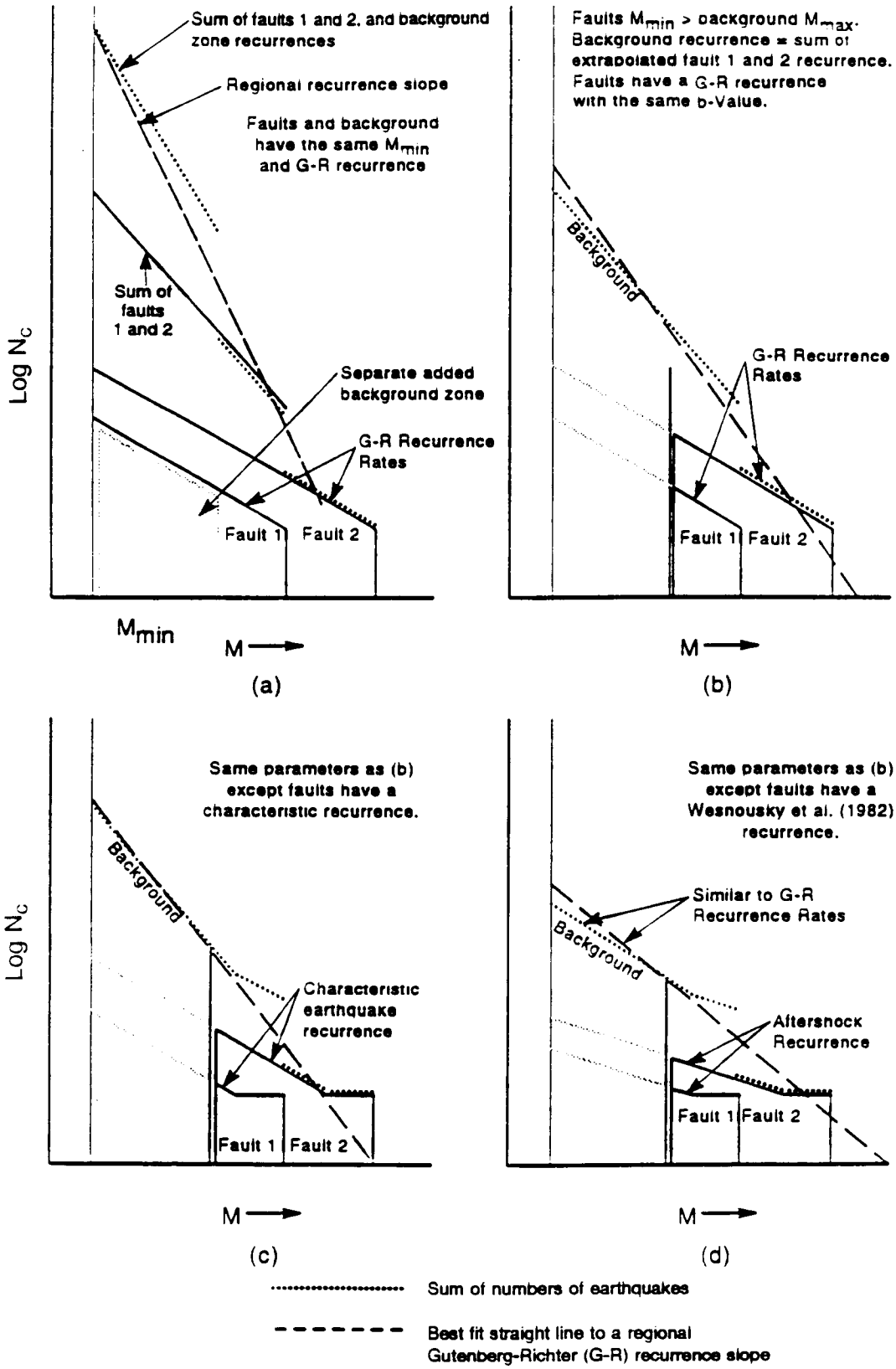

Figure 3-2. Sketch of effect on regional *b*-values of adding a background zone

regional linear *b*-slope as a function of magnitude. The use of constant *b*-values near 1.0 for individual faults is therefore suspect.

The region-wide *b*-values produced from a SEISM 1.1 code calculation could be derived during processing, using diagnostics that save all M and distance values chosen by the Monte Carlo routine. However, such diagnostic files are extremely large and challenge available work station storage capacities. A subroutine could be coded to retain a matrix of M and distance category sums, thereby providing a more manageable file from which a recurrence curve could be generated. This plot could be used to verify that the regional *b*-slope developed during a calculation satisfied a straight line for all magnitudes. This verification is beyond the scope of this sensitivity study but it remains as a possible future effort. Although attempts were made in this study to preserve the regional recurrence relationship, it is likely that the relationship deviates from the form observed in complete data sets. That a regional recurrence relationship is a straight line with a slope near 1.0 appears to be an important criteria to test in PSHA calculations.

3.3 POTENTIAL EXPANSION OF THE ADJACENT MORE HIGHLY ACTIVE SEISMIC ZONE TO ENCOMPASS YUCCA MOUNTAIN

Larger more distant faults are more directly related to the Pacific-North American continent plate boundary system and would be expected to differ in their activity rates from typical Basin and Range faults. However, the site is closer to these large faults than most of the Basin and Range tectonic province, and seismic activity near the site may be influenced by large earthquakes occurring on these large, more distant faults. The effect of strain changes consequent to large earthquakes on the Death Valley-Furnace Creek fault zone or within the Walker Lane seismic belt may be significant. For example, the activity rate increased near the site, as evidenced by the occurrence of the 1992 Little Skull Mountain earthquake following the 1992 Landers, California earthquake. Such an increase may be of more importance than the shaking induced at the site by large earthquakes on these distant large faults. It its possible that as crustal stress increases with time because of a large asperity on the San Andreas fault, e.g. the bend in the San Andreas, movement may be induced on semi-parallel faults further east. The Death Valley-Furnace Creek and similar faults may be candidates for such increased activity. This potential effect was not tested in this sensitivity study but could be approximated by assigning the high average *a*-value derived from large distant faults to both zones A and B of Model 5. Because an enlargement of the adjacent high activity zone (Walker Lane or the Ventura-Winnimucca zone of Ryall et al., 1966) is likely to occur only for a part of any 10,000-yr period, this procedure would produce an upper bound. Therefore, there is some uncertainty in seismotectonic models proposed for the region. Some faults may be more prone to movement than others from the activation of these large nearby faults or fault zones, Morris et al. (1994). This theory could be employed in a PSHA calculation to quantify its effect on hazard. Other new or more complex hypotheses can be expected prior to and during licensing and the hearing process.

4 COMPARISON WITH PUBLISHED PROBABILISTIC SEISMIC HAZARD ANALYSES RELATING TO YUCCA MOUNTAIN

Table 4-1 is a summary of the original computation, the revised computation with two background zones, and several published hazard results including those summarized in Hofmann (1994). Results from two other studies are also summarized, those of Campbell (1980) and of Wong et al. (1994), which is also reported with additional detail, in Quittmeyer et al. (1994).

The Wong et al. study for YM includes recently gathered data on fault slip rates by the DOE and uses a logic tree procedure with a background zone. M_{max} for the background zone, 6.25, is stated to control the hazard except for the 1 in 10,000-yr value. The use of an $M_{max}=6.25$ could be justified on the basis that several earthquakes near this magnitude have occurred on previously unknown blind thrusts in California during the past decade. Smith and Arabasz (1991) suggest this value for the Intermountain Seismic belt at the eastern margin of the Basin and Range. dePolo (1994) argues that the background zone M_{max} should be based on the magnitudes of earthquakes which show no fresh surface rupture, whether they are associated with known faults or not. He argues that if the diameter of a circular rupture area associated with a given magnitude is less than crustal thickness, it may rupture at depth but not at the surface. These arguments lead to a recommendation of a background M_{max} of 6.5-6.6. Many of his examples were either accompanied by distributed surface fault offsets or clearly occurred on known faults or lineations. All examples are at the eastern or western margins of the Basin and Range tectonic province. Because a thorough investigations of faulting and lineations is being carried out for YM, which lies to the east of the Basin and Range tectonics province western margin, potential earthquakes will be assigned faults and lineaments with evidence of Quaternary activity. Therefore, it is reasonable to assign substantially lower M_{max} than 6.5-6.6 for a background zone. An M_{max} of 6.25 without surface breakage may be high for the YM environment, which is not known to have thrust faults. However, proposed hypothetical buried or surface fault trends in the YM area could have a similar effect if considered in PSHA. The Wong et al. (1994) *b*-value for seismic recurrence is -0.83 rather than the -0.91 in this study. The -0.83 value is stated to be the result of deletion of all aftershocks from the seismic record. Their probabilistically determined peak accelerations are similar to those of this study based upon published expert opinion. However, this study would attribute more of the hazard to larger earthquakes occurring on faults rather than to a random earthquake in a background zone.

The Campbell (1980) analysis also used a *b*-value of -0.83 but did not use a background zone. Earlier publications, also summarized, included the NTS or YM, sometimes in broad regional evaluations of risk. Where authors published several models, they are presented in addition to the primary or principal model. Models that are similar (for example those which use a background zone and the same *b*-value) should indicate similar hazards unless new data have resulted in changed parameters. Dissimilar assumptions would be expected to produce a wider dispersion in the hazards calculated. Table 4-1 indicates that there is a considerable variation in the way in which various experts have interpreted the same or similar data, and a corresponding variation in resulting hazard. If all hazards are assumed to be 50th CP values, the once in 10,000 year hazard ranges from 0.28 g to 0.70 g and the once in 500-year acceleration ranges from 0.10 g to 0.34 g. Accelerations determined without a background zone (Hofmann, 1994) were 0.61 g and 0.18 g respectively for the once in 10,000 year and once in 500-year hazards. This study, with two background zones, also yields 0.61 g and 0.18 g for the once in 10,000 and once in 500-year hazards respectively.

Table 4-1. Summary of seismic hazard computations at YM from published data

	This Study (Model 1) Hofmann/Menchaca (1994) Model 5				Somerville et al. (1987)	Rogers et al. (1977)		Perkins et al. (1987)			Campbell (1980)	Wong (1994)	Algermissen et al. (1982)
	BE and AVE.		50th CP			A Model	B Model	Model 1		Model 2		50th CP	
Basis: Background Zone?	F N	F Y	F N	F Y	F Y (Seis.)	S Y	F N	F & S N	F N	S Y	S & F N	S Y	S & F Y
M_{MAX} of Bknd Zone	--	5.7	--	5.7	6.5	4.5 Includes W. NV Seismicity	--	--	--	5.7	--	6.25	Various**
SITE	YM				YM	NTS		NTS Region		YM (Site A)	NTS ≈ 25 km N of YM	YM	YM
Area or Radius of Study	100k km^2				100k km^2	F to 150 km S to 400 km	B & R Seis. Less W. NV Seismicity	400 km Less W. NV Seismicity	400 km	≈2000 km^2≈	31.5 km^2		
Multiple/Single Expert or Expert Team	M		M		S	S A_S B_F	S A_S B_F	S	S	S	S	S?	S
b-Value	-0.91		-0.91		-0.91	-0.83	-0.83 Variable	-0.83		-0.83	-0.83	-0.83	Various**
Recurrence Interval	Hazard (g's)												
100 years	0.08	0.51	0.07	0.13	0.20	0.2 0.06	0.2 0.06	0.28	0.04	0.06	0.12		0.05*
500	0.14	0.60	0.18	0.18	0.30	0.34 0.12	0.4 0.12	0.34	0.10	0.2	0.21	0.19	0.12
1,000	0.38	0.92	0.31	0.36		0.4 0.17		0.42	0.14		0.30	0.27	
2,500						0.5 0.25	0.6 0.26	0.52	0.19	0.25	0.41	0.37†	0.25
10,000	0.95	1.14	0.61	0.61	0.70	0.65 0.32		0.66	0.28	0.32	0.63	0.66	0.32

*As Interpreted by Perkins et al. (1986)
F in "Basis" row = fault
S in "Basis" row = seismicity

M in "Multiple/Single" row = multiple experts or expert teams
S in "Multiple/Single" row = a single expert or expert team
A_S = Model A, based on seismicity
B_F = Model B, based on fault offsets

** Several small seismic source zones with differing parameters, adjacent to or enclosing YM affect hazard

† For 2000 years rather than 2,500

Somerville et al. (1987) subtracted fault source activity rates, determined by paleo-dating of fault offsets or fault length relationships, from a broad regional historic total activity rate to set the background seismic activity level. The historic activity level had been determined by Greensfelder et al. (1980) as 0.015 M=4 events per 1000 km^2. Results from this procedure showed that background seismicity significantly contributed to the seismic hazard in the 10^{-2} to 10^{-3} per year range. M_{max} for the background zone was 6.5. Wong in EPRI (1993) recommended an added random source with 1.25×10^{-4} M=4 earthquakes per 10,000 Km^2/yr.

If M_{max} is set to 6.25, as in the Wong et al. (1994) study, and smaller earthquakes are not deleted from the fault sources, a larger increase in hazard would be expected to accompany a background zone. Model 4 of this study also showed an influence on the 10^{-2} seismic hazard from a background zone, with these assumptions. The analysis in Appendix A using high *a*-values and a different *b*-value shows a stronger effect. Other factors, use of M_W or a *b*-value of -0.83 rather than -0.91, may compensate for internal differences between this study and that of Wong et al. (1994). However, hazard results appear to be similar for this study and Wong (1994).

Differences in the *b*-value used by the this study and that of Wong et al. (1994) may be caused by several factors:

- Choice of earthquakes identified as aftershocks and eliminated from the determination
- Choice of magnitude scales
- Choice of area over which the *b*-value is determined

These same choices or expert opinions may also contribute to the determination of *a*-values.

5 CONCLUSIONS AND RECOMMENDATIONS

The process of including a background zone or zones into a PSHA for YM resulted in consideration of alternative recurrence functions for individual fault sources of earthquakes and their aggregate relationship to regional earthquake recurrence. The background zones as formulated for this study did not appreciably add to most 50th CP hazards but increased higher percentile hazards in some cases. In PSHA by Wong et al. (1994) or Quittmeyer et al. (1994), hazard was largely controlled by the background zone as they defined it. However, 50th CP hazard results of this study (Model 1) and those of DOE are in reasonable agreement for the 2×10^{-2}, 10^{-3} , and 10^{-4} per year hazards as indicated in Table 4-1. If single parameters of one model are interchanged for those of the other, however, changes in hazard might be expected even though the two models with different formulations and parameters, produce similar results. Clearly, the formulation of a background zone has an important bearing on PSHA and there are different opinions on the matter. Therefore expert opinion should be sought in multiple expert PSHA regarding background zone formulation if such an analysis is ultimately used to assess seismic or fault-offset hazard at YM. Feedback concerning the effect on regional *a*- and *b*-values from the type of fault-plane-only recurrence used should be a part of the elicitation process.

5.1 CONCLUSIONS

5.1.1 General Conclusion.

The wide range of total activity in a zone, predicted by various experts on the basis of presumed generators of large earthquakes, suggests that PSHA using paleo-fault offsets of selected faults has such a large uncertainty that its value is questionable. Experts who investigated a large number of faults would, as a consequence, indicate high regional seismic activity rates. Those who investigated only a few faults, consequently generate lower regional activity rates. Because small earthquakes do not usually correlate with large faults, it must be assumed that the smaller earthquakes consequent to a high regional activity occurs in a background zone or zones encompassing the faults. Experts who believed that only nearby faults of reasonable length could be of importance, would imply a very low background zone activity based on paleo-fault offsets. There are several very large faults in background zone A that may have Quaternary or even Holocene activity but were not considered by most of the published experts used in this study, because they were more concerned with faults closer to the site. If the activity on the ignored faults were also added to their background zones, the probability of a random earthquake would increase considerably. A similar observation can be made for Zone B. Published expert (pseudoparticipant) 6 lists a large number of faults with a consequent large regional *a*-value. Should that background *a*-value be used even if another expert chooses only 3 faults to be of concern? It appears logical that a background zone level of seismicity based on paleo-offsets can only be determined from a diligent search and investigation of every fault within that zone.

Somerville et al. (1987) and the study reported by Wong et al. (1994) and by Quittmeyer et al. (1994) avoided this requirement by using historical seismic activity for the background zone. The mathematical details of this procedure are not given. The philosophy, however implies that historical seismicity is the same as paleo-seismicity or that background zone seismicity varies with time differently than fault seismicity. Neither consequence seems likely.

Perhaps a better procedure would be to determine the geographic influence of large faults on background seismicity. In other words, assign background zones to faults out to some technically

justifiable distance. Intervening spaces, if any, could be assigned a lower background zone activity. Historically, this appears feasible in California. However, a few decades before the present, there were large gaps in California seismicity that are now filled. Examination of faults may have predicted the future occurrence of earthquakes in these gaps.

The recent occurrence of several damaging earthquakes in California on previously unknown blind thrust faults has placed the concept of PSHA in jeopardy. The faults are present but undetected and are without obvious historical seismicity. Large transcurrent faults below listric soles of obvious faults in the Basin and Range tectonic province have been proposed by some authors as controlling tectonic development and seismicity on smaller surface features (e.g. Slemmons in EPRI, 1993). Such proposed large transcurrent faults could produce magnitudes in the 8 range if they exist. Obviously related seismicity is not known. Similar such faulting at the surface has been suggested as the cause for pull-apart basins with apparently dip- or oblique-slip faults at high angles to their trends (e.g. Jordan and Minster, 1988, also referenced in Young et al, 1992). Such mega-faults, which might explain some structural features in the Basin and Range could have a large effect on PSHA at YM, but are not currently considered in such analyses. At this point, it is unknown if these proposed faults were, but are no longer, active. However, they remain somewhat analogous to the blind thrusts in California. If the proposed large transcurrent faults, either with surface expression or buried, exist, they are presently without evidence of activity. The proposed features are not fully defined, but may possibly be large potential contributors to long term seismic hazard. The implications for long term background seismicity from such faults may be larger than their direct contribution to hazard unless they are in close proximity to the site.

5.1.2 Specific Conclusions

- Hazard could increase or possibly decrease when small earthquakes are permitted to occur randomly in a background zone. For the background zone formulation used in this study, magnitudes below a certain level are allowed to occur randomly throughout a region but not on a fault. Therefore, small earthquakes predicted from a G-R recurrence on a nearby active fault would be allowed to occur at greater distances within a background zone and therefore may reduce the hazard to the site. This artifice is employed to produce a regional non-magnitude dependent recurrence slope similar to that observed. If earthquakes are simply added to the region by using a background zone with a G-R recurrence, no decrease in hazard could occur but regional recurrence will be enriched for small magnitudes. The direction of hazard change depends on the presence of nearby faults close to the site and whether regional recurrence is modeled by reducing the number of small earthquakes on faults in proportion to the number of small earthquakes permitted to occur randomly in a background zone. If the total regional recurrence does not follow a linear *b*-slope near 1.0 (as observed, e.g. Abercrombie and Brune, 1994), the PSHA model may not produce the accurate results.

- *a*-values are an important factor in calculating hazard. These values are uncertain regionally for periods of time substantially longer than the historic seismic record and for all periods of time for individual faults.

- Recurrence for faults and for an encompassing background zone,with different M_{max} than assigned to the faults, cannot all follow a constant Gutenberg-Richter recurrence slope and still maintain a constant regional *b*-slope, as observed in complete seismicity data sets.

- *a*- and *b*-values determined after eliminating aftershocks from the seismic record (a heuristic endeavor) also eliminate the risk posed by those aftershocks. Such a calculation may be less conservative than one in which aftershocks are not removed. Aftershocks can, and do, cause damage and therefore are a part of the seismic hazard. A more accurate regional *b*-value estimate may require elimination of aftershocks caused by one or very few large earthquakes during the historical record. However, if several large earthquakes have occurred, there appears to be little reason to eliminate aftershocks in estimating regional *a*- and *b*-values.

- Published expert opinions concerning the models used in PSHA are varied. As a minimum, this level of variation may be expected from those participating in a licensing hearing based upon PSHA. Therefore, if some procedures or models are less acceptable than others to NRC staff, they are potential topics in a Staff Technical Position.

- Resource requirements for PSHA analyses are nontrivial, although some of the costs for this sensitivity study are a part of a learning process. A background zone was not used in the original calculation to reduce difficulties in performing the first CNWRA western U.S. test calculation with SEISM 1.1. Other possible sensitivity studies require only the changing a variable already in place in the input files. Such analyses should require fewer resources.

5.2 RECOMMENDATIONS

The sensitivity of PSHA accuracy resulting from the assignment of linear recurrence relationships to all faults and a background zone should be investigated. If SEISM 1.1 is to be used for this purpose, some additional coding will be necessary to track the total number of earthquake magnitudes and distances generated by the Monte Carlo process to verify that the regional recurrence is similar to observations with ample data.

No other recommendations are made at this time, pending an assessment by NRC and CNWRA concerning this project's future level of activity. Several suggestions for further investigation or code development are recommended in chapters 6 and 7 of Hofmann (1994) and could be considered at an appropriate time. The output from this and the original calculation are being integrated with tasks of the Repository Design, Operation, and Construction (RDCO) and the Performance Assessment (PA) Elements of CNWRA to provide tentative input for the selection of strong motion time functions for preliminary structural analyses. It is understood that new data from DOE studies, or expert elicitation and PSHA by them, may cause future revisions of the time functions to be used in final decision making.

5.3 DISCLAIMER

This report documents efforts to add one or more seismic background zones to a PSHA performed with the SEISM 1.1 code. As noted, there are several unresolved technical issues concerning input data requirements for such zones. Quality assurance for the SEISM 1.1 code is a budget issue, and has not been completed. Please note that analyses and figures presented in this report are not at a sufficient state of refinement to be used for regulatory decision making at this time.

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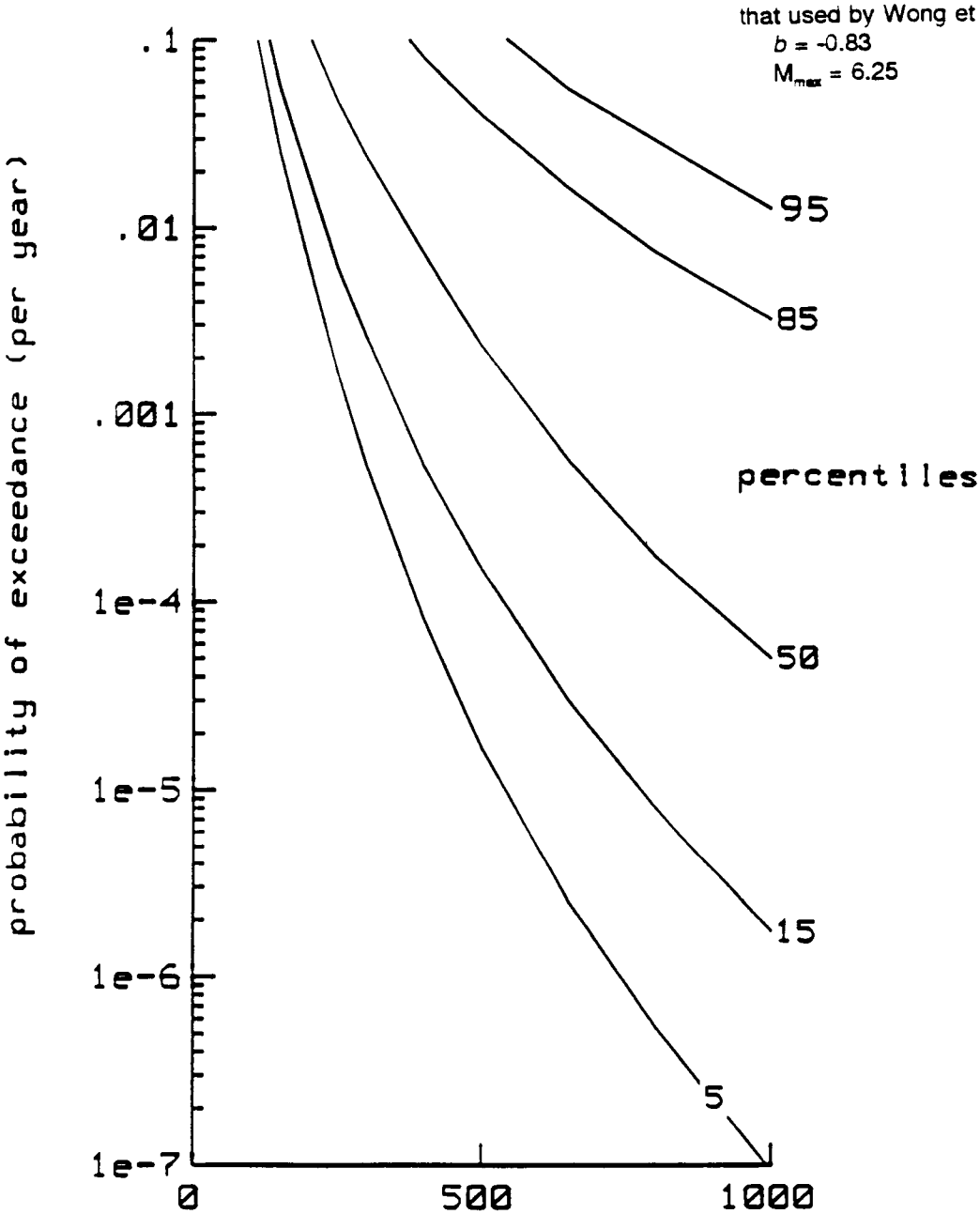
APPENDIX A
HAZARD CURVES FOR ADDITIONAL BACKGROUND ZONE MODELS

Background Zone
S-XPRT:1,2,3,4,5,6,7,10 G-XPRT:1,2,3,4,5

hazard curves using all experts

Both A and B background zone a-values = 5.23 (the average for the two zones, and is similar to that used by Wong et al., 1994).
b = -0.83
M_{max} = 6.25

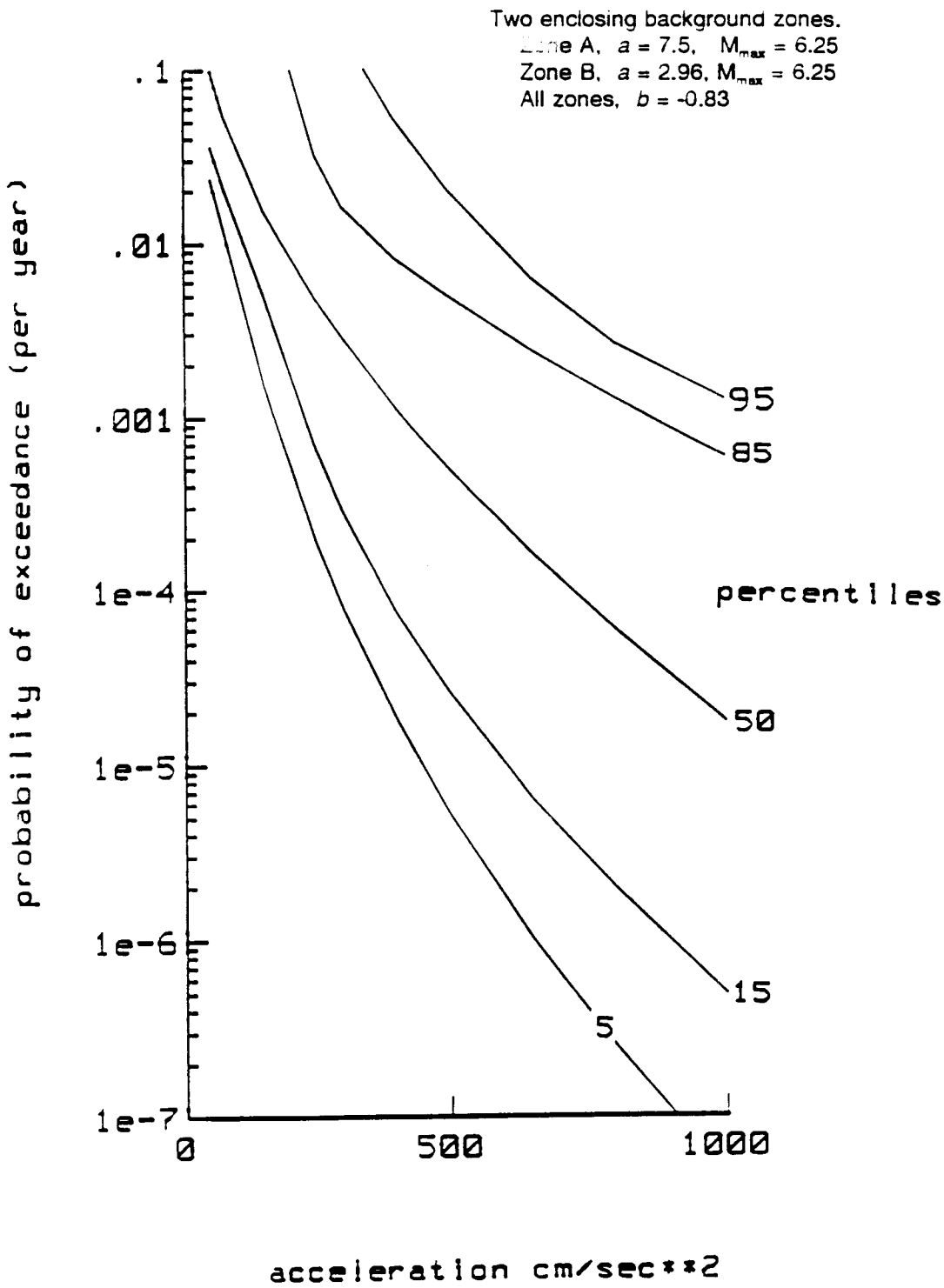


acceleration cm/sec**2

Yucca Mountain

Background Zone
S-XPRT:1,2,3,4,5,6,7,10 G-XPRT:1,2,3,4,5

hazard curves using all experts



Yucca Mountain